AMORE - Concept Study for a lunar research village

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Interest in creating a lunar base for further space exploration has intensified in recent years. Several companies are solving the different challenges in the implementation of such an ambitious project. The scale and intricacy of such a base lead to its need for self-sufficiency. This multinational project needs to: (a) have a technical life-cycle longer than 15 years, (b) be self-sustainable and financially viable, (c) allow for continuous expansion, and (d) maintain the users' well-being. To fulfil these criteria, a base need to be scalable, modular, and sustainable. The mission architecture needs to allow for In-Situ Resource Utilization (ISRU), recycling, crew physical and psychological health, and high performance. Astronauts are the most crucial resource of any crewed mission. Hence, human factors and architecture are identified as critical aspects. The concept-study Advanced Moon Operations Resource Extraction (AMORE) takes existing designs into consideration but integrates the users' psychosocial health needs. These change with the increasing duration of each crewed mission and the number of crews. Scalability and functional upgrading allow for long-term planning. The layout of the habitat elements supports its growth. The concept that was generated outlines a modular base. It consists of (a) an initial core, (b) a quiet module that accommodates sleeping, social, dining and working areas, and (c) a loud module for working, exercise, noisy subsystems, and communal areas. Garden areas are incorporated into both modules and function as the main element of the Life Support System. These modules are large-diameter inflatable cylinders with ellipsoidal tops covered by a composite regolith superstructure. Eight modules serve the needs of a crew of sixteen. This concept allows for the expansion of the astronaut selection pool, elevates the performance of the crews, and nurtures their well-being.

I. Introduction

As part of the annual nine days Space Station Design Workshop (SSDW) which is held annually by the Institute of Space Systems at the University of Stuttgart, Germany (IRS), space station concepts are developed competitively by international, interdisciplinary teams of students and young professionals.

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Recently, interest in private-public cooperation in the space sector has sparked a new era of space travel where companies compete to develop competitive solutions for the ever-growing space market. Within this context, during 2021, the participants of SSDW were tasked with developing a primarily privately funded, long-term, self-sustaining, manned moon base with private-public interests. Various concepts have been and are developed that cover various aspects of this task. The novelty of the SSDW concept is the highest-possible self-sufficiency by utilizing in-situ resources and the resulting reduction of supply flights to the Moon, which reduces the environmental impact of such a mission. The AMORE concept study additionally works with adaptive, modular systems that allow easy scaling of the habitat so that it can respond to evolving demands. It is the stated goal of the concept to make AMORE sustainable through its small number of flights, intelligent design, and economic set-up. Through the involvement of a wide number of disciplines, this holistic approach will be tested and improved from all perspectives. In its final stage, AMORE will be an established lunar base, ready to pioneer numerous research missions and serve as a growing research and training post for further space exploration.

Such a moon base would be the first of its kind and thus would be a major engineering milestone paving the way for future space exploration as well as deep space missions.

Within this pioneering concept, our team approached the issue from a user-centric approach, setting out user needs and requirements first, through the lens of both physical and cognitive human factors. This allowed the team to develop a base, which would allow for sustainable work, and would manage stress by reducing in its sources and facilitating the users' coping mechanisms.

As such, this paper will focus on the human factors and architectural outputs of the developed concept, while also briefly exploring various associated challenges including technical, financial, and operational challenges will be briefly explained. However, this is a concept. This means, that this research includes no guarantee for completeness in any kind. It a first step and an impetus for future lunar habitats.

II. Methodology

To develop the various aspects of such a diverse concept, while within a limited time frame, a group of approximately 25 members was split into groups focusing on different systems and aspects of mission development. The teams were: a) Project Management and Logistics, b)Finance, c) Systems Engineering, d) Human Factors and Ergonomics, e) Architecture, f)Mission Analysis, g)Propulsion, h) Attitude Determination and Ascent and Descent Vehicles, i) Electrical Power Systems, j) Thermal Control Systems, k) Communications, l) Radiation Protection, m) Life Support Systems, n) Robotics and Extravehicular Activities, o) Structure, and p) Science.

The workshop organizers, in preparation of the workshop, provided all teams with individual *recipes* that included both expected outcomes and valuable references. Lastly, experts on all aspects of the above-mentioned aspects were available to the team throughout the workshop and helped the team both in small meetings and by providing feedback during two Preliminary Design Reviews and a Mission Definition Review.

The team was composed of people with diverse backgrounds. This included variety in nationality, level-of study ranging from Bachelor to PhD students and even study backgrounds from designers to human factors and engineers. It was therefore crucial for the system's engineering team to ensure everyone's mutual understanding of responsibilities, system tasks, requirements, design strategy and deadlines/milestones. This was accomplished by using regular meetings in big and small groups, as well as by providing various documents clearly capturing various things such as the design approach, requirements writing and interpreting as well as the use of the concurrent design tool ValiSpace. ValiSpace is an online proprietary platform that allows for concurrent creation and linking of design documentation. Team members used the platform to outline the system and subsystem assumptions, requirements and budget details for mass, power consumption, volume, communication Requirments and more. Concurrent design is ideal to permit a multidisciplinary team to assess and produce mission concepts quickly. The team members worked in parallel and used ValiSpace to obtain inputs from other team members and capture their own critical outputs for everyone else to use.

As time was limited, the team was encouraged to follow a "SWAG – Scientific, wild-ass guess" strategy in their designs. Further, literature for a transfer habitat design for a Mars exploration mission was provided, as it featured a detailed mass and component breakdown of a manned space mission[1]. This approach aimed at combating "blank page syndrome" and to ensure that the iterative process of concurrent design could start sooner. To combat inaccuracies, a margin philosophy was also defined, roughly based on ESA's margin philosophy for science assessment studies[2]. Unless a component was based on a COTS component or high-TRL design a 20 % margin was applied to the budget for the respective component's mass, power etc. Further, a 20% system-level margin was used to account for overall inaccuracy in system-level description.

As the SSDW '21 took place fully digitally the use of "Gathertown" was crucial to the team's success. Gathertown facilitated a sense of "presence" and improved overall team cohesion. Further, it made spontaneous conversation and especially innovation possible. Everyone was encouraged to be always on the platform to reduce the "delay" between requiring someone's input and being able to talk to them to obtain it. Often it took less than a minute to find a specific person and pull them into a meeting – a crucial aspect of allowing rapid concurrent design and iteration of the system.

III. Mission Objectives and Requirements

A. Objectives

To translate the mission description given out in SSDW '21, the mission design team drew objectives based on it.

The sustainability mentioned by the scenario was interpreted in various aspects. Sustainability does not only refer to the areas of life on the moon. Since the mission called for a privately funded mission, financial independence was an important objective. The AMORE Space Station should be profitable during its operation and must be self-sufficient after a certain time. Support from Earth is indispensable for the construction and the first

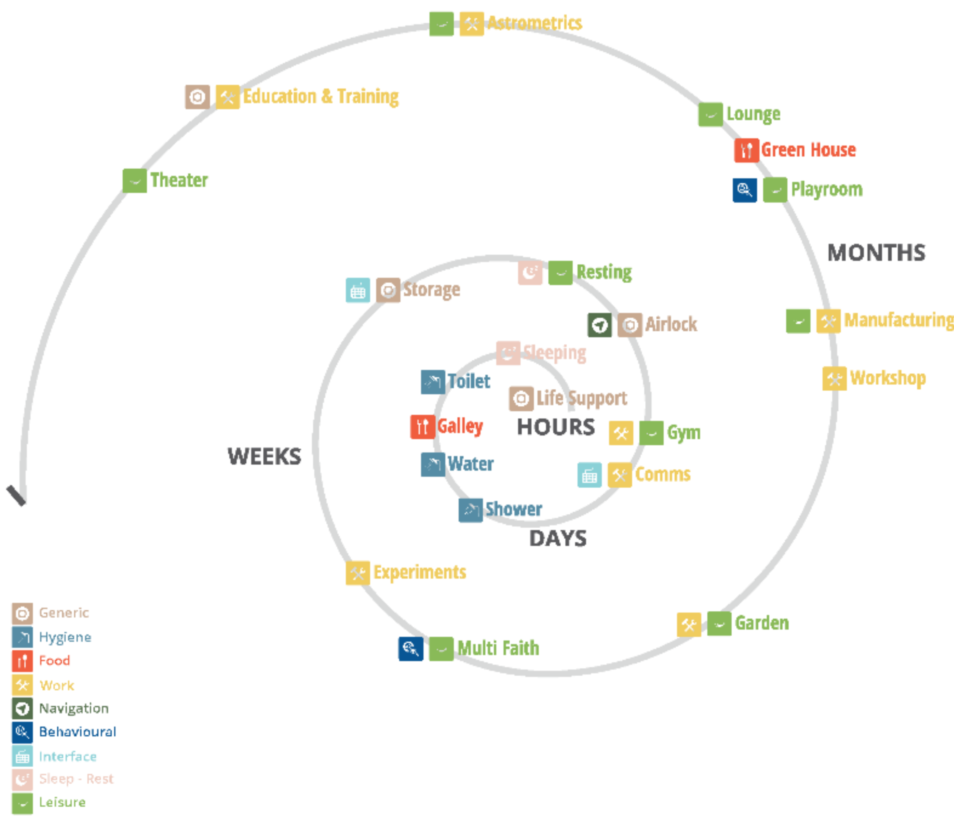

Figure 1 - Helix showing the different uses that are required as the mission duration is extended. [3]

transports but should be reduced bit by bit to allow for rational expansion. A fundamental component to reducing costs and increasing sustainability for Earth and the Moon is In-Situ Resources Utilization. By using resources on the lunar surface, savings in transportation and emissions should be achieved. By extracting oxygen through electrolysis, water and food can be obtained on the Moon. Additionally, a gradually more sustainable Life Support System would be needed to support a permanent and expanding base.

As the lunar environment will be one of the ever more challenging environments for human presence, an important aspect of the sustainability of the base was the maintenance of the users physical and mental health. This needs to be set out to reassure both the safety of the crew and its efficiency. [4]

Moreover, the extreme temperature variations, the absence of an atmosphere and pressure do not lead to a life-supporting environment. This must be fully provided by the AMORE Space Station, and also the protection against small impacts.

The primary mission (2030-2042) should allow for the establishment of the near-self-sufficient base. By 2042 the base should be able to accommodate a permanent crew of sixteen individuals and an incoming crew of four. Beyond 2042, options for further expansion should be allowed. All segments of the station should be designed around existing launchers and vehicles to minimize implementation cost.

B. Requirments

To communicate between teams in a concurrent way, a variety of mission level requirements were set out. These allowed for the objectives to be translated into guidelines for the design and for the management team to have a set of criteria against which to validate and compare different proposals.

Given the extreme nature of the lunar environment certain aspects that affect the entire mission were considered. All systems should be either tolerant against radiation or shielded from it. Systems must be able to endure large temperature variations between day/night cycles or phases of over 6 months of either constant sun exposure or darkness. Systems must be tolerant against regolith dust or be shielded against it. To accommodate human life for extended periods of time the same requirements as on any spacecraft apply with the addition of enhanced radiation protection and dust mitigation.

To develop requirements for a sustainable living space for the astronauts the human factors team utilized existing requirements given from NASA's standards for physical ergonomics and augmented new requirements that pertained to the cognitive ergonomics and others that incorporated various aspects of the astronauts working environment. To better understand the characteristics of the space station as a working environment, Eklund's extended-HTO analysis (Human – Technology – Organization) model was used to identify several factors that might function as hindrances or facilitators in the wellbeing of the crew and the success of the mission.

To generate requirements regarding the inner architectural space of the base, the approach of Environmental Psychology was used. According to G. Evans, five distinct aspects affect the user's mental health and their stress coping capacity. These are described as Stimulation, Coherence, Affordances, Control and Restorative[5]. At the same time, given the expanding nature of the base, and the different durations of stay for different crews, the expansion of both space and variety in uses was made apparent. As detailed in Figure 1 the uses that the station would need to accommodate in each stage would depend on the duration of the crew's mission.[3]

Lastly, following both empirical evidence from S. Haupik's interviews in her book, *Architecture for Astronauts: An activity based approach*[6], and evidence from various studies[7]–[10], the importance of plants in the environment was considered. This led to the proposal of Closed Loop Environmental System that utilized plants as part of the system.

C. Site Selection

The selection of the sight was influenced by several requirements: A Day/night cycle defined by the thermal and power requirements, a semi-planar terrain for large scale construction, proximity of ISRU related locations, scientific value, and several smaller craters in the vicinity to accommodate fuel storage and radioastronomy in the future were all considered. As such, a specific location, near the rim of Shackleton crater, in the south lunar pole was selected. In *Figure 2* the analysis regarding luminosity, slope and height that was used to identify the base area can be seen.

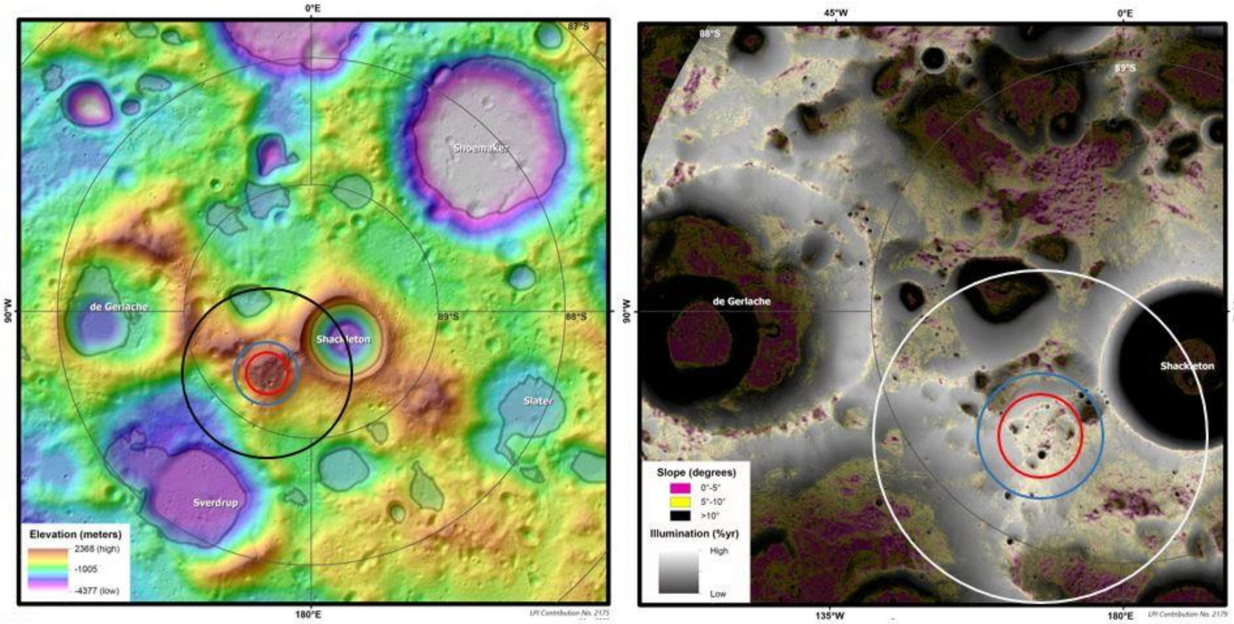

Figure 2 - (Left) Selected Landing Location in red, overlayed on elevation map.[11] (Right) Location Site overlayed on slope and luminosity map.[12]

IV. Mission Design

D. Mission Phasing

The A.M.O.R.E. Operation can be split into three initial phases and one late expansion phase, each with a dedicated purpose and function.

In Phase 0 (2027-2028) the primary infrastructure will be set up. On the first launch planned in 2027 a group of scouting rovers will be deployed to the landing zone to determine the exact landing/building spot, search for ISRU options and provide basic construction. At the same time a communications network will be deployed into a stable elliptical inclined lunar orbit[13]. On the final launch of this mission the Core module will be ferried and deployed onto the moon to be then buried in regolith by rovers.

Phase 1 (2028-2031): provides the first crewed missions to establish the human presence. The first two missions will bring their lander with them and leave it on the gateway station after departure to provide a lander for the following missions. These initial missions continue construction and scouting as well as construction of the first inflatable structures and greenhouses to validate ISRU concepts and prepare the base for increasing crew numbers. This phase also sees the ferrying of a fleet of ISRU rovers and scientific equipment utilizing the low volume of crew transfers, due to the small crew, to expand the capabilities for future phases.

Phase 2 (2032-2035): expands the ISRU and scientific capabilities of the station by the deployment of more mining and processing equipment, additional living quarters and the construction of a radio-telescope. A larger fleet of rovers and support vehicles is also be deployed and the crew is raised gradually to twelve individuals. Water and fuel extraction/production will be established beyond a proof of concept towards meaningful quantities.

Phase 3 (2035-x): continues the expansion with additional core modules, living quarters, greenhouses, processing facilities and gradual increase of the crew as per demand of future objectives. At this phase, the base has the capacity to accommodate external crews and payloads from both private and public entities as a service. At the same time, the estimated capability of resources extraction could, given the demand, reach a level of providing mined fuel from the moon to the lunar orbit and Gateway’s Near Rectilinear Halo Orbit.

Figure 3 shows the sequencing of both launches and deployments of different proposed modules.

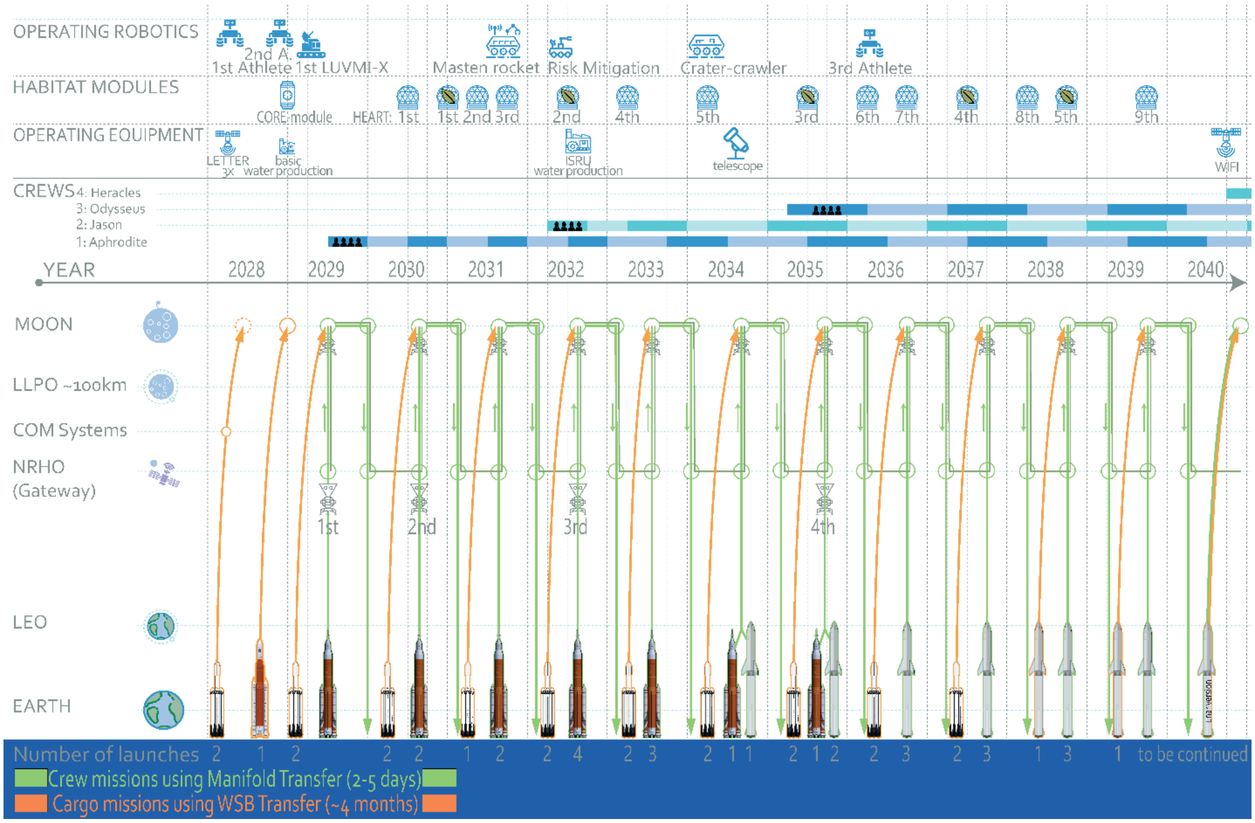

Figure 3 - Mission Diagram, from bottom to top, the launch vehicles that will be used for different phases of the mission, the transfers they will do to different orbits. The gradual integration of different crews is shown. The arrival and full deployment of different systems is shown.

E. Launchers and Vehicles

A.M.O.R.E will rely in the use of currently available, and upcoming launch vehicles (Commercial & Agency-Owned) which will be key in the initial establishment and further development of the platform. Capability of transporting a reasonable amount of mass and volume to LLO in relation to the modules used for initial establishment of the platform is one of the leading aspects that was critically analyzed to choose the appropriate launch vehicles. The chosen configuration for this goes as follows:

1) SLS Block 1B (Heavy Cargo & Crew): SLS Block 1B has a planned launch capability of transporting approximately eighteen tons of payload in addition to a fully fueled – fully crewed Orion module using Block 1B's Universal Stage Adapter. This allows for the transportation of a human lunar lander in addition to a human crew in one mission.
2) Falcon Heavy (Recurring): With a Hohmann TLI payload mass capacity of around fifteen tons and an extended fairing volume of 5.2 by 18.38 m
3) (Diameter x Height), the Falcon Heavy proves as an excellent option to transport smaller modules and any other additional equipment and cargo that may be needed.
4) Starship (Planned): As the launch capabilities and date for a start of operations of this commercial launch vehicle is not yet fully defined, it has been set as the eventual replacement for the Falcon Heavy starting in 2038. It would provide crewed, and cargo launch services using its cargo and HLS variants.

AMORE requires a landing system for transporting a crew of four from the Gateway to the lunar surface before the HLS is available, therefore, two custom-designed human landers will be transported along with the first crewed missions.

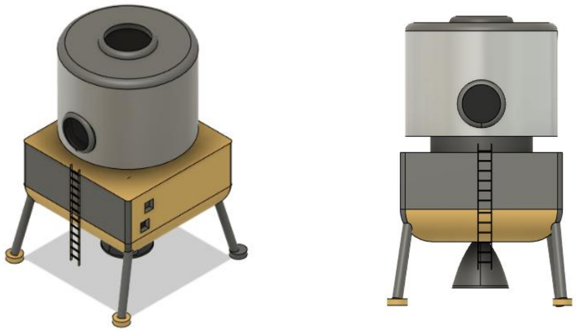

Figure 4 - Two views of the proposed lander.

This vehicle utilizes a Mitsubishi LE-5A 121.5kN Liquid Oxygen/Liquid Hydrogen engine for propulsion, which is an oxidizer/fuel combination which can be sourced from lunar ISRU operations.

F. Robotics

To facilitate the mission, robots will accompany the astronauts in their journey to the Moon. Robots aid the operations of mission by conducting specialized tasks that would be difficult for humans to do alone. For this mission, the use of robots will achieve three operational objectives: Construction, Exploration and ISRU.

The first objective is to construct the base. Prior to astronaut arrival, AMORE will send specialized construction robots. These building robots will be used to set-up the initial core module and deposit at least one meter of regolith on top of it. This deposition will also be used for the future modules of the base and as such the rovers will need to have the capacity to stabilize the regolith using targeted sintering. This preparation stage will ensure the reduction the mission risks in general, as the base's safety can be validated. NASA ATHETE rovers were identified as suitable high TRL technology for this building phase. The ATHLETE is a large 6 legged rover capable of navigating the lunar terrain [14]. A Mars mission scenario plan has studied using the ATHLETE with an assortment of developed construction tools, which raised the research team's confidence in its capacity to complete the required tasks[15]. Based on previous scenarios, it can be assumed that tasks such as 3D printing and regolith excavation can be managed by 2 ATHLETEs. Furthermore, ATHLETE's modularity will be utilized by adapting modules for various operations, such as transportation, EVA assistance and remote experiments..

The exploration of the Lunar surface provides an exciting new potential for scientific advancement. Potential Lava tubes can provide a glimpse into the geological past of the moon, as well as host future lunar bases [16]. The use of small autonomous drones can help map these phenomena, safely collect samples and travel in and out of the lava tubes. This higher resolution mapping of the surface can also provide further economic value as the data will be invaluable to future lunar mission planning. Most importantly, the exploration of the tubes may yield mineral and ice deposits that could additionally support the ISRU objectives of the mission.

It is necessary to utilize resources available on the moon to achieve some degree of self-sufficiency of the Lunar base. This will take the form of three stages, each employing a unique type of robot. First, LUVMI-X rovers [17] will prospect the lunar surface for an initial high yield crater mining technique. Afterwards, a novel rocket mining rover developed by Masten Space Systems can be used obtain resources necessary to supply the base[18]. The final stage turns the focus to research and development of drones that can mine in areas less accessible, but still economically viable, such as permanently shaded regions and the lava tubes as part of AMORE's long-term planning.

G. Human Factors Considerations

Having set out the limiting factors of the base architecture through identifying the used vehicles, the site location and the robotics capabilities, the bases inner characteristics were developed.

Given the stressing conditions to a crew during an extended mission to the lunar surface, the aim was to develop a *good* interior space that minimized stressors and was optimized for crew efficiency. Studying the way Evans 'criteria could be used to affect the users health we identified high level properties from each category and created

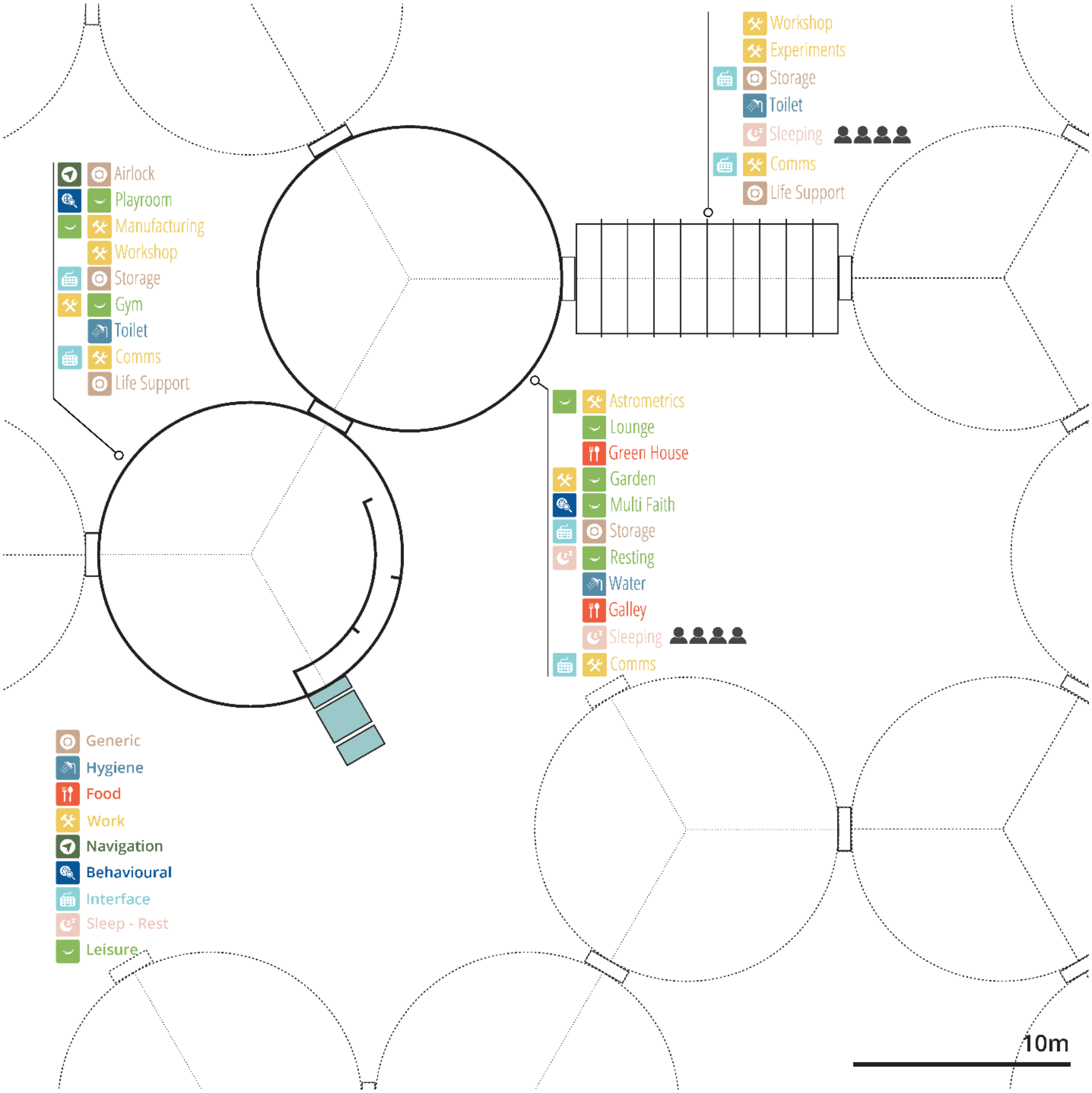

Figure 5 - Separation of uses within the three modules of the initial station configuration.

requirements using those criteria and information from previous stations[5], [6].

1. Stimulation

To manage the stimuli in the working and living environments of the station the different uses and uses' categories have been separated throughout the station. This allowed for complex spaces that would avoid crowding and would allow the users to fully use the station through the day. An overall mitigation for avoiding problems with this approach was to consider noise and activity level in separating resting and working areas. This was to be done to the better extent possible within the core module, but for the larger module, the aim was to separate quiet and loud activities.

2. Coherence

To allow for a smooth experience within a complex and expansive lunar base, the design team was encouraged to use simple and repeating architectural motifs. Another aspect that contributed to the coherence of the space was the directionality of any windows that were to be placed in the station, which would always point towards earth, which would in this way function as a common exterior vista throughout the station and as a landmark. At the same time, as the Moon's Orbit is tidally locked with Earth, the view of our planet would be horizontally locked at a certain heading, while at the same time oscillating over and under the horizon vertically. This motion of Earth would allow for a vista that gives a sense of the passage of time in an otherwise hostile and almost timeless environment.

3. Affordances

Since affordances has to do with our interaction with the build environment and mechanisms with in it, the research team did not outline requirements in this domain. This was done in the belief that affordances affect later design stages.

4. Control

One of the most important aspects of an environment that acts both as a working and living space is its' ability to adapt to its users' needs. At the same time and seeing the problems that emerged in all previous stations, the base should offer the users choices over where they would be able to be, work and rest and to avoid crowding. At the same time, a need emerges for spatial hierarchy, which is usually lost in low layout complexity space stations.

Because of this the decision was made to implement plans that would allow for the creation of gradients of private and public spaces, which would aim to create both public, semi-public, semi-private and private spaces. This would allow to create a space that despite its limited capacity would offer richer experiences.

Lastly, some parts of the station were to remain not cramped to allow for personalization by the astronauts and flexibility in changing aspects of the interior architecture.

Given that the mission planned now will utilize the same modules for at least 20 years, the interior architecture elements were described as to be independent of the structure, and in that way reconfigurable.

5. Restorative

The restorative aspect of such a space would be crucial to helping the astronauts coping mechanisms. This problem was approached in three ways. Firstly, as mentioned in *Control*, the space station layout offers intricate private spaces that the user could use to isolate from the rest of the crew in certain times for quiet and meditation or prayer. Secondly, resting spaces close to the windows were aimed as to help the users coping mechanisms through the process of *salutogenesis*[19], [20]. Lastly, the use of living plants and "green spaces" was encouraged for the architectural designed team.

H. Lunar Station

The initial module that is described is called the Core Module. It is a cylinder fourteen meters tall and five meters wide, as confined by the launch vehicle. After delivery to the lunar surface, by utilizing the already deployed rovers, the module would be lowered into a horizontal position and should be covered with a layer of semi-stabilized regolith.

After the Core Module is deployed and covered, the first crew will transport to the base. The timeline is such that cosmic radiation will be minimized since the solar activity will be reaching a maximum. In the polar regions of the moon this means that most of the radiation will be travelling close to parallel to the horizon. Because of the nature of the deposition technique (gradually pushing dirt onto the habitats) the base will be better protected in the first stages by the horizontal, directional solar radiation, rather than from the omni directional CGRs.

The initial Core Module is divided into two vertical levels and hosts various mission critical systems such as communications, redundant Life Support Systems, Command and Control and more. Simultaneously it hosts the tanks that will be used for the later deployed ECLSS. Since the limited space of the habitat does not allow for private spaces, fully developed resting areas, and forces the crew in a communal area simultaneously, the mission's duration is limited to three months for this initial stage.

Figure 6- Floor Plans and cross-section of core module

By utilizing both human labor and robotic assistance, the first HEART (Habitable Earthlike Atmosphere in Regolith Tents) module is constructed in approximately three months. This includes both the pressurization of the dome, the deployment of inner superstructures and the deposition of regolith on top of the dome. The first HEART Module acts as a living module. The Core Module remains as the emergency shelter and the facility for various core systems.

In later stages, the Core Module acts a separator of two expansion sides of the base, with the capacity to isolate either one of the sides in case of emergency while not compromising the entire station.

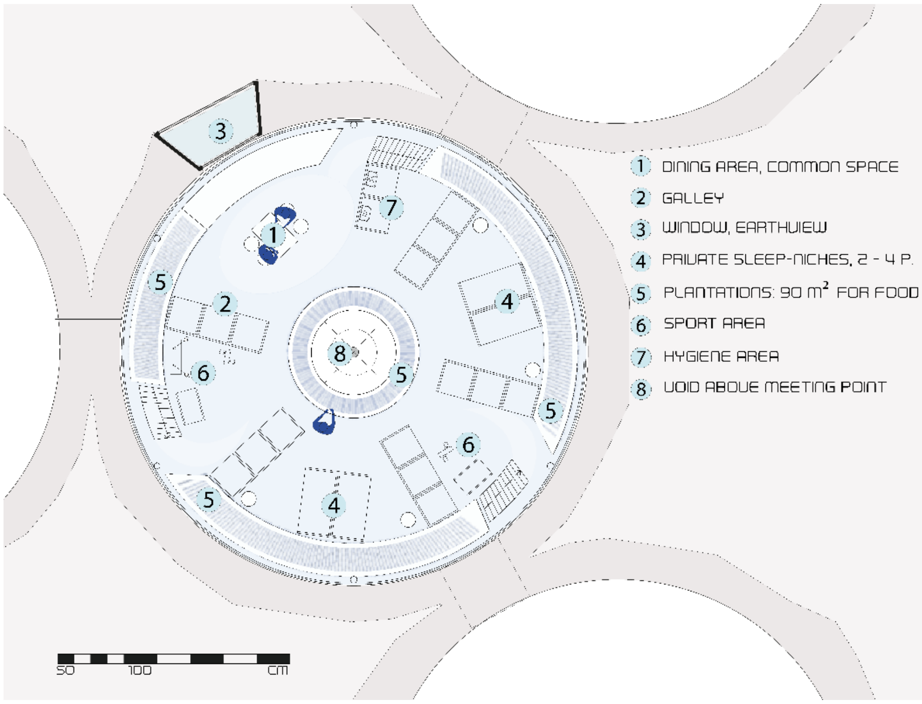

Figure 8 - Upper Level of HEART module

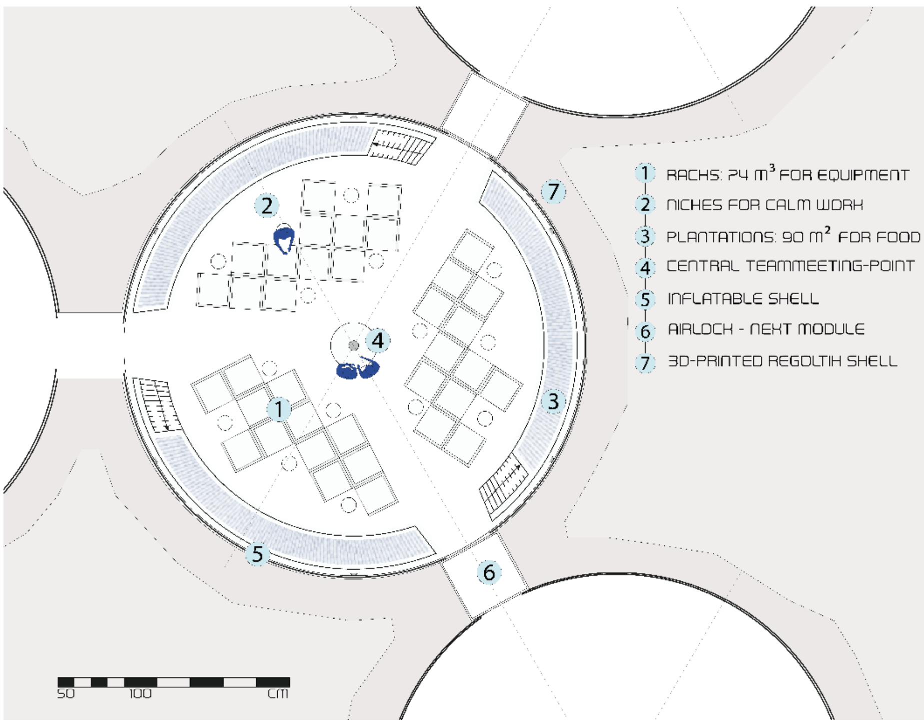

Figure 7 - Floor Plan of Lower level of HEART Module

The first HEART module is a standard living module. It houses a crew of four to eight, planting systems and compatible subsystems. The planting systems lay in extensive lightweight shelves around the inside of the inflatable, regolith-covered dome. A ceiling divides the space into two floors. On the lower level are the racks that house the

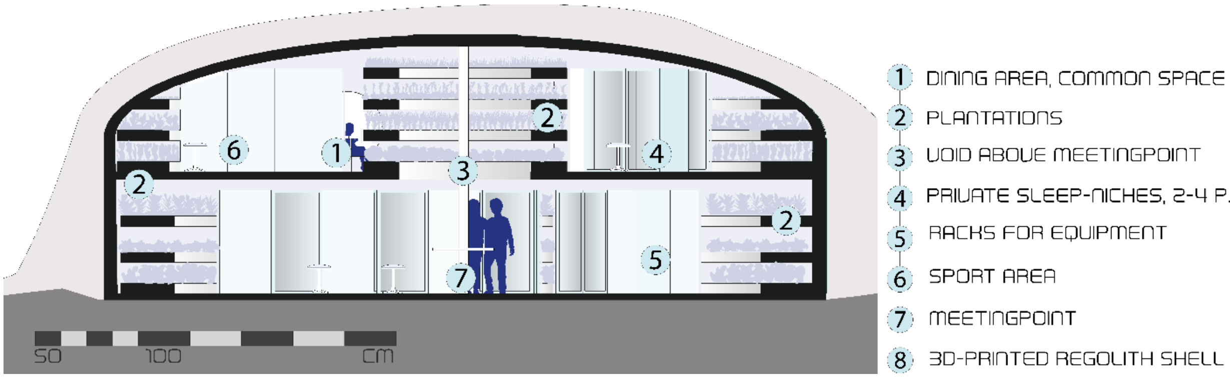

Figure 9 - HEART Module Section

subsystems and scientific units. Through their arrangement, they form a three-axis, centered development and, in between, compact blocks with niches that offer space for concentrated work. In the center is space to gather and discuss. In the center of the module, the upper floor allows for an opening that creates an atrium in the center of the module. This allows for ventilation and air circulation, while at the same time giving both floors more visual *space.*

The upper floor is accessed using three staircases that branch off from the access axes, embedded in the planting systems. Thanks to the low gravity, they can be steeper than under terrestrial conditions. On that floor are the crew members' private bedrooms and retreats, sanitary areas and a communal cooking, dining, and lounge area with a view towards the earth through the window. Windows in space represent a particular vulnerability despite their protective structure against radiation, extreme temperatures, and other dangerous factors. Nevertheless, the positive influence of a visual connection to the Earth and the surrounding on the human psyche cannot be neglected.

Equally important is private retreat space where crew members can regenerate. It is created in the HEART module by having double racks with sleeping quarters and the closed back of storage racks facing each other in such a way that a triangular space is created between them, the top of which opens to the gallery. Like the outer wall, the gallery is enclosed by planting systems that protect the isolated areas from views from the other side. The three staircases mean that it is not necessary to walk past any of these areas. In an emergency, however, they can be passed without further ado. This suits the divergent needs of easy access, escape and retreat at the same time.

As stated before the inflatable modules are characterized either as *quiet* or *loud*, depending on the hosted uses. The *loud* HEART module differs from the *quiet* one only on the upper floor, where training facilities are located instead of living areas. For this purpose, it offers more space for the subsystems on the upper floor as well. In particular, the loud or otherwise incompatible systems such as ECLSS are housed in this module.

Each of the 14 m wide modules is located on a triangulated grid. They relate to airlock systems, which can also provide an exit from the Habitat. Due to the modularity of both the architecture and the interior design, the habitat can be easily expanded and adapted to current needs. After a development period of approximately ten years, it will be sufficiently expanded by 2040 to accommodate four crews of four people each for one year. 14 HEART modules and one CORE module provide capacity for a self-sustaining habitat thanks to ISRU, which can perform a variety of scientific experiments and can be expanded into a training unit for astronauts. Its modularity makes it resilient to disruptions, as each module has its own atmosphere that can be controlled locally through the interconnecting airlocks.

New domes can be added to the system without difficulty thanks to its modularity. This scalability of the habitat allows it to grow easily in line with its future functions.

I. Structure, Radiation Protection and Thermal Management

A safe, efficient, and robust structure is constructed to support the crew and life support systems. The harsh environmental conditions along with constraints such as material, weight, and microgravity are considered for designing the structure. The resulting structure shall withstand temperature in the range of -180C to 120C, maintain the interior pressure in the range of 34.5 kPa and 101.3 kPa and effectively shield astronauts and equipment from harmful radiation on the lunar surface. A hybrid of rigid and inflatable structures was selected for the modules because of the benefits they offer in terms of strength, weight, and volume. The structure is divided into two parts: Core Module and Habitat modules. Initially, the module inflated by oxygen cylinders is constructed. This structure is supported by Kevlar fabric to protect from punctures. A regolith structure of 1m thickness is constructed on top of this inflatable structure to protect the astronauts from harmful radiation and small impacts.

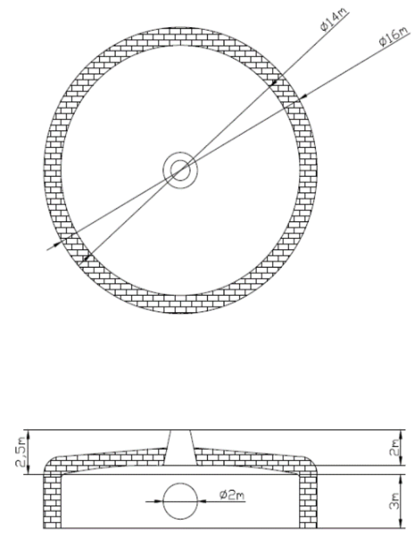

Figure 10 - Regolith shell over the habitats structure

These structures are subject to harmful ionizing radiations on the structure of the moon. that causes specific biological effects, which can be divided into deterministic and stochastic. Deterministic effects are the consequence of absorption by the human body of a significant dose. A manifestation of deterministic effects is radiation sickness. Stochastic (random) effects are the result of damage to the genetic material of a single cell and manifest as cancers or inherited diseases. The dose that causes these conditions can be arbitrarily small and are determined by coincidence at their beginning. To protect Astronauts from this harmful radiation, a combination of Regolith, Aluminum, HDPE, Kevlar, and Nomex is used. For emergency situations (such as SPE), the core module is additionally equipped with a reinforced radiation bunker with very thick walls which are also designed as a place to rest and sleep. This allows to reduce the dose absorbed during the mission in phases where astronauts do not perform useful work and give more opportunities to stay longer in the base or perform EVA work.

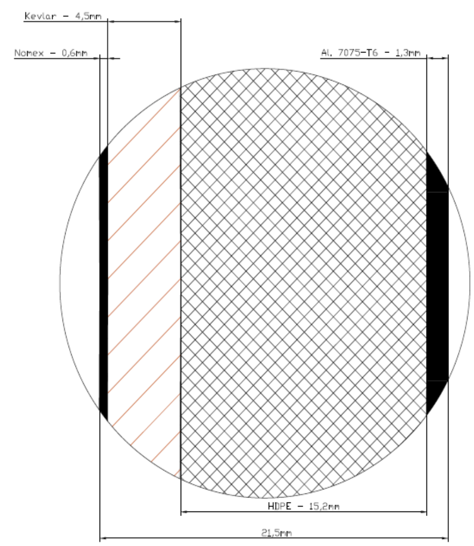

Figure 11 - Detail Section of Core Module's hull

The temperature fluctuations on the lunar surface range from -180C to 120C, but the internal temperature of these structures must be maintained at an ambient temperature of 22-25C for optimal performance of equipment and astronauts. The thermal control system of these structures is designed to adapt itself to lunar nights and days where the temperature reaches extreme limits. This is addressed using both active and passive thermal system. Before the regolith construction on an inflatable structure, a twenty layered MLI of thickness 1.5cm is added at the beginning of the mission to ensure no equipment is harmed before the completion of regolith construction. Regolith of one meter thickness along with a composite of insulation is added on the outermost wall which acts as an excellent insulator against external temperature conditions such that regardless of external temperature almost no heat is conducted to the interior of the structure. The heat produced inside the structure by life support equipment is in the order of magnitude of 16KW which is dissipated into space using a Body Mounted Condenser Radiator painted with black paint to reduce absorptivity.

As reconfigurability and adaptability were core design drivers, all internal structures, including the flooring of the second level, were described as to be independent of the inflatable structure. They should be supported by internal scaffolding that can be incorporated inside the equipment racks in the lower levels.

J. *Green* CELSS

To accommodate both the need for plants within the station and to integrate them into the life support system, hydroponic greenhouses were proposed as the main means of in-situ food production. At the same time, this aimed to also address the goal of having a self-sustainable base as the greenhouses can facilitate oxygen production and CO2 scrubbing.

To accommodate the initial core stage during phase 0, a fully developed semi-closed loop Life-Support System should be deployed. This aims to act both as the initial system, and a backup during the validation phase of the greenhouses, and to function as redundancy in operational scenarios where the other systems are not available.

Our proposed system aims to reach a self-sufficiency of 90% by 2040.

Our solution makes plants an integral part of human life in space and aims to generate an environment where the astronauts will develop a healthy interaction with their surroundings, both physically and mentally.

K. Station Future

The AMORE Space Station has an enormous potential for future development. Further exploration of the lunar surface, craters, lava tubes. Increased resource extraction and station expansion will allow to go to self-sufficiency with the goal of full autonomy. By 2040, it is planned to host sixteen astronauts on board simultaneously. The international aspect will allow any available missions. One of the most important is a deep space exploration. The use of the AMORE Space Station's infrastructure will be supporting of potential deep space travel, allowing for resupply and preparatory trainings. There will also be potentials for space tourism, which would allow financial independence. Further development of the station will allow the Human habitat to move one step forward, beyond the Earth and would provide a platform for manned and robotic exploration across the solar system.

V. Conclusion

During the 2021 SSDW, our research team was able to develop a full preliminary concept for a lunar base. Our work showcases how we are now closer than ever to building human habitats on the lunar surface.

With the announcement of ISS decommission by 2030, and the Artemis program on the immediate horizon, it is evident that now, more than ever, public, and private programmed to the moon could happen. This would allow for the further development of technology and the transition of humankind to a space-faring species.

The need for research both on the mission architecture level and in the specific aspects of a station is evident. During our work, we identified sufficient studies on lunar basis designs, that a review would be helpful to identify the approach our community is having towards the challenges in developing such habitats.

We also hope that this paper showcases that an approach that set architecture in the forefront of mission design has the capacity to converse with engineering teams, in order to design vehicles and stations that are meant to be lived in.

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