Terraforming Moon

Humanizing Lunar Living through Human-centric Design

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AR3A010 Research Plan I Lunar Architecture & Infrastructure Graduation Studio

TU Delft MSc Architecture 2024/25 Q1

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PROBLEM STATEMENT

Lack of space architecture precedents that prioritizes human behaviour in the design. Transitional spaces which has potential to enhance the spatial and social experience of lunar habitation are typically generalized to corridors.

RESEARCH QUESTION

How to incorporate human-centric design principles in the transitional spaces of long-term lunar habitation to create a more humanized space architecture?

LIMITATIONS & ASSUMPTIONS

Limited data on actual human experiences on the moon.

Speculations on future technologies & research
project is set in 2080, assuming:
- availability of in-situ resource utilization (ISRU) and advanced construction methods.
- feasibility to live with lunar environment, especially lunar dust and low gravity, with proper mitigation.

THEORETICAL FRAMEWORK

Background

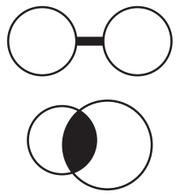
Human decentered design
using non-human actors

Dehumanization

Inhuman

Interest

Transitional Space



Outcome

Human-centric design
using human experiences as data

Habitability
the "human factor" of habitat

Affordances
mitigate mishaps / working with intuition

Phenomenology
extract data / excerpts from astronauts

Proxemics
mitigate confinement / set privacy gradients and spatial adjacencies

Third Place Theory
essential to form communities / transitional space as third place

METHODOLOGY

(1) CONCEPTUAL MODEL

Transitional space functional requirements

Experience ↔ Human-centric design principle

Dehumanized → Humanized

(2) DATA COLLECTION

Sources

Research stage

primary source

Interview
informal conversations with experts

Presentations
Moonshot+ Symposium, guest lectures

NASA Archives
Photographs, videos, journal entries

Personal social media posts
YouTube, Reddit, blogs, etc.

secondary source

Published
Books, journals, Best Practices and/or Design Guidelines

Institutional social media posts
Official YouTube (NASA, ESA)

Design & research stage

continuous feedback loop

Review / Discussion
with experts, astronauts, various users and practitioners in the interdisciplinary field of space architecture

Feedback interview
*arranged interview with users**

Social media engagement
*reach out to related stakeholders via email and/or social media**

Visual representations
presentation / project exhibition, possibly VR/AR, for feedback from general audience

**subject to feasibility*

Discussion & feedback with experts
crucial with the speculative nature of lunar habitat design

(3) ACTIVITY-BASED MAPPING

Research-based speculations on lunar living
gathering persepctives from personal experiences

GUIDELINES

Basic design guidelines:
- habitat requirements
- best practices

EXPERIENCE

mission-related activities

Human experience from:
(1) analogue missions on **Earth**
(2) space station missions in **outer space** (Low Earth Orbit)
(3) short expedition in 1960-70s on **lunar surface**

confined habitats

Space Station
mainly ISS, others for selected comparison

Analogue Environment
Hi-SEAS Mission 1, NASA

Typical Prison
Atlanta Prison, USA

"Humane" Prison
Norwegian Prison

Additional research on confined habitats
COVID-19 isolation, research centers on extreme climates

What kind of activities, movements, and functions could take place in the transitional spaces of a lunar habitat?

(4) TYPOLOGIES of transitional spaces

categorization: degree of ...

shelter | movement | privacy

Functional ↔ *Habitability*

How can transitional spaces mediate between functional areas to promote habitability and well-being?

(5) MULTISCALAR DESIGN APPROACH

functional requirement
spatial enrichment
privacy gradient

Macro
Design for Localization

Meso
Design for Adjacencies

body-object interaction

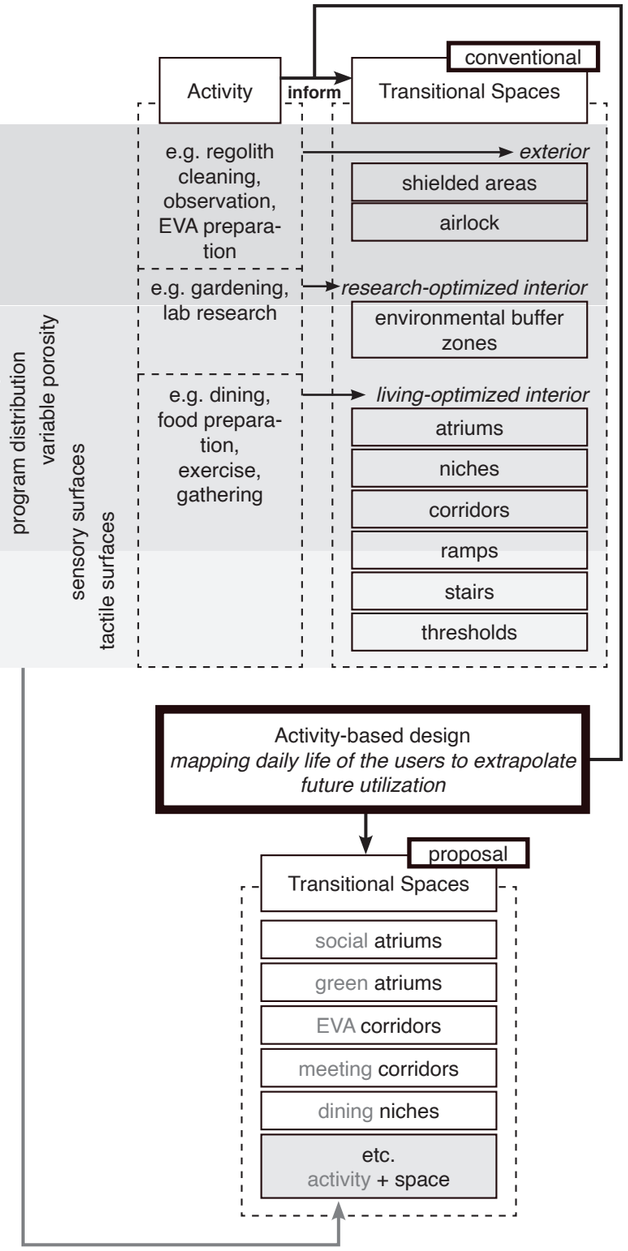
Micro
Design for Affordances

exterior-interior transitions
ISRU material
layered enclosures
program distribution
variable porosity
sensory surfaces
tactile surfaces

DESIGN DIRECTION

A lunar habitat with a library of user-refined transitional spaces

How can transitional spaces function as "third place"?
How can transitional spaces be utilized to integrate activities?



How to design such transitional spaces to afford certain activities?

1. Introduction

On December 2023, the United States unveiled its plans to land astronauts on the moon by 2025 as part of NASA's Artemis program in establishing a permanent lunar base.[1] In parallel, China is aiming for manned lunar landing by 2030.[2] All around, multiple nations are restarting the "space race", which has been stagnant since the last manned lunar landing on December 1972. Integral to space colonisation is the habitat – the protected environment where humans could live amidst the extreme extraterrestrial conditions. Yet, existing research in space habitats are mostly within the field of engineering which deals with functional optimization and safety,[3] leading to functionally-driven designs reminiscent of prison architecture to some extent as it lacks the necessary spatial and psychological qualities for long-term habitation. It is important then for lunar surface habitation to adopt a different design approach compared to the existing space station precedents, one that is driven more by human-centric design principles, in order to humanize space architecture.

The research takes reference to experiences of crew members in both space and analogue missions as the starting point, drawing on theories on human-centric design principles to inform the design. In mitigating between functionality and habitability, transitional spaces in space architecture offers an interesting design potential, on pushing the boundaries of enclosure in transition of inside to outside, on mediating between spaces to rethink the connection of programmatic adjacencies instead of the conventional corridor spaces, and on navigating through these spaces. Thus, by focusing on the activities along the transitional spaces, this research aims to interrogate the connection between the exterior and interior, and from one functional space to the other within the lunar habitat.

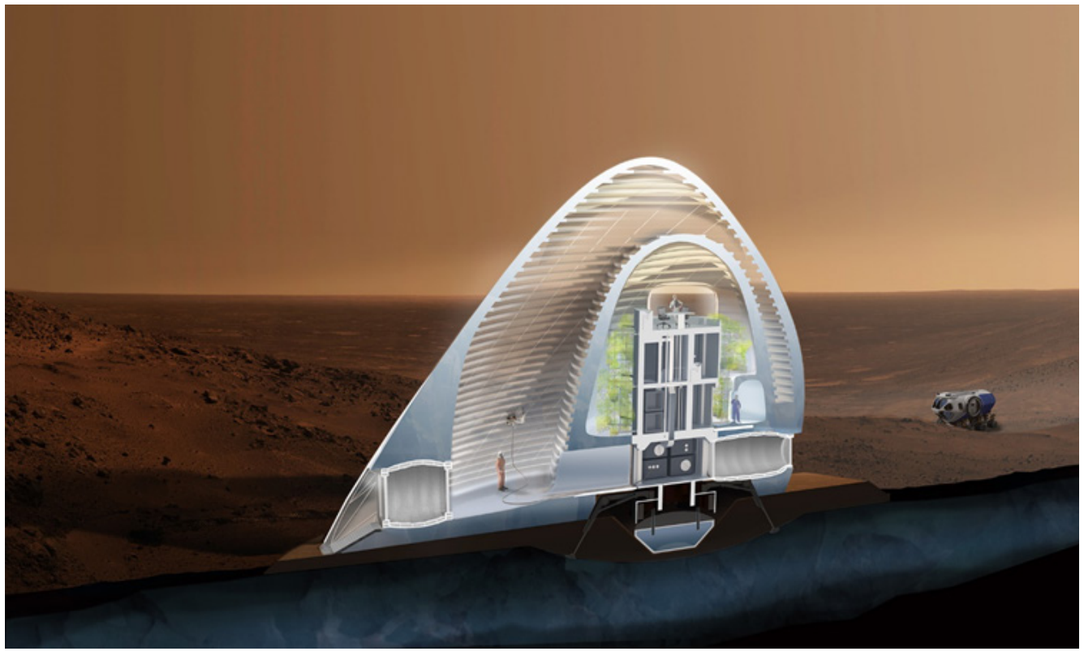


Figure 1. Example of environmental buffer space as transition between interior and exterior in Mars Ice House by SEArch+.[4].

1. Kristin Fisher, 'United States Announces Plan to Land International Astronaut on the Moon', CNN, 21 December 2023, https://www.cnn.com/2023/12/20/world/nasa-astronaut-moon-artemis-international-scn/index.html; 'NASA Shares Progress Toward Early Artemis Moon Missions with Crew - NASA', accessed 14 November 2024, https://www.nasa.gov/news-release/nasa-shares-progress-toward-early-artemis-moon-missions-with-crew/.
2. Anthony Cuthbertson, 'China Reveals Plan to Put People on the Moon', The Independent, 12 July 2023, https://www.independent.co.uk/space/china-moon-landing-crewed-mission-nasa-b2373771.html.
3. *Moonshot & Off-earth Environments Symposium*, TU Delft, 19 September 2024.
4. SEArch+, "The Habitat", *Mars Ice House*, updated 2015, accessed 20 November 2024, http://www.marsicehouse.com/habitat.

2. Problem Statement

Lack of space architecture precedents that prioritizes human behaviour in the design, especially apparent in the transitional spaces that are typically generalized to corridors and airlocks. Its potential to enhance the spatial and social experience of lunar habitation is underexplored.

Figure 2. Quest Airlock from Node 1, photograph by Paolo Nespoli and Roland Miller.[5]

3. Research Question

How to incorporate human-centric design principles in the transitional spaces of long-term lunar habitation to create a more humanized space architecture?

Sub-questions

- What kind of activities, movements, and functions could take place in the transitional spaces of a lunar habitat?
- How can transitional spaces mediate between functional areas to promote habitability and well-being?
- How can transitional spaces function as “third-place”?
- How can transitional spaces be utilized to integrate activities?
- How to design transitional spaces to afford certain activities:
- Achieve balance between promoting social cohesion and giving individual privacy? Aid the physical and mental shift between tasks when individuals move between distinct zones?

Research Objective

Creating a more humanized lunar habitat through designing user-refined transitional spaces to promote habitability and well-being for long-term lunar habitation.

5. Paolo Nespoli and Roland Miller, *Interior Space: A Visual Exploration of the International Space Station* (Damiani, 2020).

4. Limitations and Assumptions

There is no direct data on actual long-term living on the moon, thus making long-term lunar habitation speculative and relies on future technological advancement and research. There is even a possibility that it may not be feasible, depending on further research such as low gravity effects on human physiology and feasibility of long-term mitigation of the harmful lunar dust.[6] However, to focus on the spatial possibilities within the context of this research, this project assumes lunar living will be possible and is set in 2080, assuming the availability of in-situ resource utilization (ISRU) and advanced construction methods.[7]

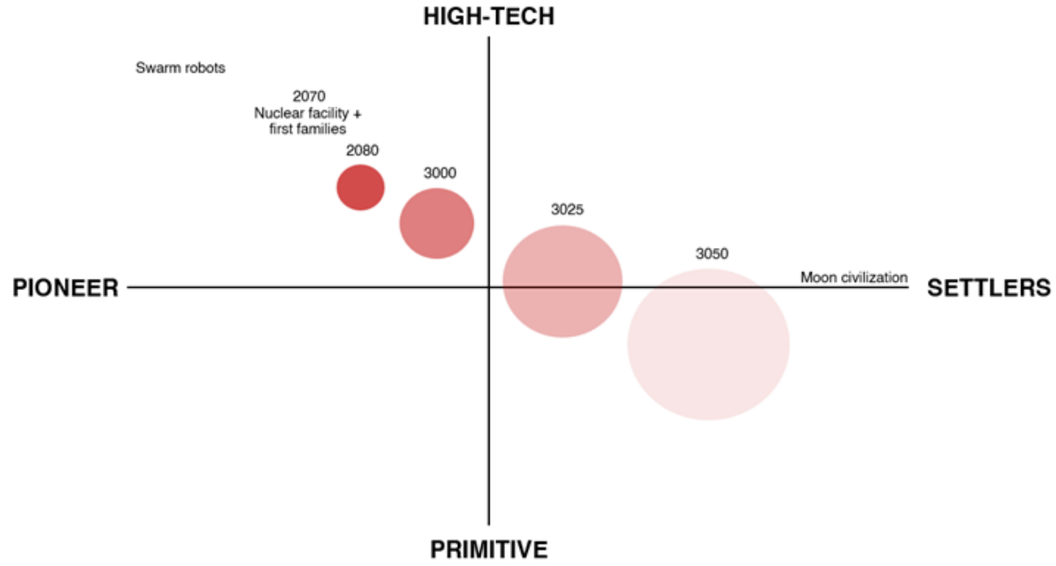


Figure 3. Timeline diagram by author.

6. Angelo Vermuelen", "Simulation-driven Approaches in Space Architecture," Lecture in *Lunar Architecture and Infrastructure P1 Presentation*, Delft University of Technology, 7 November 2024.
7. Haym Benaroya, *Building Habitats on the Moon* (Cham: Springer International Publishing, 2018), https://doi.org/10.1007/978-3-319-68244-0, page 34.

5. Theoretical Framework

5.1 Transitional Space

Transitional space in architecture generally refers to the undefined space between static spaces, transitioning from one function to the other. Winnicott, defined transition as the in-between, contributed by the two end states, as the intermediate area.[8] In space architecture, where each functional spaces are usually connected in modules, these transition spaces are typically in form of corridors or airlocks, or none at all, as spaces directly merge to other function, demarcated by doors.

In the experience of Angelo Vermuelen, a Belgian space biologist, the act of walking up the stairs as he leaves the work space on the ground floor towards the resting space on the mezzanine was quite impactful in separating the work and rest environment for his time in NASA Hi-SEAS Mission 1, an analogue environment where he lived in isolation with 7 other crew members for 4 months.

Figure 4. Angelo Vermuelen in the habitat of NASA Hi-SEAS Mission 1.[9]

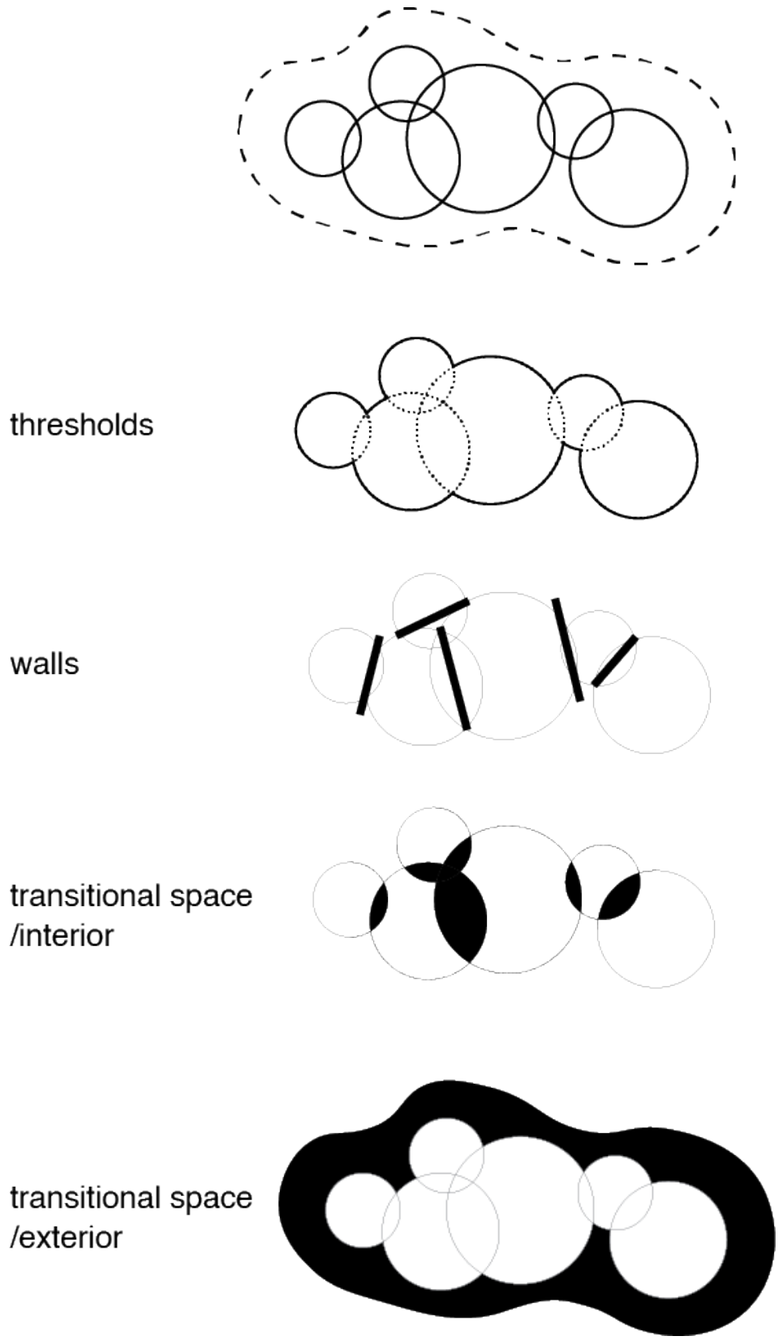


Figure 5. Diagram by author.

8. D.W. Winnicott, “Transitional Objects and Transitional Phenomena,” in *Playing and Reality* (New York: Routledge, 1989).
9. Angelo Vermuelen, “Simulation-driven Approaches.

5. Theoretical Framework

5.2 Human de-centered design

Under the extreme condition of lunar environment, habitat primarily functions as protection for humans. With the high safety demand for proven and tested applications, the bulk of concept developments on space habitations focused on optimizing the existing typology of capsule vessels and dome. The extreme of these capsule spaces with monotone corridors going around a centralized atrium connecting to repetitive and uniform units is illustrated in the image of ISS TransHab, a habitation module concept developed in the 1990s by NASA,[10] which spatially resembles the Panopticon – an ideal prison concept by Jeremy Bentham, which has been described as dehumanizing.[11]

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

Figure 6. Summary of lunar environment conditions from Architecture for Astronauts, last column added by author.[12]

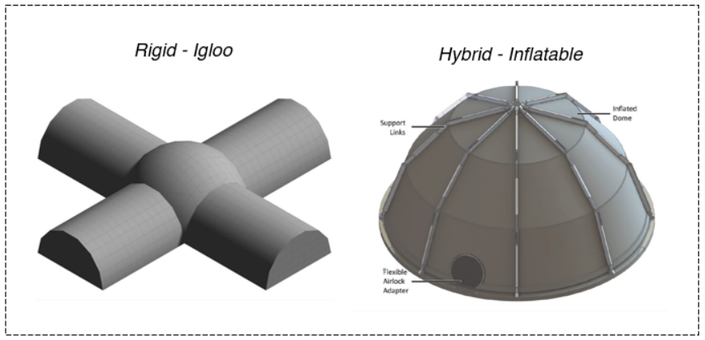


Figure 7. Evolution of lunar habitat concepts by Haym Benaroya. [13]

Table 1
Conceptual design of inhabited building schemes.

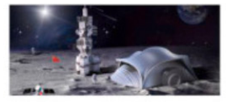
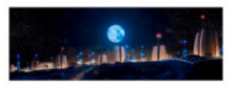
Scheme name	Proposer	Year	Description			Structural rendering
			Prefabricated core module	Inflatable structure	*In situ* material structure	
SinterHab [18]	NASA	2012	Pre-integrated rigid elements	Deployable membrane structure	Microwave sintered regolith shell	
Lunar Outpost [19]	ESA & Foster + Partners	2014	Prefabricated module	Prefabricated inflatable structure	*In situ* protective shell constructed based on 3D printing technology	
Xuanwu lunar habitation [20]	HUST & CSM	2019	–	Deployable membrane structure	Regolith blocks	
Moon Village [21]	SOM & MIT & ESA	2019	Rigid frame	Deployable membrane structure	*In situ* materials based on 3D printing technology	
Lunar Base [22]	JAXA & Kajima Corporation	2019	Prefabricated module	–	*In situ* material shell	
ICON Project Olympus [23]	ICON & NASA & BIG	2020	–	–	*In situ* 3D printed structure	
"Clover" Lunar Base [17]	HIT & CASC	2022	Prefabricated module	Inflatable structure	*In situ* protective shell constructed based on 3D printing technology	
"Red Star" Lunar Base [17]	HIT & CASC	2022	Prefabricated module (built in a crater)	Inflatable structure	*In situ* protective shell constructed based on regolith bag technology	

Figure 8. Summary of lunar base concepts by Charun Bao et al., 2024. [14]

10. Kim Dismukes, "TransHab Concept," Human Space Flight, *NASA*, updated on 27 June 2003, archived on 27 June 2006, https://web.archive.org/web/20060627190940/http://spaceflight.nasa.gov/history/station/transhab/.
11. Ujwala Pramod Solase and N. B. Masal, "Surveillance, Gazing and Dehumanization in Dystopia," in *International Journal of Innovative Research in Technology* 9, no. 3 (2022): 323-326, https://ijirt.org/publishedpaper/IJIRT155927_PAPER.pdf
12. Sandra Hauplik-Meusburger, *Architecture for Astronauts: An Activity-Based Approach* (Wien: Springer, 2011).
13. Haym Benaroya, "The Evolution of Lunar Habitat Concepts," in *International Journal of Space Structures* 37, no. 3, 2022, https://doi.org/10.1177/09560599221119103.
14. Charun Bao et al., 'Conceptual Design and Experimental Investigation of Regolith Bag Structures for Lunar in Situ Construction', in *Journal of Building Engineering* 95 (15 October 2024): 110245, https://doi.org/10.1016/j.jobe.2024.110245.

5. Theoretical Framework

5.2 Human de-centered design

To understand the factors that dehumanize space architecture, we first define the common associated terms: dehumanizing and inhuman. Dehumanizing is defined as “to deprive someone or something of human qualities, personality, or dignity.”[15] Rafael De Clerq, through drawing reference from Dehumanization of Art by José Ortega y Gasset, elaborates on the dehumanization of architecture as a tendency towards abstraction to purify architecture, foregrounding certain aspects taken to be the true objects of interest.[16] Nikos Salingaros, a mathematician and architectural theorist known for his anti-modernist views, described inhuman styles as “not adapted to human sensitivity,” that leads to man becoming inhuman through suppression of our natural reactions to the physical surroundings.[17]

Space habitat typologies, such as the ISS TransHab, derived its form and spatial configuration by measures of achieving efficient transportability, economy, and protection – all of which are non-human actors. In the case of the Panopticon, the intention to enable central surveillance of every inmate’s cell drives the form – the reasoning itself is inhuman and dehumanizing. Though the concepts are different, the resulting function-driven-form implies the lack of provision in positive human qualities. Where the Panopticon is dehumanizing by having a space that enables the act of dehumanization, the ISS TransHab dehumanize through not focusing on the human factor.

The dehumanization of these spaces, although not intended for captives, in a way psychologically could turn the space architecture into a place of confinement, as illustrated from the experience of Beth Healey, a 28-year-old medical doctor, in her 14 months stay in Concordia Station analogue mission – simulated mission environment taking place on Earth. She mentioned in her blog that “the most frightening aspect (of partaking the analogue testing) was not the lethal cold outside, but the isolation inside,” and how each individual would react to it.[18]

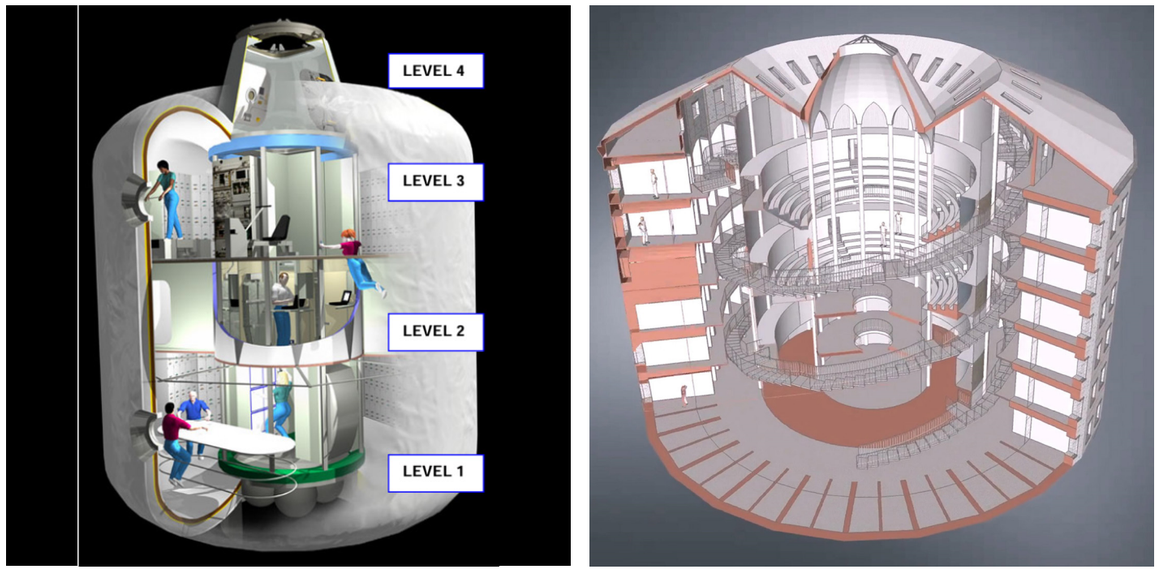


Figure 9. ISS TransHab (left) and the Panopticon (right).[19]

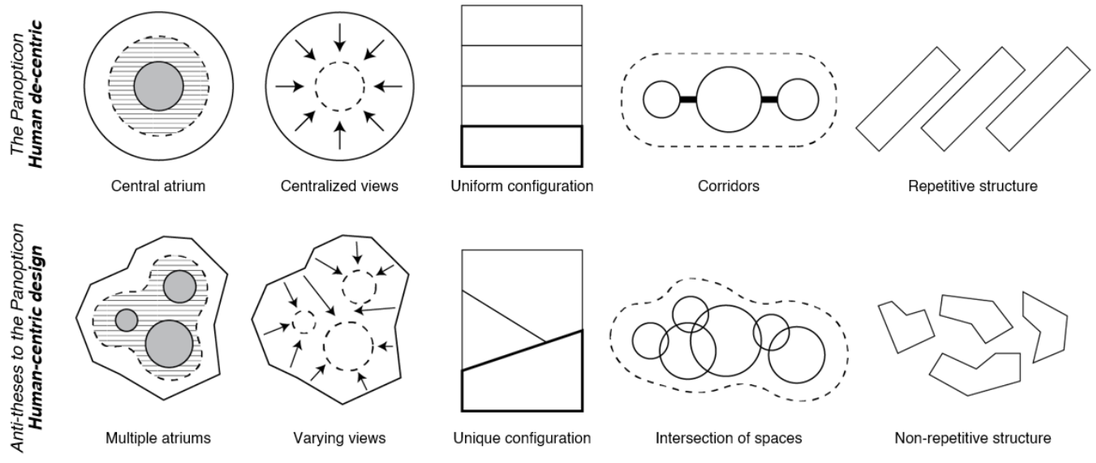


Figure 10. Spatial abstraction of the Panopticon and its anti-theses by author.

15. “Dehumanize (verb),” Merriam-Webster Dictionary.
16. Rafael De Clerq, “The Dehumanization of Architecture,” in *Journal of Aesthetic Education* 56, no. 4 (202): 12-28.
17. Nikos Angelos Salingaros and Christopher James Alexander, *Anti-Architecture and Deconstruction* (Sustasis Foundation, 2013).
18. Olga Bannova and Marc Cohen, *Space Architecture: Human Habitats Beyond Planet Earth* (DOM Publishers, 2021), page 96.
19. “S99-05363,” International Space Station Imagery, *NASA*, updated 30 August 2001, archived 7 December 2001; Myles Zhang, “Computer Model of Jeremy Bentham’s Panopticon,” (Master Thesis, University of Cambridge, 2019), https://www.myleszhang.org/2019/11/11/jeremy-bentham-panopticon-animation/

5. Theoretical Framework

5.3 Human Centric Design Theories

Habitability
In designing lunar habitats, the primary requirement is protection against the extreme lunar environment. However, when designing for long-term habitation, a functioning habitat should provide habitability in addition to protection. Sandra Hauplik-Meusburger, a space architect, summarizes the different definitions of habitability in *Architecture for Astronauts*.[20] Fitting her conclusion in the context of lunar habitat, habitability is defined as the suitability and value of a lunar habitation for its inhabitants – focusing on researchers – in the specific environment of a lunar surface and over a certain period of time – in this case, long-term.

Phenomenology and activity-based design
The lack of human experience in space means first-hand accounts from the astronauts is incredibly crucial, especially for human-centric design. Christian Norberg-Schulz, on his theory for phenomenology in architecture, argues on the concept of place, that each place is shaped by unique physical, cultural, and historical context.[21] Drawing upon this, it means architecture that goes beyond functionality to create a place, associated with human experience and perception as basis to design spaces, which would be essential to space architecture that lacks the human-centric perspective. Foundations on experience-based space architecture has been laid down by Hauplik-Meusburger in her book *Architecture for Astronaut*s, which summarizes and evaluates selected space habitats through activities in a habitat, based on data and personal experiences of astronauts.[22]

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

Figure 11. Astronauts note on sleeping.[23]

20. Hauplik-Meusburger, *Architecture for Astronauts.*
21. Christian Norberg-Schulz, *Genius Loci: Towards a Phenomenology of Architecture* (New York: Rizzoli, 1980).
22-23. Hauplik-Meusburger, *Architecture for Astronauts*.

5. Theoretical Framework

5.3 Human Centric Design Theories

Affordances

Quoting David J. Shayler put it in Disasters and Accidents in Manned Spaceflight, “the history on space exploration is full of reports about mishaps”. For example, the broken air hose in ISS Destiny module is due to extensive grabbing by the astronauts, as it is the only “handhold-like” object near the window – a favourite spot for the astronauts.[24]

Affordance theory by James J. Gibson, explained the actionable possibility of an environment – e.g. objects, surfaces, food – in relationship to the humans and animals, shape our perception, in what he calls as “to afford”.[25] As a lot of requirements in lunar habitation remains unknown, affordance theory is useful to provide a framework to anticipate behaviours.

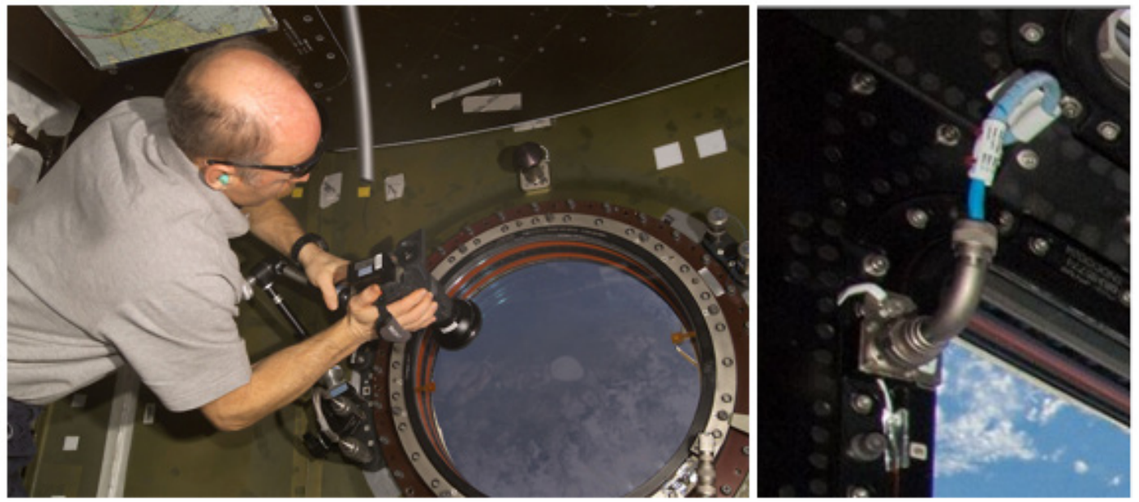


Figure 12. Broken air hose in ISS Destiny Module, due to extended use for grabbing.[27]

Proxemics and Third Place Theory

Within the confined lunar habitat, setting privacy gradients and strategizing functions of transitional space will be crucial to foster sustainable communities. Edward T. Hall in defining proxemics, theorizes on privacy gradient zones, emphasizing on the use of space for interpersonal communication.[26] This, combining with Third Place Theory by Ray Oldenburg as places between the workplace and home, gives a foundational framework for transitional spaces to balance social cohesion and individual privacy, a crucial space to form communities.

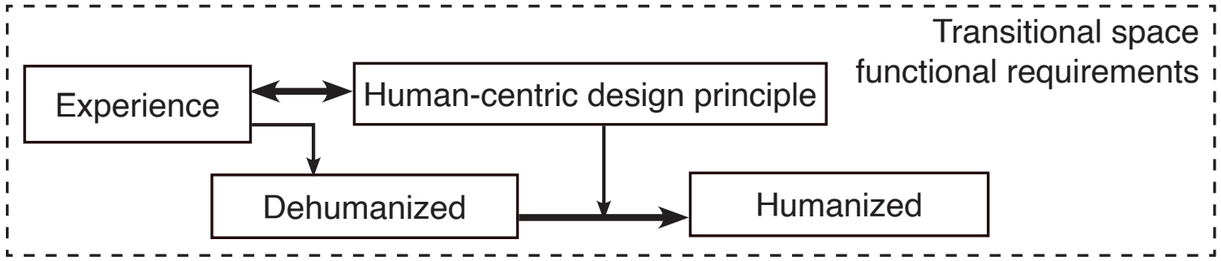
“Skylab and Shuttle-Mir experiences have confirmed that the availability of an open, communal area is very important for crew morale and productivity during long duration isolation and confinement in space.

Figure 13. Dedicated dining table in Skylab Station, accompanied by excerpt from *NASA Human Integration Design Handbook*.[28]

24. Hauplik-Meusburger, *Architecture for Astronauts*.
25. James J. Gibson, “The Theory of Affordances,” in *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin, 1979).
26. Edward T. Hall, *The Hidden Dimension* (New York, Doubleday, 1966)
27. Hauplik-Meusburger, *Architecture for Astronauts*.
28. Hauplik-Meusburger, *Architecture for Astronauts*; NASA, *NASA-STD-3001 Volume 2: Human Integration Design Handbook, Revision 2* (NASA, 2022), https://www.nasa.gov/wp-content/uploads/2023/03/human-integration-design-handbook-revision-1.pdf?emrc=673db194d6b45..

6. Methodology

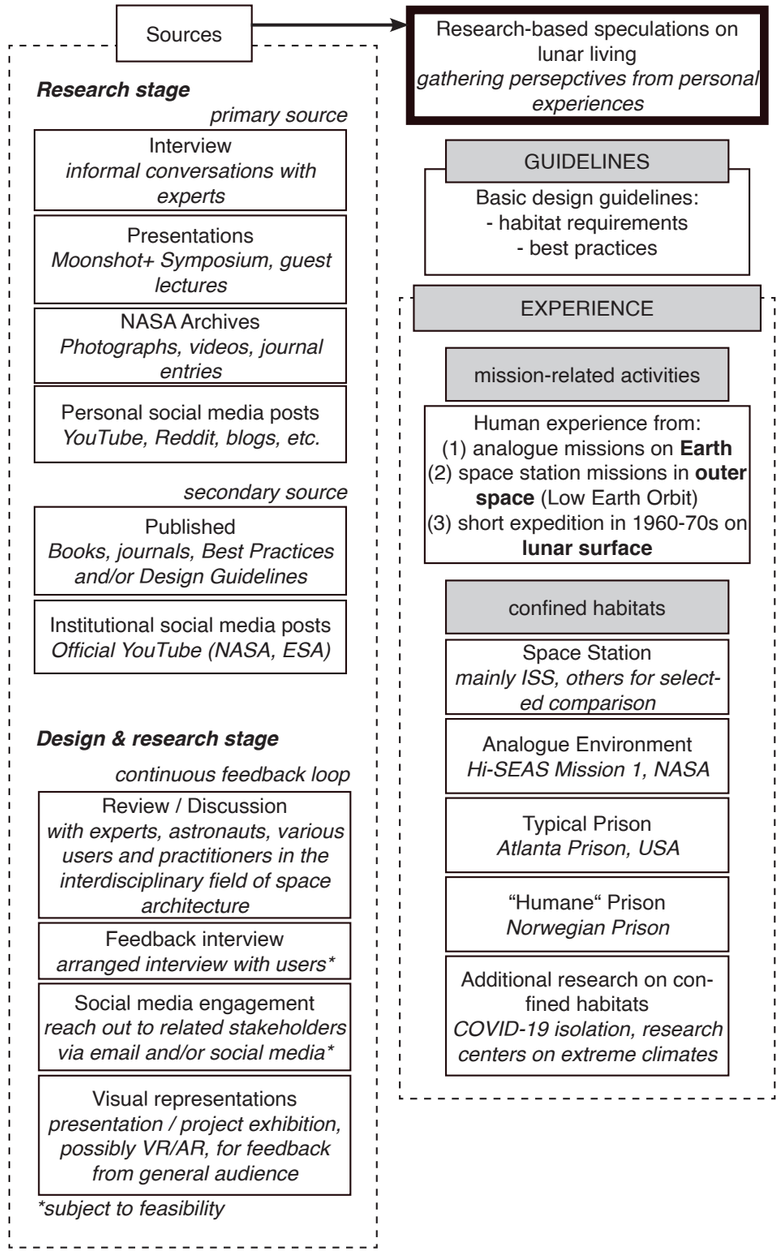
6.1 Conceptual Model



The research is based on experiences of people living in space and analogue environments, postulating on factors that influences creation of dehumanizing design, then using human-centric design principles cross-checked and informed also by experiences to create a more humanized design, all within the boundary of the functional requirements of transitional space.

6.2 Data Collection: Guidelines and Experience

This research mainly draws on two categories of data, guidelines and experiences. Guidelines on lunar habitation is based on habitat requirements and best practices published by official organizations and research bodies such as NASA and ESA. Human experiences on mission-related activities such as analogue missions on Earth, space station missions in outer space Low Earth Orbit condition, and short-term expeditions on lunar surface are used to extrapolate long-term human habitation requirements. Further speculations on mitigating psychological and psychosomatic effects for long-term confinement is taken from confined habitat experiences, comparing living on space station and analogue environment to that on prison architecture, COVID-19 isolation, and artic research centres.

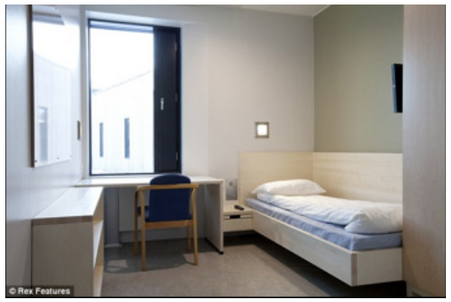


6. Methodology

6.3 Activity-based mapping

To this regard, a method of mapping of “a-day-in-my-life” in International Space Station (ISS) and prison is done to compare the activities of an astronaut and a prisoner, making adjustments from the activity-based approach mapping done by Hauplik-Meusburger in comparing the different space stations.[29] Although the astronauts and prisoner are subject to different political, moral, and environmental conditions, the subject of isolation and living in confined habitat is applicable as means of comparison.

It is interesting to note that when these spaces are abstracted to public and private spaces – the public indicating communal areas where there is possible interaction with others, whereas the private indicates private quarters in the ISS, and locked cells in the prison – we can observe the movement across public space in regards to changing activity. In the Norwegian Prison, which is dubbed as the most humane prison system in the world with the lowest reconviction rate, there is quite a lot of time spent moving across communal spaces for different activity, whereas there is limited movement in the communal space in Atlanta Prison. Although further research needs to be done on the relations of the spatial movement, investigating further on the impact of transition between spaces would be of interest in this project.



Halden Prison, Norway

La Palma Correctional Center, Arizona, USA

Arizona State Prison USA

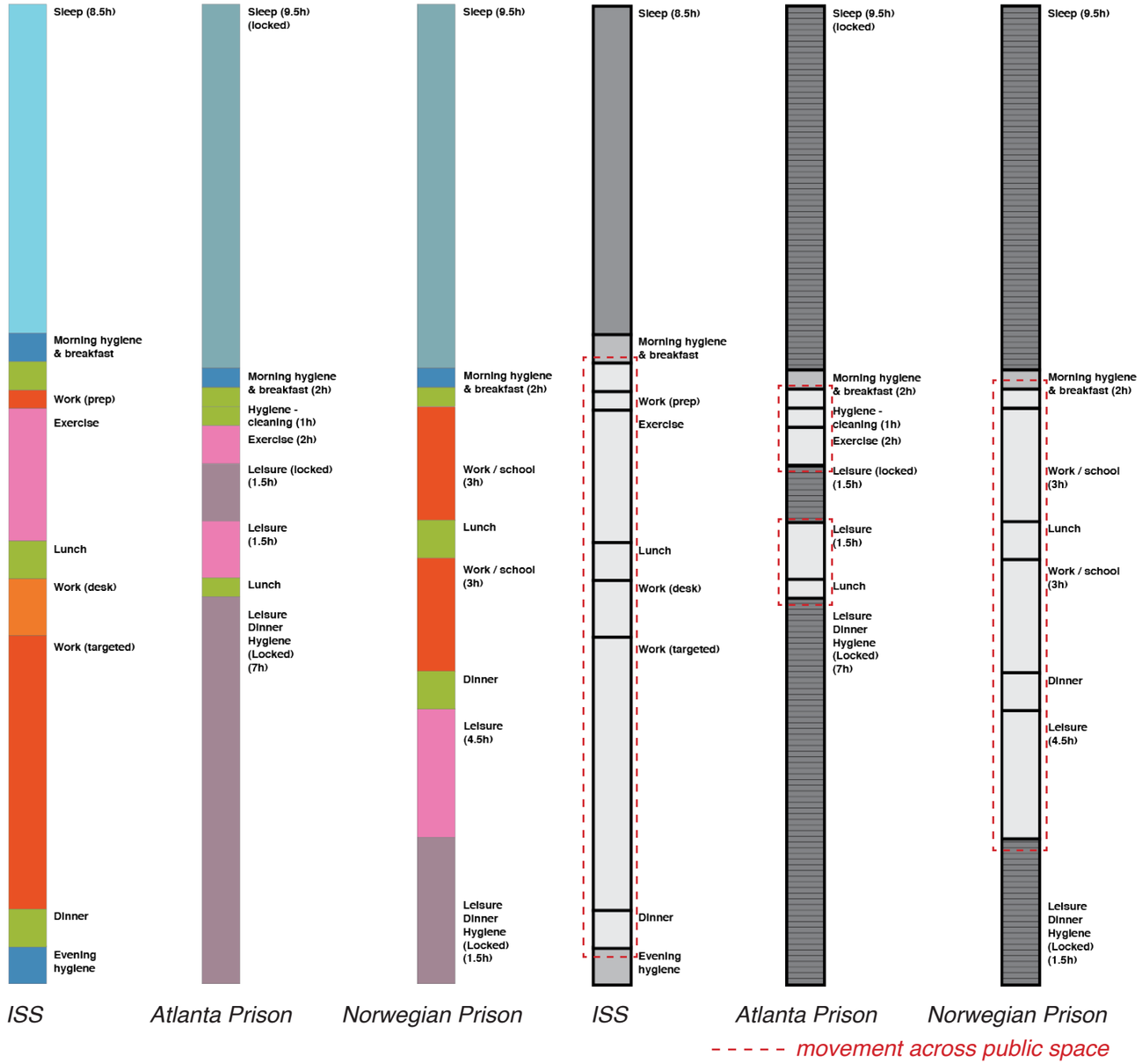


Figure 14. A-day-in-my-life 24 hour activity-based mapping across spaces (left) and Activity-based mapping across spaces, abstracted in relation to private and public spaces (right), by author.

29. Hauplik-Meusburger, *Architecture for Astronauts*.

6. Methodology

6.3 Activity-based mapping

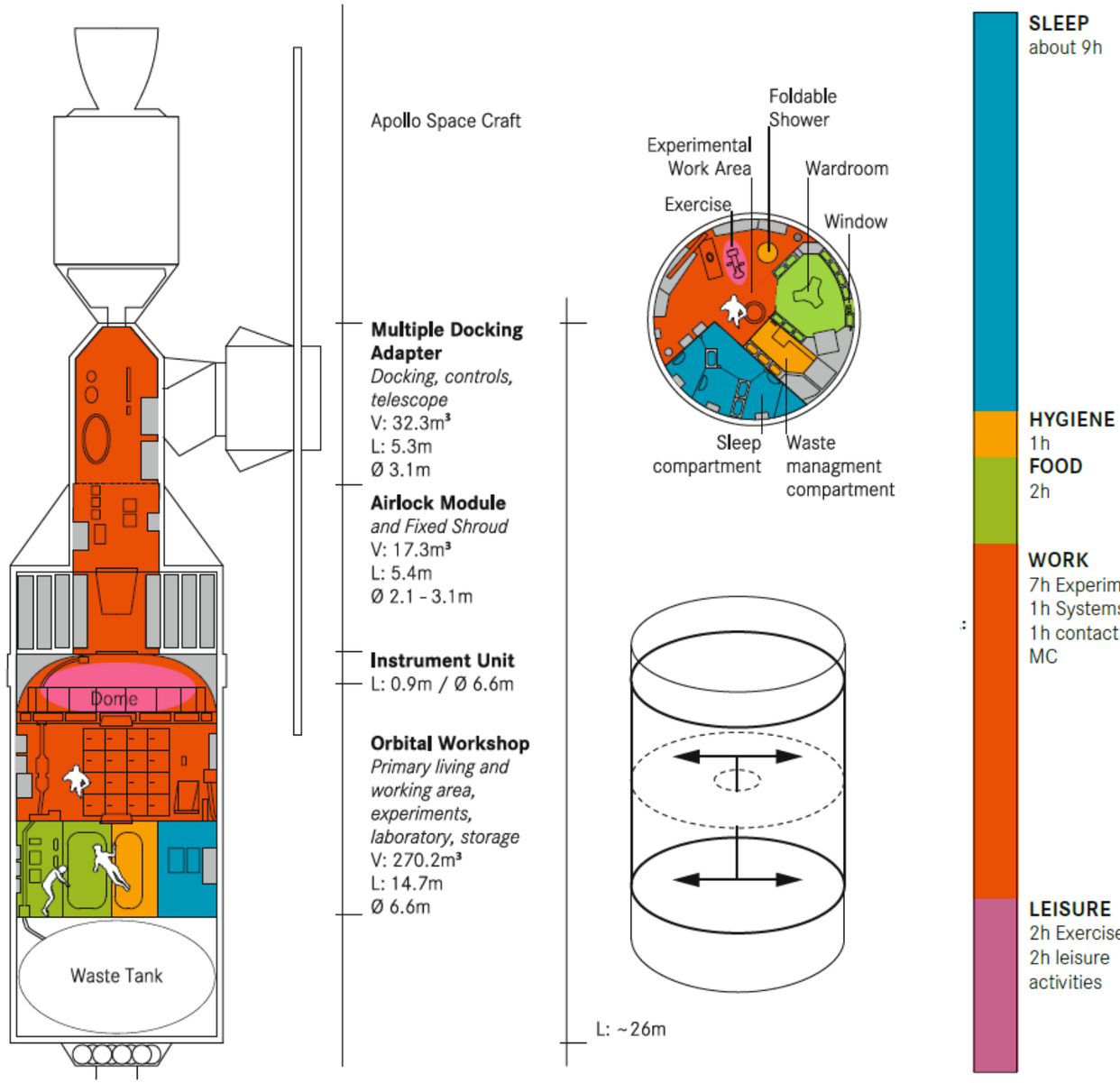


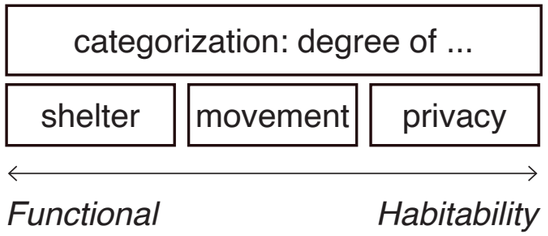
Figure 15. Skylab Space Station interior layout, with annotations on spatial and time allocation by Hauplik-Meusburger, based on NASA documents.[30]

30. Hauplik-Meusburger, *Architecture for Astronauts*.

6. Methodology

6.4 Mapping the transitional spaces typologies: between functionality and habitability

To establish the boundary of functional requirements within the different transitional spaces, different transitional spaces within lunar habitation will be categorized in terms of functionality and habitability, in the degree of shelter, movement, and privacy, to show the degree of which these transitional spaces can adopt and integrate different functions.



6.5 Multi-scalar design approach

As functional area across different scales have transitional space, the design will adopt a multi-scalar approach, from macro, meso, to micro. Macro-scale transitional spaces mediates between the exterior and interior, through pushing experiential transitions by possibly interacting with the local environment instead of just conventionally shielding it off. The meso-scale will explore the spatial arrangement of spaces, on relation between functional areas, which incorporate strategies for adjacencies: privacy gradient, spatial adjacencies, and activity-based program distribution, strengthened by proxemics and third-place theory, all in aiming for a richer variant and experience in transitioning between spaces. A parametric approach will be used to allocate the adjacencies of the spaces, basing on the activity-route of the users. Lastly, the micro-scale will focus on the body-object interaction of surfaces and objects. Applying the theory on affordances, it will take into account the importance of human intuition based-off past experiences in space habitats and extrapolating human movement based from photographs and videos of astronauts on the moon in the NASA archives.[31]

Macro
Design for Localization

Meso
Design for Adjacencies

Micro
Design for Affordances

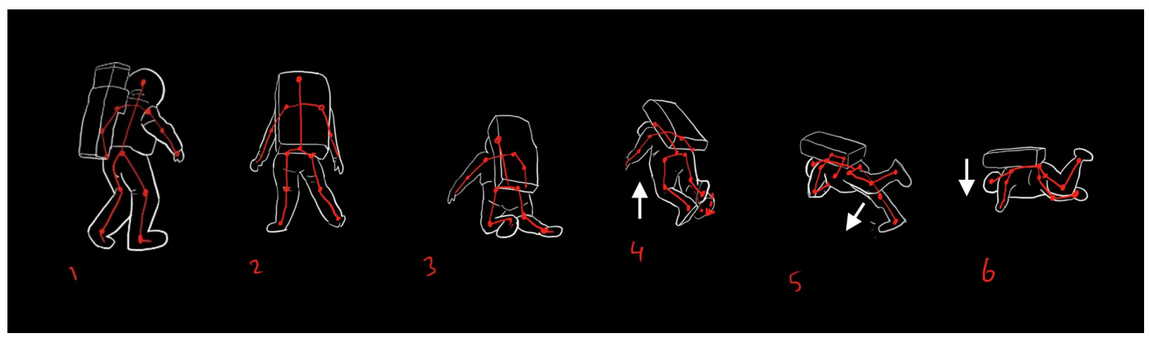


Figure 16. Lunar Movement Analysis by author, based on Astronauts Falling on the Moon (1972) in Apollo 17 Video Library, NASA Archive. [32]

31. Hauplik-Meusburger, *Architecture for Astronauts*.
32. “Astronauts Falling on the Moon,” Apollo 17 Video Library, *NASA Archive,* 1972.

7. Design Direction and Conclusion

7.1 Macro-scale: Localized layered enclosures

Inspired from the GeoTube towers with the gradual change to the envelope from the salt disposition build up, it will be interesting to introduce similar methods in a lunar environment – to connect humans with the lunar environment, providing local experiential enclosures as transition between interior to the exterior. Through early concept discussion with experts, it is possible to use lunar dust – transforming what ESA dubbed as the most problematic challenge into a promising material.[33]

7.2 Meso-scale: Third-place transitional spaces

Corridors promotes continuation into the next destination, whereas having rooms as a transitional space can promote stops for interactions – a social function highly recommended by crew members to promote team solidarity and cohesiveness, possibly functioning as the "third place" for lunar habitation.

7.3 Micro-scale: Afforded surfaces

Micro-scale will focus more on surface geometry and direct relation to the human body. For example, having individual nooks to transition towards private functions, or changing floor inclination to change the movement pace leading to certain functions.

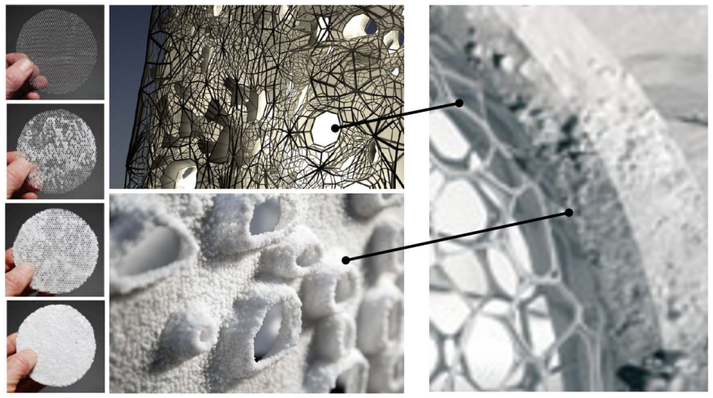
7.4 Conclusion

In conclusion, this project aims to design

a lunar habitat with a library of user-refined transitional spaces,

informed by guidelines and experiences to speculate lunar living, with human-centric design strategies appropriated across scales, in hopes that focusing on humanizing the transitional spaces will impact its adjacent spaces – thus contributing towards a more human-centric lunar habitat.

33. Advenit Makaya, "Advanced Manufacturing for Off-Earth Settlements," in *Moonshot & Off-earth Environments Symposium,* TU Delft, 19 September 2024.



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

- 2nd 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

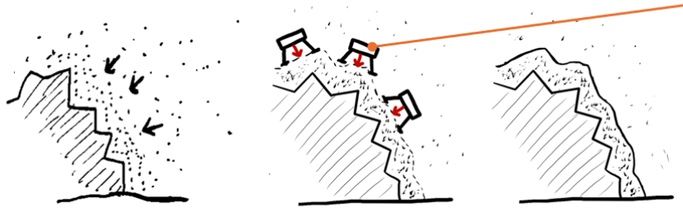
- With laser heat, based on in class discussion with expert

Transparent material

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

Application scheme

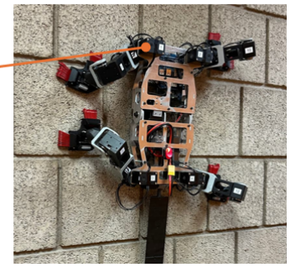
**developed during discussion with expert*



(1) Grow
Electrostatic envelope attract lunar dust

(2) Pack
Laser sintering

(3) Protect



Climbing robot LORIS

Figure 17. Concept feasibility of incorporating lunar regolith in macro-scale by author.

Figure 18. Reference project for micro-scale. The End of Sitting by RAAAF & Barbara Visser (2014).

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