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Envisioning the Moon Village – A Space Architectural Approach

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Abstract

In 2016 Director General of ESA, Jan Wörner, introduced his idea called MOON VILLAGE about future possibilities for international cooperation for human spaceflight. This idea was the starting point for the 2018 'Moon Village design studio' at the Vienna University of Technology. During the intensive semester course, 35 master students have developed hypothetical scenarios for a future Moon Village. The studio was supported by the European Space Agency (ESA) and several space experts from space related entities have accompanied the studio with theme-specific lectures and workshops. Based on the students' initial political and societal vision for a future Moon Village, they developed individual architectural projects, incorporating the technical, environmental and operational requirements of building and living on the Moon. Eventually all space architecture projects present the multi-cultural and open concept of the Moon Village. This paper presents the outcome of the design studio. It starts with summarizing the programmatic idea and educational strategy of the design workshop. The main part of the paper discusses the different typologies that have been developed for the concept of an international and multi-cultural Moon Village. Eventually common themes that concern the actual development of a future Moon Village are summarized.

Keywords: Moon Village, Space Architecture, Design Workshop, New Themes, mobile lunar base, In-Situ built lunar base, Resilience

1. Introduction

The idea of the Moon Village is not yet a real project or an ESA program. It represents an intention or rather a vision for exploring the Moon on an international level. The term 'village' is a synonym for a community that is open to any interested parties to join forces and share interests and capabilities. In that, it includes astronaut activities as well as robotic endeavors for scientific, technical, commercial and touristic activities. The Moon village idea has gained momentum and led to a number of international discussions, activities and networks.

Public entities, like NASA with its concept for a lunar gateway space station are planning to go back to the Moon. Also private companies and foundations strive for the Moon. Jeff Bezos, founder of Amazon and Blue Origin, has been talking about his commercial ideas of Moon missions such as 'Amazon-like' deliveries and a cislunar transportation system. "*Bezos has the resources to privately fund his own mission to the Moon and beyond, but is that what we want? Should the first lunar community be a company town?*" asked Frank White, the author of the overview effect in a recent article [1]. The Moon Village idea and its implications for space architecture as a Mixed-Use Space Business Park has already been explored by Brent Sherwood [2].

The 2017 founded Moon Village Association has about 150 international members and attaches importance to its governmental independency. Overall, a completely new group of lunar promoters is getting organized.

At the university level, the theme of the Moon Village opened up many new discussions. For previous design studios at the Vienna University of Technology, [3, 4] the incorporation of the environmental, operational and human-related constraints was of greatest importance. For this design studio the topic of the Moon Village opened up an additional socio-political level.

Relating to the saying of the influential architect Cedric Price "*Technology is the answer, but what was the question?"*[5]. The authors await critical conversation on all levels to take place and consider it important to cross-link professions and academic schools from various fields. It is also a question of 'how we and how the young people want to live in the future'. Nevertheless, its outcome could affect life for the citizen of Earth for centuries.

In the following, the programmatic idea and educational strategy of the design workshop is summarized. The main part of the paper discusses a selection of different typologies that have been developed for the concept of an international and multi-cultural Moon Village.

2. The Moon Village Design Study

The Moon Village design study took place from March to June 2018 at the Vienna University of Technology. During the intensive semester course, 35 master students have developed hypothetical scenarios for a future Moon Village. The studio was directed by Sandra Häuplik-Meusburger and strongly supported by the European Space Agency (ESA). Renowned space experts from space related entities have accompanied the studio with theme-specific lectures and workshops. The design studio program started with intensive preparation.

2.1 Analysis and Research

All lunar facilities, habitats, transportation systems and other infrastructure are dependent on the lunar environment. Environmental and operational constraints include radiation, micrometeoroids, gravity, dust mitigation, temperature extremes, diurnal cycle, and atmospheric conditions. Other challenges related to human activities include food production, storage, recycling, hygiene and waste collection. Social constraints and challenges include intensive social interaction and isolation, personal space and territorial issues. [6]

All those conditions were very new to the students. In order to get the most knowledge within the available time, students were grouped into small teams and given a research topic to study, condense and present to the whole group. Research topics included: Moon Characteristics and Environmental Challenges, Lunar Missions and Science Opportunities, The Architecture of the International Space Station, Lunar Habitats and associated facilities and technical systems, Habitat typologies and Construction possibilities, Life Support systems and Greenhouses, Robotics and Industrial Manufacturing, Human Factors and Habitability, as well as Lunar Bases in Science Fiction.

2.2 Input lectures

In addition to self-study the 3-months course was designed to include input lectures from renowned space experts and professional. The first lecture was delivered by Piero Messina on the ESA idea of the Moon Village. In particular, he asked the students to think of new programmes. Prof. Irmgard Marboe provided an input on Space Policy and Space Lay. Austrian Astronaut Franz Viehböck talked with the students about his life onboard the space station Mir. With Christophe Lasseur the students had the possibility to discuss their ideas on Life Support System, Greenhouse and the use of In-Situ-Resources. Gernot Groemer shared some experiences of the analog mission by the Austrian space forum and gave additional input on Moon relevant physical facts.

2.3 The Moon Village Workshop

The aim of the first two-day-workshop was to discuss relevant issues prior to the design of the Moon Village architecture. In order to prepare for the workshop, students prepared posters on the topic of the Moon Village. Rumi Nakamura, scientist from OEAW, joined this preliminary presentation. Input lectures from ESA Moon Specialist Bernard Foing and Space systems specialist Norbert Frischauf enlivened the discussion among the students. Former TU diploma student of Sandra Häuplik-Meusburger and current YGT at ESA, Marlies Arnhof, supported the students with additional valuable input. Further Space engineering students from the technical college FH Wr. Neustadt joined the workshop teams.

Following the presentation, the students teamed up into five teams and produced reports on five topics. Key issues are summarized below.

Working Group 1: Explore Together

The working group highlighted the importance of cultural diversity, tolerance and equality. Open questions include the form of responsibility and universal laws. The group proposes multi-functional shared spaces that would not only save resources and physical space itself, but also to create new lifestyles that will change the way we live our lives.

Working Group 2: Resources

This working group summarized resources available on the Moon, such as solar power or substances contained in the lunar soil, such as oxygen, hydrogen, helium-3, aluminium and others. In particular this group highlighted potential in-situ-resource utilisation processes. In addition to open technical questions, the group was concerned about future stakeholders, environmental damages and ethical consequences of moon mining. Considerations comprise the impact on future generations, importance of the Moon's role in human culture, stakeholders in lunar heritage and the visual impact from Earth.

Working Group 3: Humans and Robotics

This working group dealt with the mission timelines, production processes, new technologies, robot and human relations and activities. Important considerations concern the production and storage of energy and its reliability, as well as the use of new technologies for human well-being. Human-robot activities included transportation systems, maintenance, life-support, wearables and medical applications. Open questions include considerations on constant monitoring and privacy requirements and to what extend machines shall be included into societal processes.

Working Group 4; Resilience and Sustainability

The members of this working group discussed key components for an open modular, dynamic and flexible framework. Those included space transportation and surface systems, the technical framework and infrastructure development, power systems and waste management. Key discussion issues for achieving social resilience included knowledge exchange, typologies of networks and communication, and public and private partnerships.

Working Group 5: Masterplan

Working group 5 addressed potential aspects of a master scenario. Preliminary steps discussed include: the finding of a good starting point, transportation, the architecture and infrastructure for the first module, scouting and expansion, self-sufficient systems and adaptability.

After the first workshop, students started to develop a vision for a future settlement on the Moon and began to work on a hypothetical scenario, addressing the questions of what would happen and who would be involved. Each student team, which consisted of 2-3 people, developed their individual scenario and a timeline as part of their project. In addition, the teams were asked to connect to neighbouring facilities in order to simulate the Moon Village idea (Fig.1).

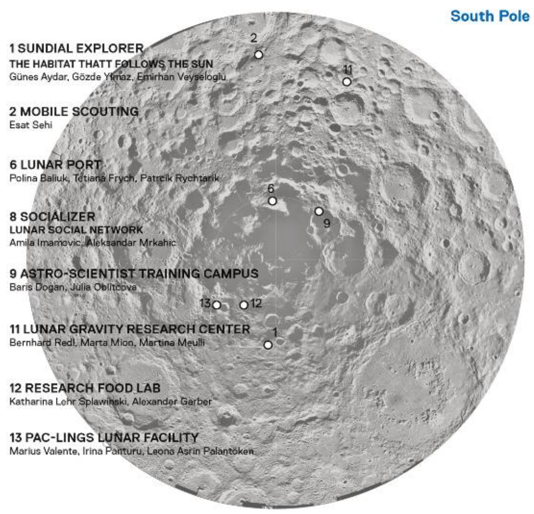

Fig. 1. Locations of final projects (on the South Pole). The idea of the Moon Village was simulated by the design studio participants in that, neighbouring facilities were integrated in a common master plan. (credit: HB2, TU Vienna)

2.4 Space Architecture Workshop

The second intensive 3-day workshop concentrated on Space Architectural issues. Based on the students' initial political and societal vision for a future Moon Village, they developed individual architectural projects, incorporating the technical, environmental and operational requirements of building and living on the Moon. Eventually all space architecture projects present the multi-cultural and open concept of the Moon Village. The three-day space architecture workshop took place from 23rd to 25th of May. Miriam Dall'igna, design system analyst at Foster + Partners, provided a lecture on the 3D printing projects and research of Foster + Partners. The following two days consisted purely of table-critique-sessions with Sandra Häuplik-Meusburger, accompanied by guest Space architect David Nixon and Miriam Dall'igna (Fig.2). The goal of the workshop was to foster an idea for the project and to strengthen the individual concepts of the students. A checklist of typical design issues [Table 1] was provided to the students as a reference.

Fig. 2. Typical table critique during the workshop. Projects were discussed using models and plans. (credits: HB2, TU Wien)

Table 1. Checklist of typical space architecture design issues [7]

Checklist of space architecture design issues	
Basic Concept	
Lunar Location	Geography, topography, latitude, longitude.
Human Population	Size, gender, role, permanent, temporary.
Overall Configuration	Functional layout, accommodation range, total volume, per-person volume, ingress / egress.
Habitable Elements	Architectural shapes and sizes, berthing techniques, foundation techniques.
Construction Methods	Prefabrication, deployment, assembly, manufacture, hybrid methods.
Payload Schedule	Number of payloads, payload types (elements, components, equipment, materials, consumables).
Security and Safety	pressure containment, radiation shielding, thermal range, contamination exclusion
Life Support	Atmospheric revitalization, power supply, water recycling, waste management, ecological control.
Phasing	Crew visited, intermittent occupation, permanent occupation.

2.4 Final presentation and discussion

The final presentation and concluding panel discussion took place on the 26th of June, in the Festsaal of the Vienna University of Technology. David Kendall, past Chair of the UN Committee on the Peaceful Uses of Outer Space and adjunct faculty member of the International Space University, provided valuable and straightforward comments to each of the projects presented. The review was complemented by Piero Messina from ESA and Sandra Häuplik-Meusburger from the TU Wien. After the presentations a walkabout through the exhibition allowed a closer look on the projects.

A panel discussion by distinguished space experts concluded the last day of the Moon Village design studio. Each panellist started with a fifteen-minute presentation of a relevant lunar topic. Sandra Häuplik-Meusburger, space architect, Senior Lecturer and Studio Coordinator, introduced the design studio and led the panel discussion.

The first short lecture was held by Piero Messina, a member of the Director General's Cabinet and ESA's Strategy Department. He talked about how the idea of the Moon Village developed and what it strives to achieve. Christian Köberl, director general of the Natural History Museum in Vienna, covered the subject of lunar exploration by giving an overview of the scientific rationale. Cosmonaut and founding member of the Association of Space Explorers, Dumitru-Dorin Prunariu, presented the history and future outlooks of human exploration of the Moon. The last panellist was Irmgard Marboe, Professor of International Law at the Department of European, International and Comparative Law at the Law Faculty of the University of Vienna and member of the Space Law Committee of the International Law Association. She approached the topic of legal and ethical aspects of the Moon Village.

After the presentations, the panellists were joined by Irina Panturu, a student of the design studio, for the panel discussion. Subsequently, the discussion was continued at a reception with drinks and animated conversations.

Fig. 3. Group photo of the students with the panellists and space experts. (credit: HB2, TU Vienna)

3. New Themes for a Moon Village

Developed projects included rover concepts, a moon observatory on the far side, a lunar port and a wide range of scientific research bases. Interestingly, the idea of the Moon village brought new topics to the fore. In addition to rover concepts, research laboratories, the idea of how we can sustainably live together in a multi-cultural society led to a number of new lunar base typologies, which will be introduced in the following.

3.1 The mobile infrastructure idea of 'The Sundial Explorer'

The Sundial Explorer (Fig. 4, 6) is a mobile rover type habitat that is used as infrastructural element, to maintain life support of itself and other lunar bases. As the mobile habitat travels from one base to another, it will carry life supportive goods (eg. water) and people.

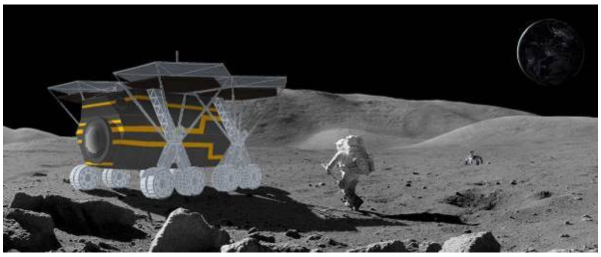

Fig. 4. Rendering of the Sundial Explorer. (image credit: HB2, TU Vienna, Design Studio Moon Village, Aydar, Veyseloglu, Yilmaz, 2018)

Its design is optimized in terms of use of energy and resources. The habitat follows the sun while travelling and is self-sufficient for 14 days. The Sundial Explorer will start with an elliptical path around the South Pole Aitkin Basin and Malapert Mountain, as they are seen as optimal locations for scientific research and water gathering (Fig. 5). By creating an elliptical path that extends to the equatorial regions, research on equatorial regions is enabled, while water for life-support can be extracted from the Malapert Mountain on a regular basis.

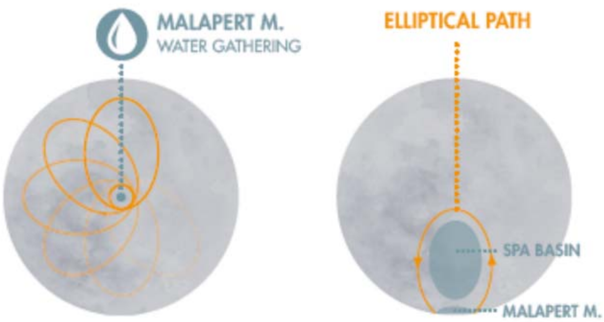

Fig. 5. Transportation concept around the Malapart Mountains. (credit: HB2, TU Wien, Design Studio Moon Village, Aydar, Veyseloglu, Yilmaz, 2018)

While the Sundial Explorer follows a dedicated path, small autonomous rovers can be released for sample collection.

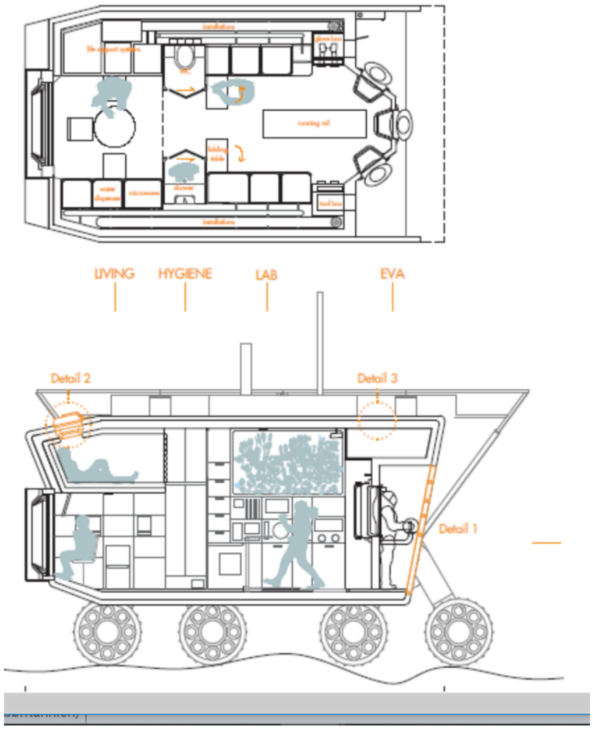

Fig. 6. Section of the Sundial Explorer (credit: HB2, TU Wien, Design Studio Moon Village, Aydar, Veyseloglu, Yilmaz, 2018)

3.2 The idea of an Astro-Scientist Training Campus on the Moon

The *Moon Campus* (Fig. 7) is envisioned to be the first astronaut training centre on the lunar surface.

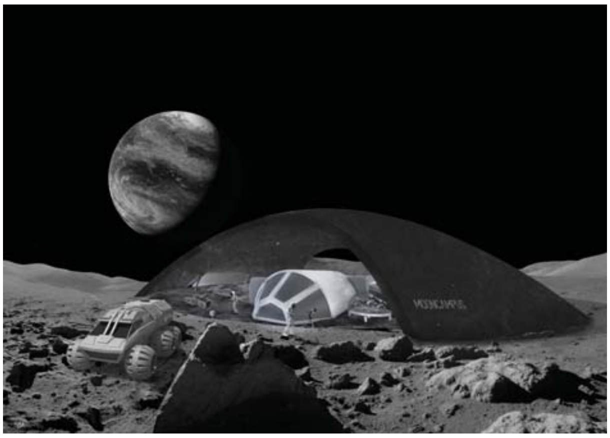

Fig. 7. The Astro-Scientist-Camp with two simultaneous missions. (credit: HB2, TU Wien, Design Studio Moon Village, Dogan, Oblitcova, 2018)

The concept of the Moon Campus is to train highly professional specialists to become "Astro-Scientists"- astronauts and scientists at the same time; able to perform complicated EVA missions, perform advanced research in the conditions of reduced gravity and other surface operations. The goal is to learn new skills, to retrain skills learned before in the real lunar environment and to prepare to go for further deep space exploration in the future.

The surface part of the *Moon Campus* is placed under a dome to protect the so-called Astro-Scientists in training from radiation and meteorites (Fig. 8). The campus itself consists of training and workshop areas, living areas, sport facilities and Virtual Reality training areas for learning new skills. Living together in the provided spatial conditions is considered to be part of the training as well.

Fig. 8. Section of the astronaut training centre, showing the work and living areas. (credit: HB2, TU Wien, Design Studio Moon Village, Dogan, Oblitcova, 2018)

The open design of the *Moon Campus* allows every future Astro-Scientist to have access to maintenance and life support systems, in order to be able to control complex lunar bases themselves after the training. In general, maximum 7 people will be in training to be able to perform simultaneous surface and research missions with 3-4 trainers supporting them.

3.3 The idea of an experimental Research Food Lab & Lunar kitchen Tube of Eden

The *Tube of Eden* (Fig.9) concentrates on food production and cooking. Cooking is a unique cultural feature of humankind. Eating is an activity that everyone has to do and it is a pleasure and a social activity. The project creates a research facility that offers possibilities to research: establishing a life-friendly environment; growing plants, fungi and algae; breeding insects; recycling, processing and preparation methods; recipes; creation of new plants; storing of terrestrial seeds for possible emergencies; as well as psychological effects of plants on humans in space.

Fig. 9. View to Earth. (credit: HB2, TU Wien, Design Studio Moon Village, Garber, Lehr-Splawinski, 2018)

The food lab is located on the lunar South pole, near Shackleton crater. It accommodates 5-10 individuals, each of whom will stay for approximately 6 months. In addition to food scientists, there will be cooks, chefs, grandmothers and other individuals with culinary background. In addition, several ‘helpers’ will work along with human inhabitants. These will be natural helpers as we know from earth (bees, earth worms and microorganisms), semi-futuristic devices such as farming robots as well as life supporting systems sustaining a liveable atmosphere and providing water, electricity and light.

Fig. 10. Plan of the final layout. (credit: HB2, TU Wien, Design Studio Moon Village, Garber, Lehr-Splawinski, 2018)

The spatial arrangement of the facility in the geometry of a ring allows long and varied strolls (Fig. 10). This shall encourage inhabitants to exercise physically. It also creates a certain sense of wideness in an enclosed structure. In addition, specific windows to the outside allow views to the Moon and Space. This is fascinating. Maybe it can also become frightening at some point.

Fig. 11. (credit: HB2, TU Wien, Design Studio Moon Village, Garber, Lehr-Splawinski, 2018)

The function of the ring-shaped lab would change over time. From the research facility itself, it would progress to a mere garden (Fig. 11) with attached production units. The food lab could turn into a restaurant for visitors.

3.3 The idea of the lunar recycling facility Pac-Lings

The *PAClings Lunar Facility* (Fig. 13) will be in charge of the waste management for all other facilities and thus maintain and improve the living standards on the Moon. By collecting the human and bio waste, the facility will recycle these organic materials through different processes. At the end of the recycling cycle fertilizer for the greenhouses will be produced, in order to make the lunar settlement independent from Earth. The by-product of this process is the gas methane, which will be stored in tanks to later be used for heating.

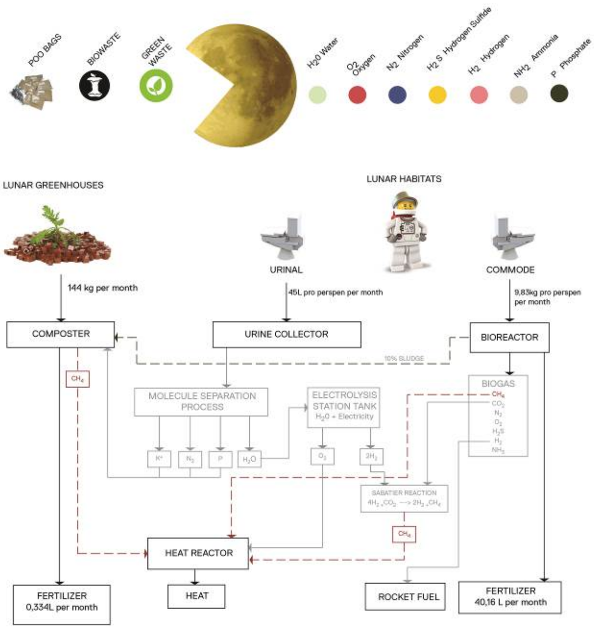

Fig. 12. Chemical processes of the recycling process. (credit: HB2, TU Wien, Design Studio Moon Village, Palatöken, Panturu, Valente, 2018)

The architecture is based upon the different recycling processes (Fig. 12). It consists of two different types of inflatable modules, which are connected with airlocks. An important aspect of the architecture is the biosafety level 4, which consists of multiple decontamination showers, air and water recycling needs for every laboratory.

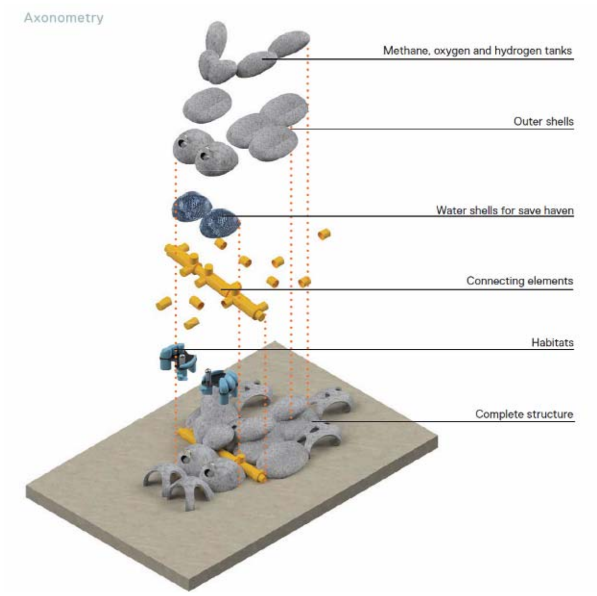

Fig. 13. Schematic overview of the recycling facility and its infrastructure. (credit: HB2, TU Wien, Design Studio Moon Village, Palatöken, Panturu, Valente, 2018)

The living modules are strictly separated from the rest of the laboratories and can only be entered after a decontamination process. The habitat will provide space for three people. Each habitat is equipped with a fully functional life support system and even has a special mechanism for collecting condensed water (Fig. 14).

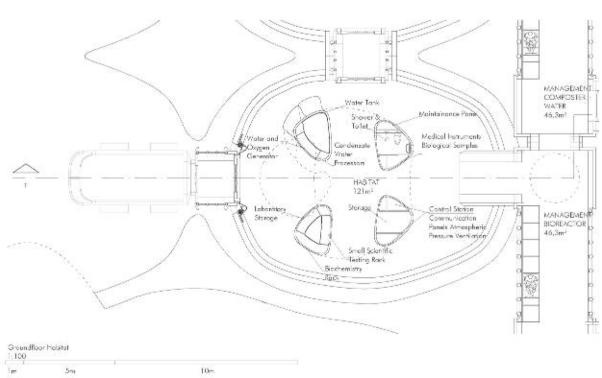

Fig. 14. Floorplan of the habitat showing the air fountain for collecting condensed water with small houseplant racks. (credit: HB2, TU Wien, Design

Studio Moon Village, Palatöken, Panturu, Valente, 2018)

3.4 The idea of a Lunar Socializer

One of the crucial issues of the long-term Moon Village experience are social aspects and challenges the inhabitants will be confronted with. The *Lunar Socializer* (Fig. 15) stimulates people to engage and spend more time with their fellow villagers as well as to offer activities and content for which they would not necessarily have the time or the means at their base.

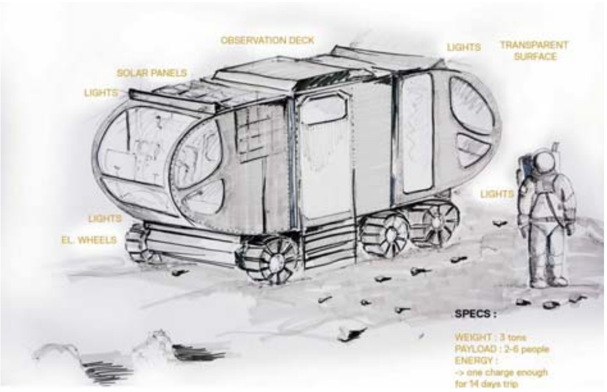

Fig. 15. The concept of the lunar socializer vehicle. (credit: HB2, TU Wien, Design Studio Moon Village, Imamovic, Mrkajic, 2018)

Because every day-life on the Moon would be psychologically demanding and monotonous, the project aims to connect inhabitants from all lunar bases with each other. The Lunar Social Network isn't tied to one specific location. In order for it to function, the assumption is made, that there are already several Moon bases populated with people. Once this is achieved, the Lunar Social Network can start to develop (Fig. 16). Its use is intended for everyone living and working on the Moon.

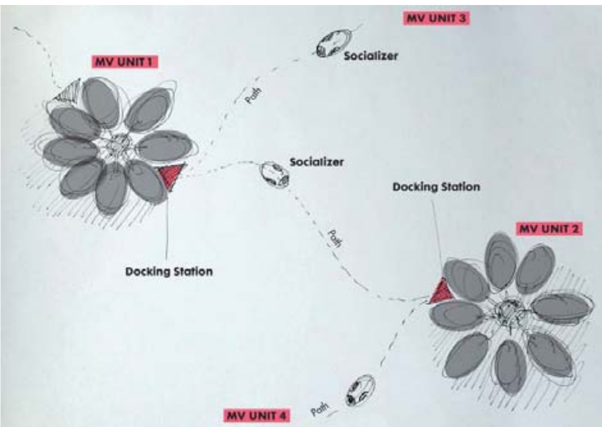

Fig. 16. Early concept of the project, showing the Socializer connecting multiple lunar bases. (credit: HB2, TU Wien, Design Studio Moon Village, Imamovic, Mrkajic, 2018)

The main concept of the Lunar Social Network are the Lunar Socializer Vehicles, which would connect different Moon bases and also transport people from one base to another, offering them a completely different experience during the voyage. Docking / charging stations (Fig. 17) are placed along the paths between the lunar bases. One proposal for the location of the stations is the trio of craters Ptolemaeus, Alphonsus, and Arzachel, northeast of Mare Nubium. This is a very interesting area carved with long valleys and it would provide an excellent opportunity for sightseeing and retreat from the base.

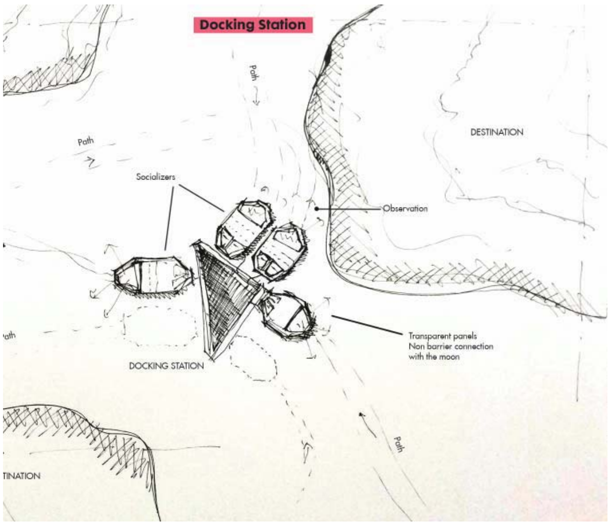

Fig. 17. Docking / charging stations are placed along the paths between the lunar bases. (credit: HB2, TU Wien, Design Studio Moon Village, Imamovic, Mrkajic, 2018)

One Lunar Socializer Vehicle would be able to carry between 2 to 6 people and it would be operated from a fixed control deck at the front of the vehicle. It's called The Socializer because the idea is that the vehicle isn't just a transportation system, but that it also offers enough space and content to make the trip between moon units interesting and stimulating.

3.5 The idea of a lunar gravity Research Centre

This design team wanted to establish a research center on the Moon in order to test lunar-gravity and the possibility to reproduce and live in a lower gravity environment. There are certain issues that can only be discovered if people will actually live on the Moon, especially the physiological effects of low gravity on human body and the way to live with it. For them, the Moon is seen as a test base for permanent life far away from Earth – including the founding of families and giving birth to children.

Johann-Dietrich Wörner himself, the general director of the European Space Agency (ESA), said that the Moon Village is "*a stepping-stone, a test bed ... to go further, for instance, to Mars and beyond*" [8]. The *Lunar gravity Research Centre* (Fig. 18) is placed in the Amundsen Crater, as it is characterized by heavily terraced walls, where a protected cave could be created. The idea is to bring people on the Moon gradually, in two steps.

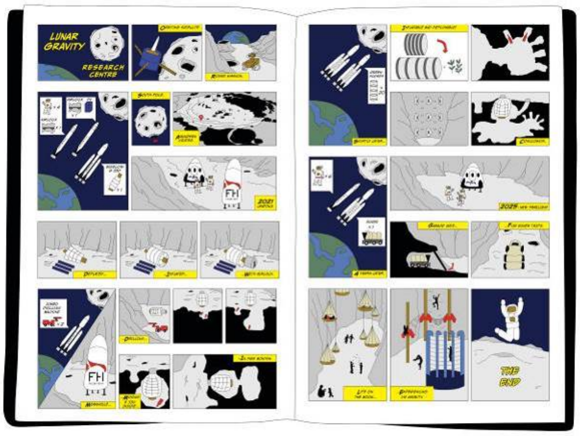

Fig. 18. Storyboard of the lunar gravity research center. (credit: HB2, TU Wien, Design Studio Moon Village, Meulli, Mion, Redl, 2018)

The first two couples will reach the Moon together with the preliminary habitation module, the Bigelow's B330. Shortly after, another launch will bring two jumbo drilling machines to the Moon. They will start to build the lunar base by drilling the nearest crater's slope. When the cave will be big enough, they will move the Bigelow's module inside the cave, in order to protect it for the long term (Fig. 19). People will start to live inside the lunar cave while the construction continues. With two more launches, twenty inflatable and deployable greenhouses will be brought to the lunar center. By doing this, the crew will eventually become self-sufficient from Earth.

Finally, when the construction phase will be over, three more couples will be sent to the Moon together with a lunar rover. At this point, real life on the Moon will begin. The whole center will be like a commune, where people share space and live together and start a family life.

Physical exercise is certainly a fundamental moment of daily life on the Moon. Instead of having a specific space for the gym, the goal is to integrate necessary activities into the daily schedule of the astronauts. Everything will be designed for a low-gravity environment: climbing walls, trampolines, suspended beds, and spaces to be used in total freedom are at the center of our project.

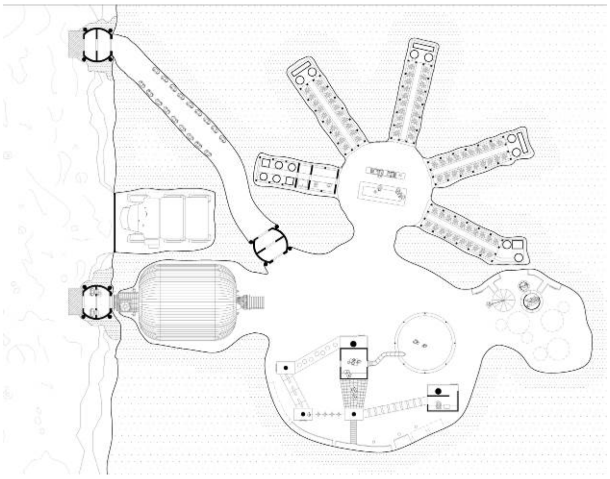

Fig. 19. Plan showing the preliminary modules and its expansion. (credit: HB2, TU Wien, Design Studio Moon Village, Meulli, Mion, Redl, 2018)

6. Conclusions *and Outlook*

The studio results have again shown that academic institutions can bring original and top-level solutions for complex themes. In addition to environmental, operational and human-related considerations, the topic of the Moon Village integrated an additional socio-political level.

The first cooperation between the authors of this paper took place in the frame of the 2003 ESA Habitat Design Workshop [9]. The initiative was triggered by the lack of academic options by an interdisciplinary group of young professionals, called the Moon- Mars Habitat Working Group. With support from ESA, the group put together an intense one-week programme aimed not only at generating innovative designs but also at studying the group dynamics of a stressful, cross-disciplinary work environment. The workshop was the first interdisciplinary initiative on space architecture related topics and at the end of the week, five final designs were presented to a jury composed of ESA staff, industry representatives, external experts and MoonMars organizers.

Critical thinking on global themes is highly relevant and to cross-link professions and academic schools is of great advantage. As a possible next step, existing academic activities shall be supported and reinforced towards a professional international program with the goal to deliver innovative concepts for upcoming challenges.

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