

Building Beyond Earth: Creating a Scientific Facility on the Moon

Yuetong Huang *

Western Reserve Academy, Hudson, Ohio, United States

* Corresponding Author Email: Huangy27@wra.net

Abstract. The Earth's resources are now being further complicated to an engineer by climate change and population growth. As such, the quest for alternative habitats is more than ever before necessary. In this paper, we discuss the plausibility of a sustainable human habitat on the Moon with special reference to Moon Village Project for a collaborative effort toward lunar colonization. We go on to describe, in detail, the enormous challenges that would be met in erecting a structure on the Moon with respect to the highly laminar environmental situation, the scarcity of resources, as well as the plight of energy generation during prolonged lunar darkness. In the spirit of an answer to that problem, we suggest designing a scientific Moon campus with artificial intelligence help, which must present an entire underground structure for optimized space utilization and energy preservation. Our proposition includes advanced life support systems and possible ways to do certain types of scientific research such as lunar geology, space medicine, and astrobiology. Through the utilization of local resources together with cutting-edge technology, this investigation is geared to finally identifying a blueprint for sustainable lunar habitation and helping achieve the grander aspiration of human expansion beyond Earth.

Keywords: Lunar habitation, Moon Village Project, Sustainable space architecture.

1. Introduction

As the Earth increasingly buckles under the weight of overpopulation and the degradation of the environment, the space race toward other habitats have taken on a new urgency. While the top contender for this title of a new home for mankind is most often said to be Mars, our satellite, the Moon, can provide a real quick test, presently being the only celestial body mankind has set foot on. The hostile environment of the Moon, extreme in temperature with no atmosphere and scarce resources, is a unique and very invaluable analogue for technology development towards sustainability, especially with prospects of life beyond Earth.

The idea of a Moon base has been an airy nothing, but today's reality in space research brings humans quite close to such environment. Living on another planet other than Earth is still a far cry dream, though experts believe it is possible [1]. Before setting off to populate another celestial body, thorough research and testing should be done to make long-term habitation plausible. In this light, the Moon Village Project comes up as a most formidable suggestion for a collaborative work towards a sustainable human presence on the Moon [2].

The energy question is perhaps the most critical of all problems relating to lunar colonization. Although abundant during the lunar day, solar energy is highly unreliable since it is virtually absent during a 14-day lunar night. As a solution, newer plans from Russia and China suggest building a nuclear power plant on the Moon [3].

There are many risks and problems, from environmental dangers to the lack of resources, but they only go to show what a tremendous thing the creation of a lunar base would be. This paper will discuss these problems and make architectural proposals for a scientific facility that can support a small experimental group on the Moon. This will, we hope, help advance the discussion on how to solve the main problem of energy, material, and construction in colonizing the Moon, and open new views on the design of future lunar habitats.

2. The Moon Village Project

The Moon Village Project was created by Dr. Sandra Häuplik-Meusburger. Jan Worner originally introduced the idea of Moon village to the Vienna University of Technology [2]. The Moon Village Design Studio students designed different architectural ideas around this topic. In this project, “village” is understood as a community that welcomes all interested parties to come together and exchange interests and skills [4]. This encompasses robotic attempts for scientific, technological, commercial, and tourism purposes in addition to astronaut activities. Students are separated into different groups to research the Moon's environmental challenges and characteristics. In the workshop, students received help from specialists, with the joining of Space engineering students from the technical college FH. In five groups, they focused on different specific areas involved in this project: the procurement of resources; what are some of the resources that are already available on the Moon? Proposals included solar energy, possibly provided through solar panels as an important energy source for the station [5]. Some elements contained in lunar soil still need to be studied.

Meanwhile, considering potential future changes and different routes to consequence, the project sought to consider how the Moon would be impacted by environmental changes and how these changes would affect the foundation of the village? Another area of research focused on societal formation: since this Moon village project was to involve numerous scientists experimenting on the Moon, how could we make sure to create a safe and comfortable atmosphere while considered to be psychologically comfortable too [6]? Another area considered potential robotics and technologies that would help ensure the program is kept running, including but not limited to medical equipment and facilities, transportation, monitors, emergency shelters, and backup plans [7]. A final group concentrated on the sustainability and durability of this project. To be specific, maintenance of infrastructure and environment for sustainable resources and future development. After the first workshop, students start to develop their hypothetical scenarios to simulate the whole idea. Later in a three-day workshop, students start to design their own architecture projects with a follow-up discussion on their designs to give individual feedback based on a checklist.

They later introduced and explained a few design ideas. First, the Sundial Explorer: a small mobile habitat that travels around the Moon to provide sources or just works as a temporary living place. From inside, the layout looks like a limo. Its design maximizes the utilization of available resources and energy. It is self-sufficient for four days. They also have small autonomous rovers that are used for sample collections.

The idea of a lunar socializer was also proposed for the mental health of astronauts. Lunar socializers will take the form of a vehicle that is not fixed in a certain spot but could be anywhere around the station providing entertainment for people. The main idea is to let astronauts socialize on their way traveling from one place to another [6].

Inside Moon Village, there is a Moon Campus that is used for training astronauts to be also scientists. They will be trained in scientific knowledge to do exploration on the Moon. The whole station will be placed under a dome for protection; in the Moon Campus, there will not only be a place to train but also include basic living facilities for astronauts to have daily life [2]. Food labs will be placed separately on the south side, as they believe that it is important to cook in human society. They will experiment with planting, cooking, and experimenting with plants and food.

Where are all the wastes produced going to be? Here comes the idea of a recycling facility. The foundation will be on many recycling processes. To maintain a nice environment on the Moon, most of the organic materials will be picked up to make fertilizer for the greenhouse, and even the by-product of this making process will be saved for later heating usage [8].

As a conclusion of this section, it explains one of the Moon Village projects proposed by Dr. Sandra Häuplik-Meusburger. Including how they started to do research and plans, discussions into more specific aspects of architecture, and original ideas of different hypothetical facilities that will be used in the Moon Village [2].

3. Challenges for Space Architecture on the Moon

Space architecture refers to the theory and practice of designing and building environments tailored for human habitation in outer space. Building on other planets and specifically on the Moon presents several unique challenges due to its differences from the Earth's conditions. In this section, we will describe those challenges.

3.1. Lunar Environment

One of the principal challenges in establishing habitats on the Moon lies in the environmental differences between the Moon and the Earth. Firstly, Earth possesses a thick atmosphere primarily composed of nitrogen and oxygen, offering protection from harmful radiation and regulating temperature. In contrast, the Moon's exosphere is extremely thin, with almost no atmosphere, leaving its surface exposed to direct solar radiation and resulting in drastic temperature fluctuations. According to NASA, temperatures near the Moon's equator can soar to extreme highs (127 °C) during daylight and plunge to freezing lows (-173 °C) at night [5].

Earth's surface features a diverse array of ecosystems and geological formations, including extensive bodies of water and landmasses. In contrast, the Moon's surface is heavily cratered and lacks abundant water and vegetation. However, in 2020, a team of scientists utilized SOFIA (Stratospheric Observatory for Infrared Astronomy), an infrared telescope housed inside a 747 jumbo jet, to detect the presence of water that could potentially be distributed across the entire lunar surface. This water is found in bubbles within lunar glass or between grains of lunar dust, providing shielding from radiation. The discovery of water on the Moon offers a realistic prospect for sustaining human life [9].

Lunar dust poses a significant challenge for construction on the Moon. The lunar surface is covered by a layer of fine particles, commonly referred to as lunar dust, which consists of pulverized lunar soil, known as lunar regolith. During the day, solar ultraviolet radiation levitates the dust, and at night, it is lifted by solar wind flux. This dust presents a threat to equipment and mechanical components, including motors, drills, and gears used on rovers and manufacturing machines. Additionally, lunar dust contains a significant number of particles that are toxic to the respiratory system [10].

3.2. Materials needed for construction

Designing for construction on the Moon requires careful consideration of materials suited to the unique lunar environment. The materials used for construction must withstand the environmental challenges on the Moon, including extreme temperature changes, without degrading or losing their properties. Transporting materials from the Earth may be costly and unsustainable long term. Therefore, the use of local resources found on the Moon, such as lunar regolith and metals, may be more suitable for long-term construction. Local materials include steel, aluminum, titanium, nickel, tungsten, iron, silicone plastics, and ceramics. Advances in 3D printing technology have also opened possibilities for on-site fabrication using lunar materials, reducing the need for transporting materials from Earth [11]. While the initial lunar structures will be transported from Earth, once a minimal human presence has been established on the Moon, the use of local resources will become the primary method of construction. Overall, designing for construction on the Moon requires innovative approaches that harness available resources and adapt to the challenges of the lunar environment [12].

3.3. Energy

To support any settlement on the Moon, considerable amounts of energy would be required. Solar power presents a viable alternative, but it necessitates efficient and durable solar panels. Moreover, lunar nights last for 14 Earth days due to the Moon's slow rotation on its own axis. During these periods, temperatures can plummet drastically, reaching extremely low temperatures. Therefore, relying solely on solar panels for energy generation may prove insufficient. However, China and Russia are currently collaborating on a plan to develop a nuclear power plant to be constructed on the

Moon by 2035 [7]. This plan offers a promising alternative source of power that operates independently from the sun, providing a viable option for long-term lunar exploration.

4. A Proposal for a Scientific Moon Campus

4.1. Architectural Layout and Design

In this section, we will design drafts of what the architecture on the Moon might look like, and how the design would support the idea of the whole Moon village. We aim to utilize most of the space underground, to exploit the potential space beneath the surface, while remaining some individual buildings on top of them as a connection to the surface. Figure 1 shows one of the ideas for the layout of all the buildings, room size can be changed based on different purposes. Some of the rooms like the dormitory, cafeteria, and laboratory storage room are necessary. Some others like gym, garden, leisure room are not. However, it will be best to include all those that are listed below, or even more, to ensure both mental and physical needs for people to live on the Moon [13]. To conserve the most amount of energy possible, those buildings on the surface will be built in the shape of a pentagon in the side view, and three solar panels will be placed on each building.

The ideal number of people in this experimental project will be 8 people. They will be Foods in earlier periods will be those that were transported from Earth, meanwhile, the garden or greenhouse can keep trying to plan edible food for long-term use. The meat will be hard to obtain in space conditions, canned meat will be stored a lot.

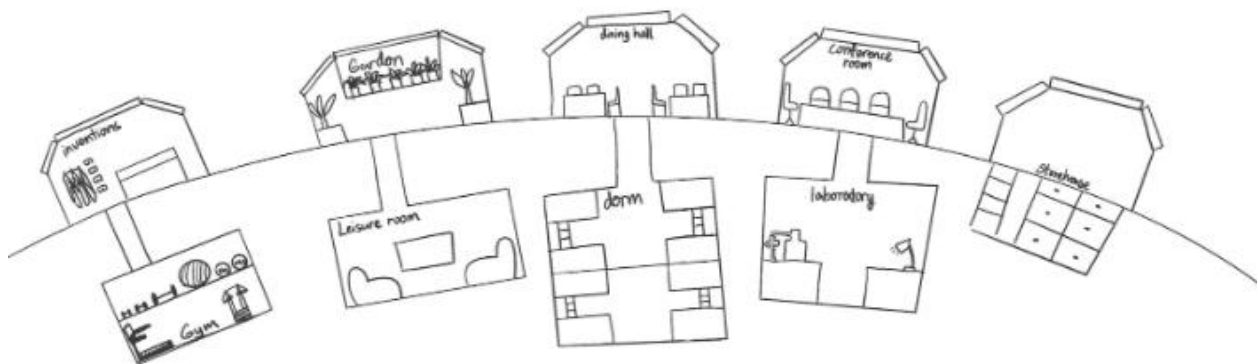


Figure 1. Schematic sketch of the campus. The campus will consist of construction underground and on the surface to maximize space.

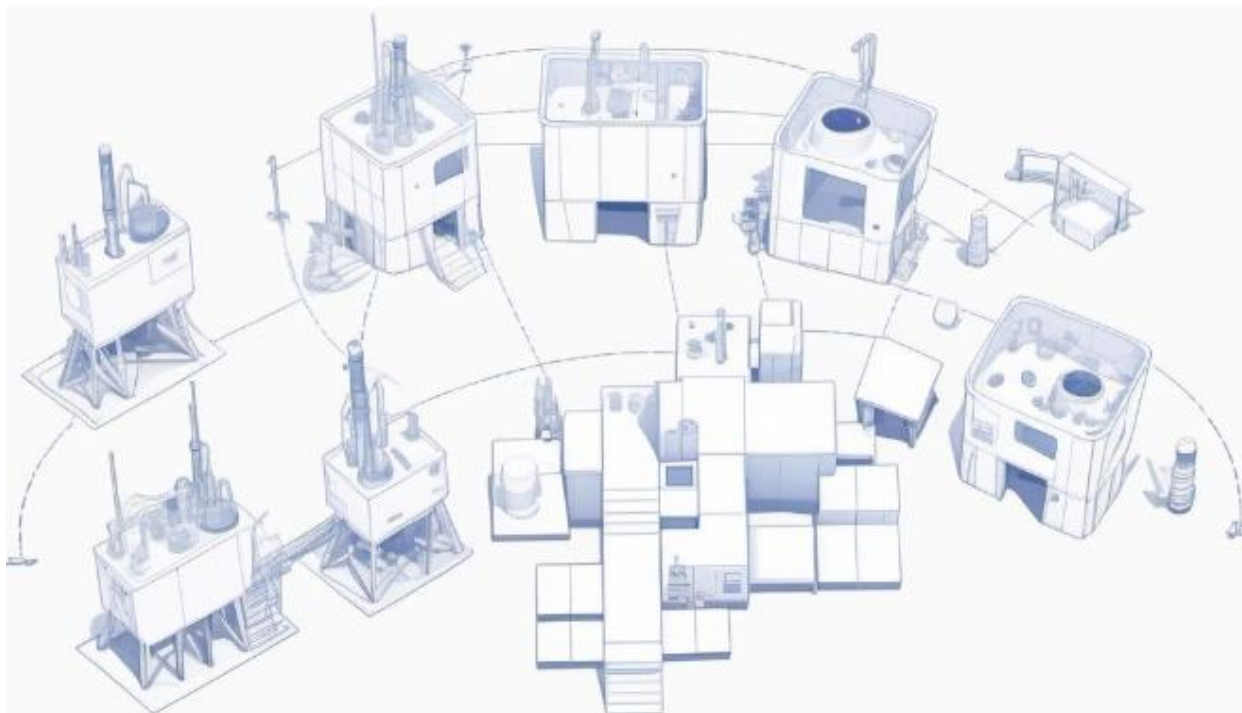


Figure 2. A three-dimensional drawing made with Artificial Intelligence using Stable Diffusion based on our own sketches.

We used generative artificial intelligence to come up with a three-dimensional proposal for the campus. Based on our sketch we prompt Stable Diffusion to create the three-dimensional proposal shown in Figure 2.

On the ground view, each house is strategically built and arranged close to each other, to be convenient for astronauts to transport between places in a short time.

From a ground-level perspective, each house is strategically constructed and arranged closely together to facilitate convenient transportation for astronauts within a short period of time.

To preserve the Moon's surface space, underground areas will be exploited for different uses. The underground area is undetermined because it could be expanded based on the space available or needed, with the consideration of connecting with the underground tunnel for convenient travel [14].

4.2. Life Support Systems

Life support would also include systems that were effective in maintaining habitability on the Moon. For example, because the Moon does not have a breathable atmosphere, oxygen would have to be generated from local resources, like the lunar regolith, which contains bound oxygen with the metals [12]. Water will have to be recycled efficiently in a closed-loop system to minimize waste products, like those in place at the International Space Station. Insulation is probably one of the largest problems since the Moon's surface has such extreme fluctuations of temperature. It would have to be solved by insulation, sub-surface construction, and perhaps some kind of geothermal heating to make a livable interior [13]. Waste management would deal with recycling biological wastes into plant fertilizer and inorganic waste for building materials or storage [14].

4.3. Potential Experiments and Studies

The Moon campus will be a base not only for human habitations but also, and possibly more importantly, for scientific work. Such vast branches of lunar geology might come under intense scrutiny in connection with the properties of regolith and other material that may be utilized to facilitate building activities or mineral extraction in the soon [13]. Experiments on astrobiology could consider how life-tech, especially microbes and plants-adapts itself to very hostile living conditions on the Moon [15]. The campus will provide a test field for new agricultural methods, including

hydroponics and agriculture with regolith-based soils, to produce food from space [7]. Also, research activities concerning astronomy and astrophysics will take a lift in studying space since the Moon does not possess an atmosphere that most of the deep-space stars could be observed better [4]. There will also be space for some experiments on space medicine and human physiology to study the effects of weighting lowly on the long run in terms of health for humans and then give an overview of what mankind is supposed to expect during future missions, for instance on Mars, where the time duration is to last about three years [6].

5. Conclusion

This paper will highlight the problems as well as the future benefits that would arise from setting up a human habitat on the Moon—essential steps toward the final colonization of space. While the Moon is host to very harsh elements such as widely varying temperatures, no atmosphere at all, and very few resources, it is very important as a testing ground for technology and strategy which can eventually support human life away from Earth. Scientific exploration of the Moon will provide a basis for developing ways to live in space and make it possible to solve many issues critical for future manned missions to Mars and beyond.

We examined the Moon Village Project, which puts forward a cooperating vision for the settlement on the Moon, merging architectural innovation with environmental sustainability. Key challenges that our work emphasized included energy generation over the long lunar night, resourcing, and maintaining habitability. In view of these challenges, we put forward a scientific campus. We propose this facility for making the Moon habitable in the short and long term. With underground construction and advanced life support systems, this will make the environment—and thus the astronauts—sustainable and allow groundbreaking scientific research to be conducted.

Lastly, we described an AI-assisted original architectural design for the Moon campus. The design merged pragmatism with innovational technologies for the maximal efficiency of energy and space usage. Scientific, industrial community support—following them, visioning the truth; a man on Moon, analytically increasingly doable. A stride closer to the ultimate dream of human expansion into space.

References

- [1] Norbert Henn. Space Exploration - Why Humans Should Go to the Moon First. *International Journal of Sociology Study*, 2013, 1 (4): 53 - 58.
- [2] Harald Köpping Athanasopoulos. The Moon Village and Space 4.0: The ‘Open Concept’ as a New Way of Doing Space? *Space Policy*, 2019, 49: 101323. <https://doi.org/10.1016/j.spacepol.2019.05.001>.
- [3] Edd Gent. Russia and China Want to Build a Nuclear Power Plant on the Moon. *Singularity Hub*, 2024. <https://singularityhub.com/2024/03/11/russia-and-china-want-to-build-a-nuclear-power-plant-on-the-moon/>.
- [4] Brent Sherwood. Space architecture for MoonVillage. *Acta Astronautica*, 2017, 139: 396 - 406. <https://doi.org/10.1016/j.actaastro.2017.07.019>.
- [5] NASA. Weather on the Moon - NASA Science. <https://science.nasa.gov/moon/weather-on-the-moon/>.
- [6] Albert A. Harrison. Humanizing outer space: architecture, habitability, and behavioral health. *Acta Astronautica*, 2010, 66 (5 - 6): 890 - 896. <https://doi.org/10.1016/j.actaastro.2009.09.008>.
- [7] Ellery, Alex. Leveraging in Situ Resources for Lunar Base Construction. *Canadian Journal of Civil Engineering*, 2022, 49 (5): 657 – 674. <https://doi.org/10.1139/cjce-2021 - 0098>.
- [8] Honniball, C.I., Lucey, P.G., Li, S., et al. Molecular water detected on the sunlit Moon by SOFIA. *Nature Astronomy*, 2021, 5: 121 – 127. <https://doi.org/10.1038/s41550-020 - 01222 - x>.
- [9] Water on the Moon: The discovery of water on the Moon and its impact: from space missions to future colonisation. *Iberdrola*. <https://www.iberdrola.com/innovation/water-on-the-moon>.

- [10] Horanyi, M., Walch, B., Robertson, S., and Alexander, D. Electrostatic charging properties of Apollo 17 lunar dust. *Journal of Geophysical Research: Planets*, 1998, 103 (E4): 8575 – 8580. <https://doi.org/10.1029/98JE00486>.
- [11] Neil Leach. 3D printing in space. *Architectural Design*. Space Architecture: The New Frontier for Design Research, 2014, 84 (6): 78 - 83. <https://doi.org/10.1002/ad.1840>.
- [12] Happel, J. A. Indigenous Materials for Lunar Construction. *Applied Mechanics Reviews*, 1993, 46 (6): 313 – 325. <https://doi.org/10.1115/1.3120360>.
- [13] Ruess, Frederik, Schänzlin, Jörg, and Benaroya, H. Structural Design of a Lunar Habitat. *Journal of Aerospace Engineering*, 2006, 19 (3): 133 - 139. [https://doi.org/10.1061/\(ASCE\)0893-1321\(2006\)19:3\(133\)](https://doi.org/10.1061/(ASCE)0893-1321(2006)19:3(133)).
- [14] Haym Benaroya. An Overview of Lunar Base Structures: Past and Future. *AIAA Space Architecture Symposium*, AIAA 2002 - 6113, October 2002. <https://doi.org/10.2514/6.2002-6113>.
- [15] Ian Crawford. Why we should build a Moon village. *News and Reviews in Astronomy and Geophysics*, 2017, 58 (6): 18 - 21.