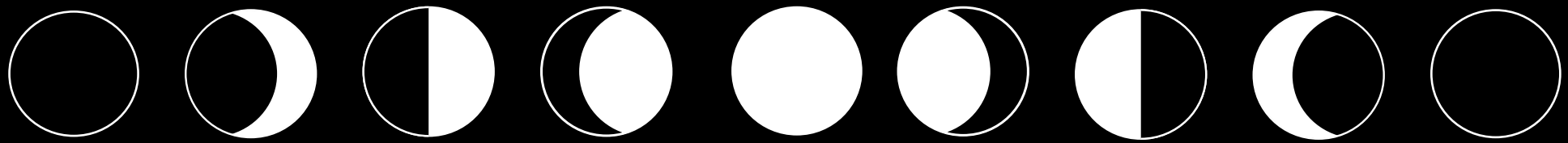
AR3A010
Research Plan

Lunar Architecture Graduation Studio

OVER THE MOON

Providing an architectural solution for the negative psychological effects of long term Lunar habitation



Sophia Benfield
5260752

19 November 2024

Tutor graduation studio: H. Bier & A. Hidding
Tutor research plan: A. Stanicic

Table of Contents

Introduction

In 1969 man first set foot on the Moon, something that had seemed impossible. Now, 55 years later, we are finally getting ready to take the next step; one of the aims of NASA's Artemis Missions is to lay the foundations of lunar bases on the surface of the Moon that can facilitate human habitation for a longer period of time(1).

However, the Moon's climate is not as human-friendly as that of the Earth. The lack of atmosphere, extremely low temperatures and unfiltered radiation will require a robust shelter to protect any human explorers from harm, as well as a durable way to provide food and water indefinitely (2). Another factor that influences astronauts wellbeing is the difference in day/night cycle on the moon. The human body relies on the 24-hour light rhythm on Earth, provided by the sun, to regulate important hormone cycles that influence people's physical and mental performance (3). Unfortunately, the Moon adheres to a different calendar, with one Moon day stretching to cover 14 Earth days and the Moon completing a full day/night cycle in 28 days (4).

Besides all these physiological needs, consideration must also be given to the mental effects of living on the Moon's surface. Smith (5) identified nearly 70 stressors created by Moon dwelling, ranging from the very real possibility of dying to boredom and from crew tension to isolation. On earth a lot of relaxation can be found outside of the home, for example, by taking a walk outside, preferably in nature; having a 'change of scenery', as it is often phrased. On the Moon this will not be possible as the surface environment is very hazardous as any EVA's [extravehicular activities] need to be planned meticulously. Even looking out the window will not show the varying blue and green views we are used to, but a colourless, rocky landscape similar to a black and white photograph (see page 4). However, one experience that has been proven to have a positive psychological effect on astronauts is Earth gazing. This entails the viewing of whole of Earth from space and has been known to induce awe and wonder in various astronauts (6) (see page 6).

Due to the dangerous conditions out on the surface, any long-term settlers will be mostly

1. Royal Museums Greenwich, "Artemis Programme: What You Need to Know about NASA's Moon Missions," NASA's Artemis Moon Missions: all you need to know, n.d. Accessed October 14, 2024, https://www.rmg.co.uk/stories/topics/nasa-moon-mission-artemis-program-launch-date#:~:text=Artemis%201%3A%20After%20being%20delayed,Artemis%204%3A%202027.

2. Haym Benaroya, "Lunar Habitats: A Brief Overview of Issues and Concepts," *REACH 7–8* (December 2017): 14–33, https://doi.org/10.1016/j.reach.2018.08.002, 17.

3. Carolina Caballero-Arce, Adolfo Vigil de Insausti, and Javier Benlloch Marco, "Lighting of Space Habitats: Influence of Color Temperature on a Crew's Physical and Mental Health," *42nd International Conference on Environmental Systems*, July 15, 2012, https://doi.org/10.2514/6.2012-3615, 3.

4. Advenit Makaya, "Moonshot & Off-Earth Environments Symposium," in *Moonshotplus. Tudelft.nl* (Delft: Delft Technical University, 2024), https://moonshotplus.tudelft.nl/index.php?title=Lectures, 3.

5. 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.

6. Anaïs Voski, 2020. "The ecological significance of the overview effect: Environmental attitudes and behaviours in astronauts". *Journal of Environmental Psychology, 70*, 101454.

confined to the Moon base, with only their fellow crew members to interact with. This monotony regarding to the environment and social relations can increase feelings of isolation and anxiety because they do not provide enough new stimuli (7).

In the past, the design of space bases was mostly left to engineers, without consulting architects. Russian architect Galina Balashova has spoken often about being the only one with an architectural vision besides countless engineers while working on the Soviet space modules (8). She was the first to consider the visual impact of the environment inside the module and incorporated colour schemes and textures to help astronauts feel comfortable and help orient them in 0-gravity. Balashova even added her own watercolours on the walls, to give the astronauts a connection to home (see page 14).

The importance of incorporating the architectural vision into space architecture, has everything to do with habitability in the long run; creating a space where astronauts can not only survive physically, but will also thrive mentally. During his time in space, former astronaut and physician Jay Buckey realised the importance of maintaining a good mental health as an astronaut, stating: “the psychological aspect is a really important one to deal with, because if it’s done right, the missions can be truly amazing, but if it goes wrong, it’s the kind of thing that can end a mission”(9).

It is imperative that any future Moon base is designed in such a way that it eases the negative feelings that will arise from living on the Moon. To accomplish this, it is important to understand how people perceive architectural spaces and the psychological responses that follow. Gaining knowledge on this aesthetic aspect of spatial perception can help identify design elements and strategies to influence the state of mind of an individual inhabiting a space.

This research will investigate different spatial interventions that can improve the mental health of long-term Moon settlers, their efficacy and how they can be implemented in an architectural design. The main research question will be as follows:

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

Possible subordinate subjects are:

1. Spatial form interventions
- form in the interior
- visual connections between rooms

2.Artificial lighting
- Automated or interactive
- Sun path - circadian rhythm

3.Creating views: real or artificial
- Earth gazing
- Screens
- Virtual reality

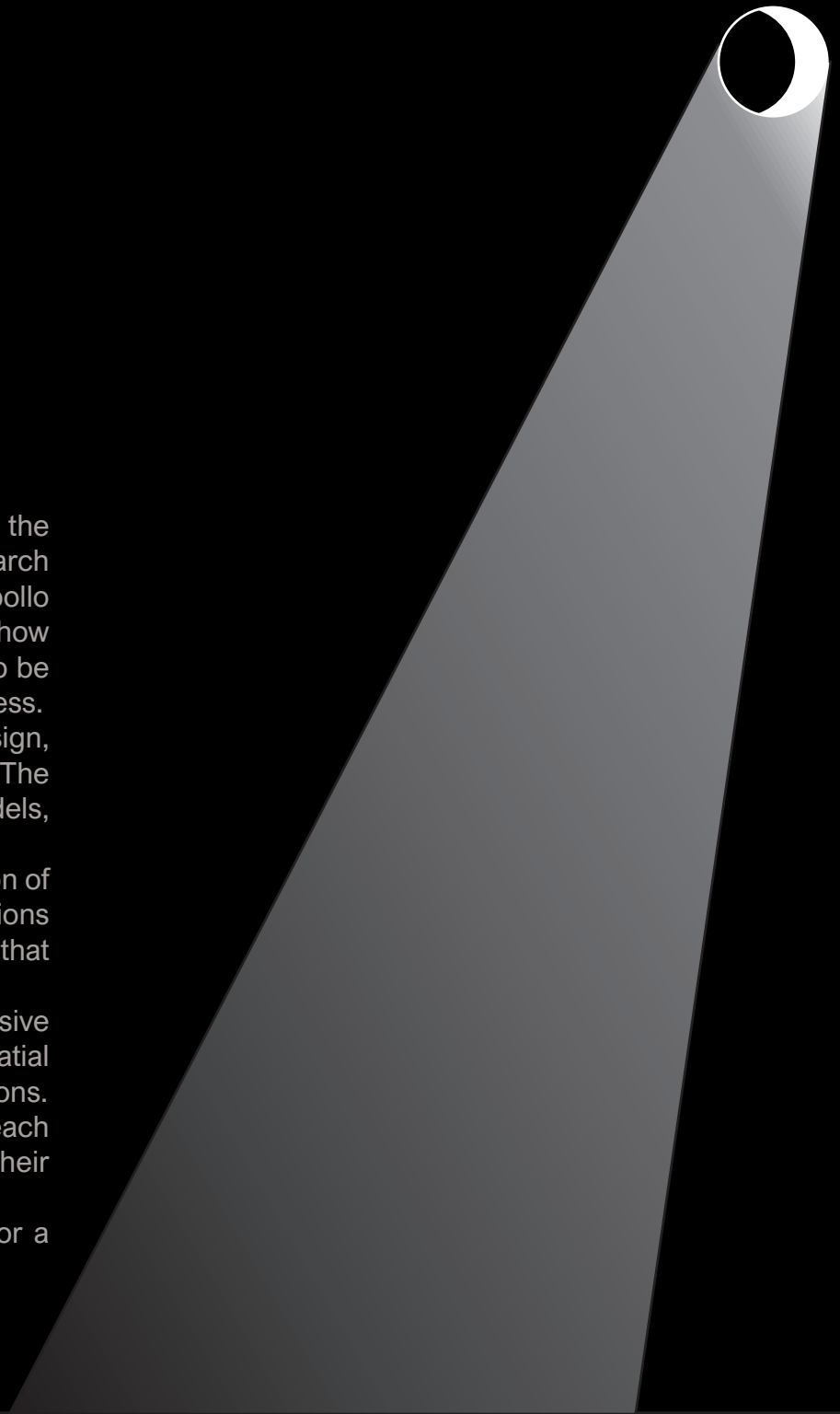
---

7. Alessandro Arone et al., “The Burden of Space Exploration on the Mental Health of Astronauts: A Narrative Review,” Clinical Neuropsychology 18, no. 5 (October 2021): 237–46, https://doi.org/10.36131/cnfioritieditore20210502, 239.

8. “I Had Complete Creative Freedom.” Vitra, February 8, 2022. https://www.vitra.com/nl-nl/magazine/details/i-had-complete-creative-freedom.

9. Kelly Oakes. “How Long Space Voyages Could Mess with Our Minds.” BBC News, February 28, 2022. https://www.bbc.com/future/article/20191029-how-long-space-voyages-could-mess-with-our-minds.

Methodology



The main topic of spatial aesthetics will be researched by first looking into the available literature on this subject and defining different spatial interventions to research further. NASA has several logs in their archives, kept by astronauts during the Apollo missions. They might hold crucial information about the crews state of mind and how it was impacted by their living space. Besides defining the interventions, it will also be important to define the criteria that will help judge each intervention on effectiveness.

The main method of investigating each intervention will be research by design, which will include testing out various options through renderings and simulations. The interventions that are considered most effective will also be tested by building models, to test the real life spatiality and if it compares to the digital version.

As the main objective is to research the emotional and psychological reaction of people to these different interventions, a survey about a selection of the interventions will be relevant. The developed renders and models can be used as impressions that partakers of the survey can react to.

To get even more accurate results, it would be helpful to create an immersive test, with the help of virtual reality, where participants can experience different spatial interventions fully. Afterwards an interview will be conducted to gauge their reactions. How the various options perform according to the set criteria will be compared to each other, with the end result being an overview of the best design strategies and their effects.

Finally, the outcome of the research will be applied to an actual design for a lunar base.

Theoretical Framework

Relevant concepts within designing for psychological wellbeing are mostly related to visual stimuli and how they affect human beings emotionally. This chapter will define the following concepts: aesthetics, the circadian light rhythm and atmosphere.

Aesthetics in Architecture

When trying to design Architecture that evokes a positive feeling for visitors, it is necessary to understand how the human brain perceives visual stimuli and more importantly how it decides which of those stimuli is aesthetically pleasing. Research by Eberhard (10) shows that how a person processes and evaluates these stimuli is mainly influenced by their personal frame of reference that has been formed by all their experiences throughout life.
However, not all is subjective. There are definitely general principles that can be identified, like preference for curved geometry (11) and certain mathematical proportions based on nature, that were already captured a long time ago by Vitruvius in his theory of Venustas (12). Neurosbiologist Semir Zeki (13) studied these two factors and found that the more general and geometric rules were most applicable to biological beauty (nature, bodies, faces), while the personal history was most influential when it came to aesthetic perception of lifeless objects. Architecture falls right in the middle of these two categories and combines both the personal framework and mathematical principles.

10. John P. Eberhard, *Architecture and the Brain: A New Knowledge Base from Neuroscience* (Atlanta, Georgia: Greenway Communications : Ostberg, 2007).

11. Maryam Banaei et al., "Walking through Architectural Spaces: The Impact of Interior Forms on Human Brain Dynamics," *Frontiers in Human Neuroscience 11* (September 27, 2017): 1–14, https://doi.org/10.3389/fnhum.2017.00477, 12.

12. Semir Zeki, "Beauty in Architecture: Not a Luxury - Only a Necessity," *Architectural Design 89, no. 5* (September 2019): 14–19, https://doi.org/10.1002/ad.2473, 18.

13. Ibid

Theoretical Framework

Light is a crucial part of architectural design, it can influence the atmosphere of a space. On Earth we rely on daylight coming in through windows and even map the sun's path to see how it will impact a room or building throughout the day. On the Moon sunlight behaves differently due to the lack of atmosphere and the reflective surface (see page 10). The human body is also very dependent on light. On earth we have the 'Circadian Light Rhythm" of the sun that the body is used to. It will need to be recreated for the wellbeing of astronauts within the habitat and this will influence the design. An understanding of this concept is therefore crucial for this research.

Circadian Light Rhythm:

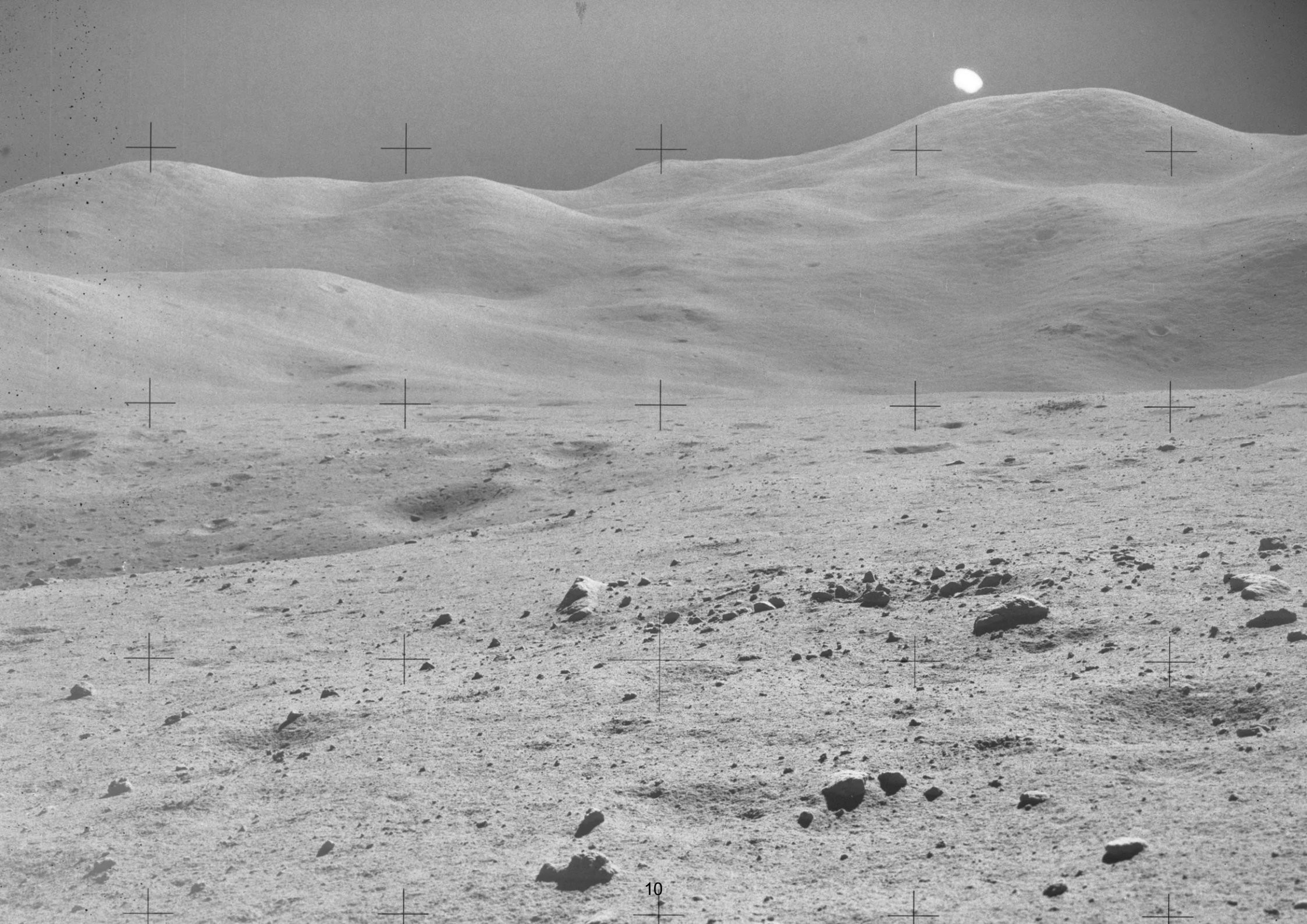
The phrase refers to the 24-hour day/night cycle that the human body adheres to every day. It is mainly influenced by (day)light/dark perception, by which the human body tracks where it currently is in the cycle. It is important to note that natural light varies each moment of the day, consisting of different wavelengths related to the position of the sun and the time of year. For example, daylight contains more red wavelengths during mornings and evenings, and more blue light around midday. Each colour range triggers the nervous system to released or inhibit different hormones. Standard artificial lighting, however, has the same light throughout the day - usually containing more blue light - and can disrupt hormone cycles. Circadian disruption causes loss of sleep, anxiety and a decrease in alertness, focus and general performance.

14. Caballero-Arce, Vigil-de Insausti and Benlloch-Marco, "Lighting of Space Habitats," 2.

15. Ibid

16. Kathleen E. West et al., "Blue Light from Light-Emitting Diodes Elicits a Dose-Dependent Suppression of Melatonin in Humans," *Journal of Applied Physiology 110*, no. 3 (March 2011): 619–26, https://doi.org/10.1152/japplphysiol.01413.2009, 619.

17. Caballero-Arce, Vigil-de Insausti and Benlloch-Marco, "Lighting of Space Habitats," 4.



Theoretical Framework

Atmosphere:

The definition of atmosphere can be given in two domains. In a physical, palpable sense, atmosphere is defined as “the mixture of gases around the earth” (18) and “the air that you breathe in a place ”(19). However, this particular research requires knowledge of the second definition, which is more emotionally based: “the character, feeling, or mood of a place or situation”(20).
There are different factors that can affect the emotional reaction to a space, like the form of objects within it and the use of light and shadow. The impact of different spatial shapes on the human perception has been tested by Ikeda et al. , differentiating between curved and angular; symmetric and asymmetric. Different geometries elicited different emotions, some more pleasant than others. Another important factor is the level of new and interesting aspects a space contained; as researched by Grobman and Shemesh, boring, unstimulating spaces evoked negative reactions .

18. “Atmosphere,” in *Cambridge Academic Content Dictionary* (Cambridge: Cambridge University Press, 1929), https://dictionary.cambridge.org/dictionary/english/atmosphere#google_vignette.

19. Ibid

20. Ibid

21. 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.

22. Avishag Shemesh, Moshe Bar, and Yasha Jacob Grobman. “SPACE AND HUMAN PERCEPTION–.” *Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA,* 2015.

Societal Relevance

With the creation of a permanent Lunar base just around the corner, it is important to consider all aspects of this new form of architecture. Most of the architecture up until now has been adapted to the Earth's environment, both physically and conceptually. Building on the Moon will require a whole new set of criteria, adapted to this unfamiliar, alien landscape.

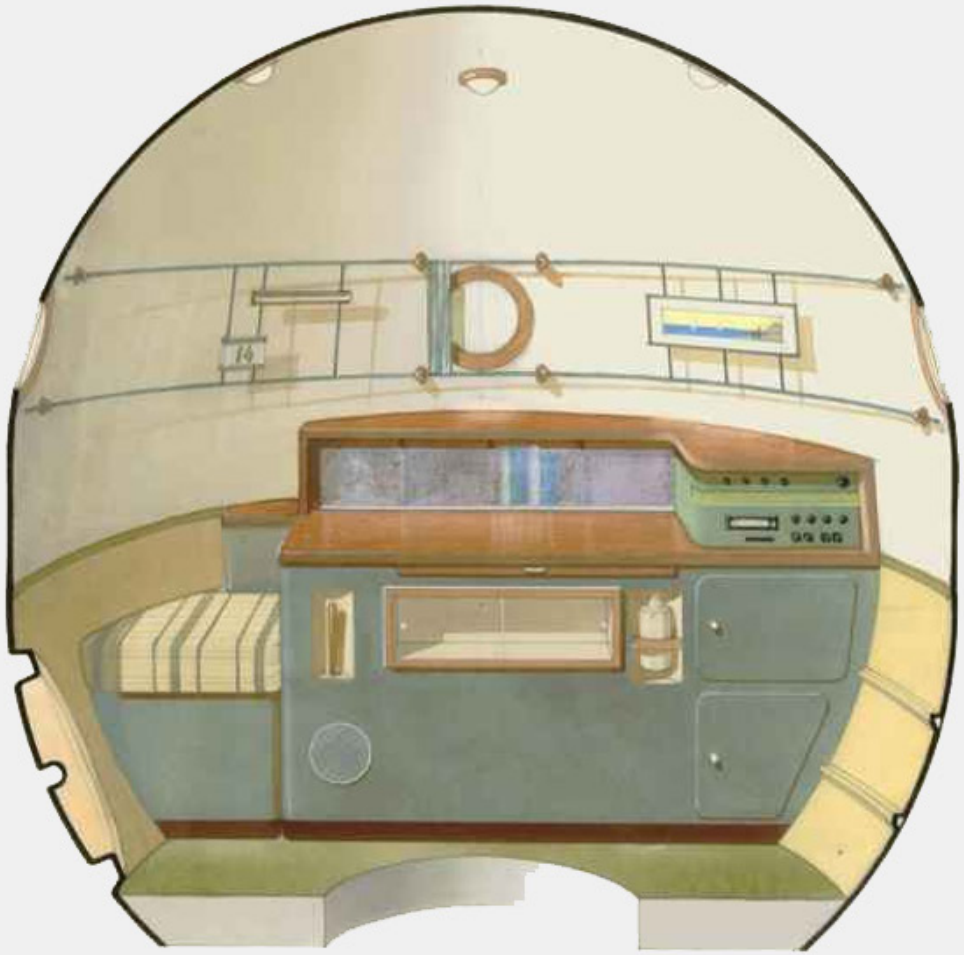
A lot of research concerning Lunar bases is focussed on the construction, figuring out the practicalities of material use, radiation protection and durable construction methods. However, those are just one aspect of making a Moon base actually habitable. Emotional and mental impact of the interior space also contributes to the success of such a Lunar base. Because even if it does the job of protecting the astronauts from harm, if the base does not provide a feeling of comfort and safety to the inhabitants, the goal of staying long-term will not be met, with the astronauts buckling under the emotional pressure. The aim of this research is to provide an architectural toolset for catering to the psychological needs of astronauts that can be applied to any future design of Lunar habitats.

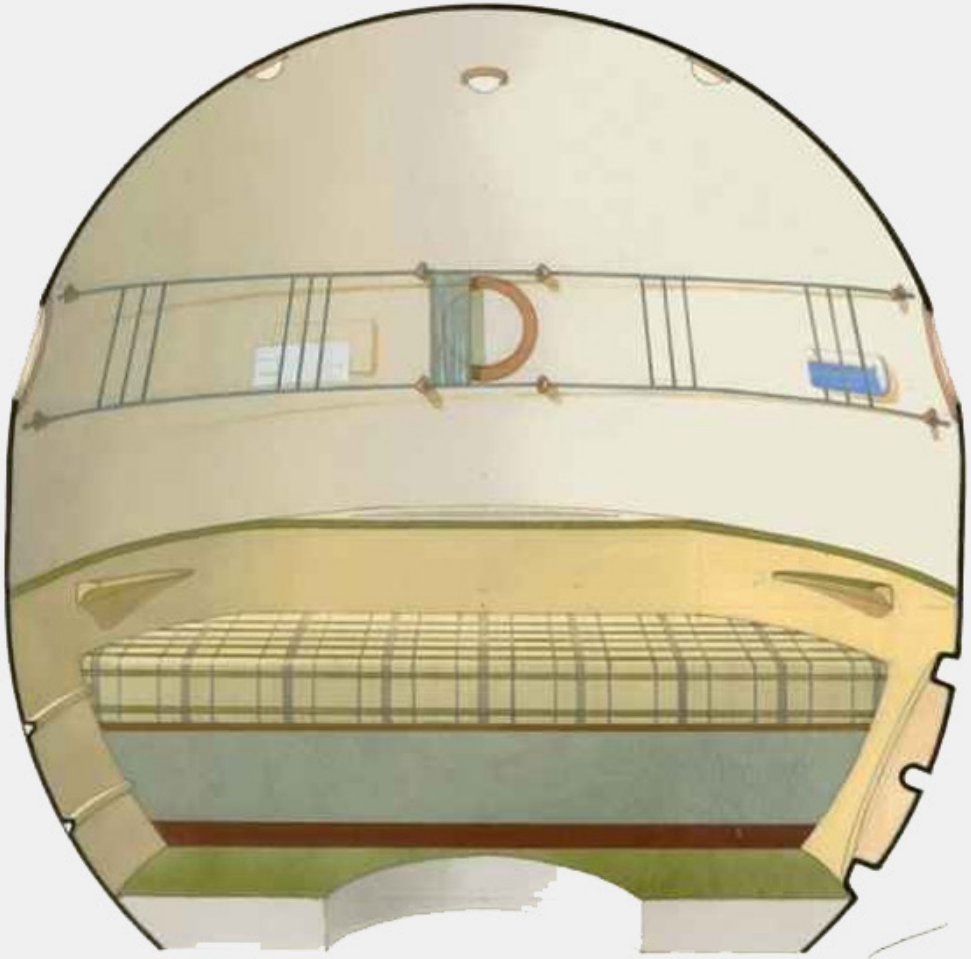
Conclusions

As future astronauts will be mostly confined to the Lunar base, when living on the moon, the (interior) design will have a big impact on their psychological state. When diving into the research, designing architecture for mental health is dependant on many different factors, mainly based on the way human brains process and react to visual stimuli. Though some general principles can be established, a large part of the aesthetic perception of an architectural space is also based on past personal experiences. Both aspects will need to be taken into account.

On the one hand, generally stimulating and preferred geometries will be identified that can be used when designing a Lunar base. This can manifest in differently shaped rooms, based on the assigned functions of the rooms. It is important to monitor the complexity of the interior space, to keep it engaging, even after 500 days of confinement to the Lunar habitat. Additionally, the lighting scheme has to be thought of as well, specifically to combat circadian disruption.

On the other hand, to adapt to the more subjective, personal aspect of designing for mental wellbeing, it might be fruitful to look into monitoring systems that gather physiological and psychological data on each crew member. Subsequently, the acquired data can be used for interactive or adaptable parts of the design, that can be changed based on the personal preference of the crew members. The ultimate challenge is to find the right balance between the needs of the individual and the needs of the collective.





References

Arone, Alessandro et al., "The Burden of Space Exploration on the Mental Health of Astronauts: A Narrative Review," *Clinical Neuropsychology 18, no. 5* (October 2021): 237–46, https://doi.org/10.36131/cnfioritieditore20210502, 239.

"Atmosphere." In *Cambridge Academic Content Dictionary.* Cambridge: Cambridge University Press, 1929. https://dictionary.cambridge.org/dictionary/english/atmosphere#google_vignette.

Banaei, Maryam, Javad Hatami, Abbas Yazdanfar, and Klaus Gramann. "Walking through Architectural Spaces: The Impact of Interior Forms on Human Brain Dynamics." *Frontiers in Human Neuroscience 11* (September 27, 2017): 1–14. https://doi.org/10.3389/fnhum.2017.00477.

Benaroya, Haym, 2017. "Lunar Habitats: A Brief Overview of Issues and Concepts," *REACH 7–8*: 14–33, https://doi.org/10.1016/j.reach.2018.08.002, 17.

Caballero-Arce, Carolina, Adolfo Vigil de Insausti, and Javier Benlloch Marco, 2012. "Lighting of Space Habitats: Influence of Color Temperature on a Crew's Physical and Mental Health," *42nd International Conference on Environmental Systems*, https://doi.org/10.2514/6.2012-3615, 3.

Eberhard, John P. *Architecture and the brain: A new knowledge base from neuroscience*. Atlanta, Georgia: Greenway Communications : Ostberg, 2007.

Ikeda,Y, 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.

Makaya, Advenit 2024. "Moonshot & Off-Earth Environments Symposium," in *Moonshotplus. Tudelft.nl* (Delft: Delft Technical University, 2024), https://moonshotplus.tudelft.nl/index.php?title=Lectures, 3.

Oakes, Kelly. "How Long Space Voyages Could Mess with Our Minds." BBC News, February 28, 2022. https://www.bbc.com/future/article/20191029-how-long-space-voyages-could-mess-with-our-minds.

Royal Museums Greenwich, "Artemis Programme: What You Need to Know about NASA's Moon Missions," NASA's Artemis Moon Missions: all you need to know, n. d., accessed October 14, 2024, https://www.rmg.co.uk/stories/topics/nasa-moon-mission-artemis-program-launch-date#:~:text=Artemis%201%3A%20After%20being%20delayed,Artemis%204%3A%202027.

Shemesh, Avishag, Moshe Bar, and Yasha Jacob Grobman. "SPACE AND HUMAN PERCEPTION–." *Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA,* 2015.

Smith, Logan M. "The psychology and mental health of the spaceflight environment: A scoping review." *Acta Astronautica 201*, 2022, 496-512, ISSN 0094-5765,

Vitra "I Had Complete Creative Freedom." Vitra, February 8, 2022. https://www.vitra.com/nl-nl/magazine/details/i-had-complete-creative-freedom.

Voski, Anaïs 2020. "The ecological significance of the overview effect: Environmental attitudes and behaviours in astronauts". *Journal of Environmental Psychology, 70*, 101454.

West, Kathleen E. et al., "Blue Light from Light-Emitting Diodes Elicits a Dose-Dependent Suppression of Melatonin in Humans," J*ournal of Applied Physiology 110,* no. 3 (March 2011): 619–26, https://doi.org/10.1152/japplphysiol.01413.2009, 619.

Zeki, Semir. "Beauty in Architecture: Not a Luxury - Only a Necessity." *Architectural Design 89,* no. 5 (September 2019): 14–19. https://doi.org/10.1002/ad.2473.

List of Images:

Page 4: Lunar Surface

Jones, Eric. *Pre-EVA-1 Right Window Pan.* Www.Nasa.Gov. NASA, November 5, 2017. https://www.nasa.gov/history/alsj/a17/images17.html#Pans.

Page 6: Earthrise from Apollo 11 mission

Johnson Space Center. *Earthrise sequence - Earth rises over lunar horizon AS11-44-6553.* Apolloarchive.com, NASA, n.d. https://apolloarchive.com/apollo_gallery.html

Page 10: Sunlight on Lunar Surface from Apollo 15 mission

Johnson Space Center. *Station 4 partial pan / up sun AS15-90-12246.* Apolloarchive.com NASA, n.d. https://apolloarchive.com/apollo_gallery.html

Page 14: Design Galina Balashova for Soyuz spacecraft

Balashova, Galina. *Final design for the interior of the Soyuz orbital Module.* Image source: Meuser, Philipp. *Galina Balashova: Architect of the soviet space programme*. Berlin: DOM publishers, 2022.