HAVEN Lunar Port and Base – Design of a Lunar Arrival Port with a Long-Term Habitat for Versatile Crew Occupations

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With the 50th anniversary of the Moon landing in July 2019, the Moon is experiencing a new boom. Space agencies, international organisation, and even the private sector are competing in what might be described as a new race to the Moon. One of the most interesting objectives of such a return to the lunar surface is the goal to establish a more permanent outpost with a high standard of living quality for the crews.

HAVEN Lunar Port and Base is an integral design for an arrival port at the Moon's South Pole. The main elements of the compound are a launch and landing area for incoming and leaving crews, a hangar to place landers and lander components into interim storage, and a long-term habitat. The habitat provides room for a permanent crew of four, which runs the arrival port and conducts research in the area of lunar habitability. In addition, HAVEN will house short-term crews of additional four astronauts for an acclimatisation and instruction period of up to ten days, before distribution to their respective research outposts at the lunar South Pole. The HAVEN design pays special attention to this versatile and fast-changing crew; the proposed architecture aims to cater the different privacy needs of the two separate sub-crews, while simultaneously encouraging an exchange of experience and expertise, as well as the formation of a larger community, in shared areas.

This paper presents the architectural design of the habitat that consists of a rigid centre component and a multilayer inflatable and accommodates all habitation needs from dedicated work and communication spaces, over private crew quarters, as well as leisure time areas, to technical support systems and a greenhouse. It will further highlight the proposal to use empty propulsion tanks of discarded lander descent stages for the construction of the habitat's radiation shielding, in order to achieve both, a more sustainable and more economic construction process.

Nomenclature

CLASS	=	Centre for Lunar and Asteroid Surface Science
CMC	=	Chariot Crew Mobility Chassis
EVA	=	Extravehicular Activity
HAVEN	=	Habitable Arrival Port, Vantage Point, and Exploration Base for a Network of Lunar Explorers
LRO	=	Lunar Reconnaissance Orbiter
LSMS	=	Lunar Surface Manipulation System
PSR	=	Permanently Shadowed Region

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I. Introduction

DESIGNING for any kind of space exploration or habitation calls for a new connection between technical requirements and spatial demands; it furthermore requires a holistic design approach that includes many different disciplines. The design for the HAVEN Lunar Port and Base was developed with such collaborative aspects in mind, both in the design process, which entailed considerations not only from the architectural discipline, but also considers aspects from the fields of robotics, aerospace engineering, biology, sociology and psychology, as well as in HAVEN's intended function as an arrival hub for international crews and a focal point for the exchange of knowledge and experience. The concept of the construction and spatial arrangement concentrates on providing maximum habitable space on the Moon with optimal packaging parameters and payload mass for lunch and flight. A deployable structure with rigid core, as well as the use of lunar regolith in discarded lander propulsion tanks for the radiation shielding has been chosen for this. Furthermore, HAVEN's spatial layout provides an innovative approach to lunar habitation by considering fast changing crews of different sizes, backgrounds, and stay durations.

II. Choosing the Lunar South Pole

While Mars has gained more and more attention over the last decade, setting up a first long-term outpost on the Moon is the logical choice. The Moon offers perfect conditions to serve as a test-bed and gateway for extra-terrestrial exploration and habitation, and thus acts as a stepping-stone towards far more distant destinations in our solar system.[1]
As specific site for the HAVEN compound, an area at the lunar South Pole has been identified.[2] Referred to as Connecting Ridge C1-0, this site on the ridge between Shackelton and De Gerlache craters offers a number of geological merits and benefits for habitation and exploration.[3] The overall merits of the South Pole as a point of interest for exploration are well established in the literature, as well as recognized by current space programs and organisations, such as NASA or ESA. [4,5]

III. Mission Scenario

A. Mission Objectives

The HAVEN mission objectives focus on two main targets:

The first focus is the construction and running of a lunar port as an arrival, acclimatisation, and distribution point for other lunar outposts. Arriving crews have the opportunity to learn how to conduct tasks safely in lunar gravity. While all procedures will be trained on Earth, many tasks require different locomotion and object handling in 1/6 G, which calls for some amount of on-site training and experience. [6,7]

The second, albeit smaller, focal point lies on the scientific and exploration objectives based at the HAVEN habitat, which are focused on the effects of lunar habitation. An important factor in the mission objectives is the reuse and storage of lander components to limit payloads and to avoid the creation of a lunar junkyard.

B. Crew Composition

One of the most crucial factors of any space mission is the social environment. While confined habitation and severe isolation have psychological effects on the crew, the social support the astronauts are used to is taken from them at the same time; they face a completely new social matrix. As S. Häuplik-Meusburger and O. Bannova put it

[2] While Connecting Ridge C1-0 has been identified as ideal site for the HAVEN mission, the outpost design is not necessarily tied to a South Polar location and could theoretically be replicated at other suitable locations on the Moon.

"Social interaction is very important for maintaining a crew's psychological health and can be facilitated through design interventions and architectural solutions." [8]

What we call a macrosociety - the complex social matrix of our terrestrial relationships – will be replaced by a much less diverse circle of social interaction. The great variety of social roles we tend to take up in everyday day life on Earth, as well as the possibilities to interact with numerous social counterparts, will be replaced by the small matrix of a new microsociety; a new community with potentially new rules, roles, and procedures. This involves intense contact with a small number of people and a rapid, often unnatural, transition into this new social group.[9] The architectural setting in which this microsociety is acting is an important factor in the development of new social structures. A well thought through spatial background can support the process of acclimatisation and integration; an unsuitable setup, with for example a lack of privacy, on the other hand can amplify the social challenges.

The HAVEN design addresses a special challenge within this new microsociety – namely, that of having not only one larger community, but two sub-groups, due to different objectives and mission durations of two simultaneous crews. At full occupation, the HAVEN habitat is home to a crew of eight astronauts. This overall crew consists of two sub-crews (Table 1): A permanent crew, as well as a changing guest crew. The permanent crew is responsible for the running of the arrival port, conducting research and instructing the guest crews, while the guest crews are those who arrive at the port and stay there for a short acclimatisation and training period. The guest crews bring to the habitat a changing social element and the possibility to enrich the microsociety on the base. However, the changing crew members and short duration of their stay also bear the potential for additional conflict in between sub-crews. It is vital to avoid friction between these two groups and ensure undisturbed working processes of each crew, as well as limit security risks of critical areas. The HAVEN design focuses on providing an architectural solution for the cohabitation of such two potentially different groups by providing both with sufficient privacy and plenty of opportunities to form a larger community. Clear lines between various crew spaces, enforced through access restrictions, as well as shared spaces in which the architecture encourages common activities and exchange guide the two crews and prevent conflict between them.

	Permanent Crew	**Guest Crew**
Crew members	4	4
Mission duration (days)	180	5-10
Objectives	• running the arrival port procedures • communications with Earth and other lunar outposts • instructing the guest crew/passing on expertise • research in the area of habitability and lunar gravity	• acclimatising to the lunar gravity • practical training of procedures in 1/6G [10]

Table 1. Crew Composition at HAVEN

IV. The HAVEN design

A. The HAVEN compound

The HAVEN compound (Figure 1) contains separate areas for habitation, energy generation, launch and landing, and component storage. A no-flight zone protects the habitation area from any hazards caused by launching and landing spacecraft.

Farthest from the habitat, at 2 kilometres distance, lies the multi-zoned launch and landing pad. Several construction techniques have been suggested for launch and landing pads in modern research. While not one single method has yet been confirmed as ideal in all aspects, the Centre for Lunar and Asteroid Surface Science (CLASS) has established a Planetary Landing Team from the world's leading experts to develop landing pad technology and materials to mitigate plume effects. [11] A novel concept envisaged by Van Susante and Metzger uses in situ rocks in a multi-zone approach. For this, the landing pad consists of a temperature and gas resistant central zone with a sintered surface or interlocked pavers. An outer apron, which doesn't need to resist direct plume impingement but

[10] The training includes lessons in the indoor training area (locomotion, fine motor skills, suitport handling, maintenance, medical emergency protocols), as well as on an outdoor EVA training site (locomotion, rover-driving, sample-taking, medical emergency protocols, robotic maintenance).

prevent soil erosion by a horizontal layer of gas, can carry supporting equipment like rovers or landing beacons.[12,13] A permanent reusable pad with an overall diameter of 120 meters, using this multi-zone approach, will be created at HAVEN before the arrival of the first crew.

Between the launch/landing areas and the habitation zone lie HAVEN's storage hangar and Resource Processing Zones (energy, water and oxygen, and waste processing). The relatively close proximity of the hangar to the pad enables a fast transfer of landers between the two areas, while still keeping the necessary safety clearance. Landers will be placed here during the crew's stay on the Moon, until the ascent module is needed for departure. Furthermore, both, discarded descent stages of crewed landers and cargo landers, are stored in the hanger to protect the components and valuable materials. This enables the use of these parts for future constructions, such as the use of the tanks for habitat shielding, as well as prevents the further expansion of the lunar junkyard.

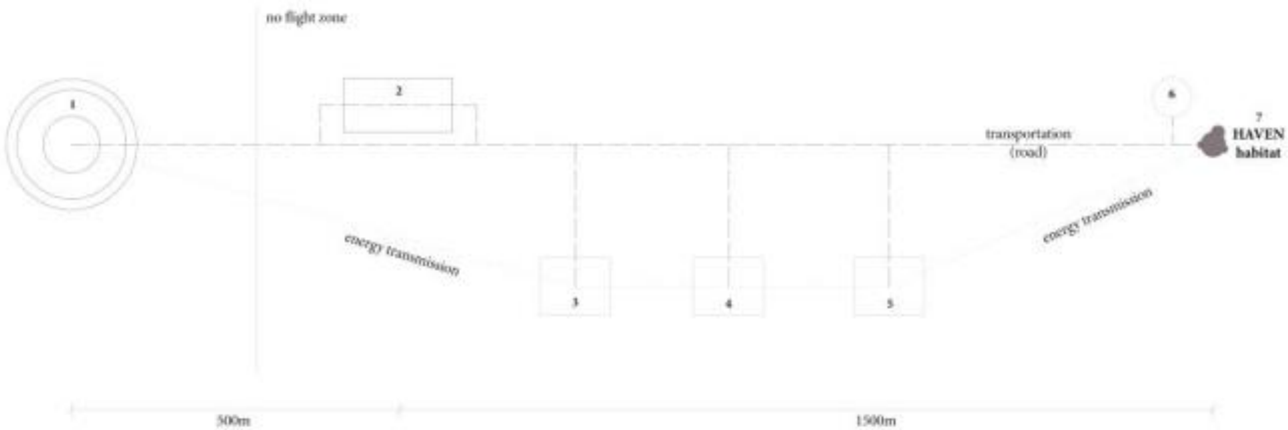

Figure 1. Facilities at the HAVEN compound. *(1) Launch and landing area. (2) Storage hangar. (3) Waste processing. (4) Water/oxygen production. (5) Energy zone. (6) EVA and 1/6G training site. (7) Habitat.*

B. The long-term habitat

The HAVEN habitat itself consists of a rigid centre component of cylindrical shape, which is extended by a multilayer inflatable torus with oblate sides (Figure 2). Together, these two parts create a habitable volume of 73.5 m^3 per crew member, distributed over two levels. This conforms with the 70m^3 per crew member which are recommended for long duration (>180 days) surface bases.[14]

For launch, flight, and landing the inflatable is stored in external folds around the rigid centre, allowing the interior to be used as logistics storage space during transportation from Earth to the Moon.

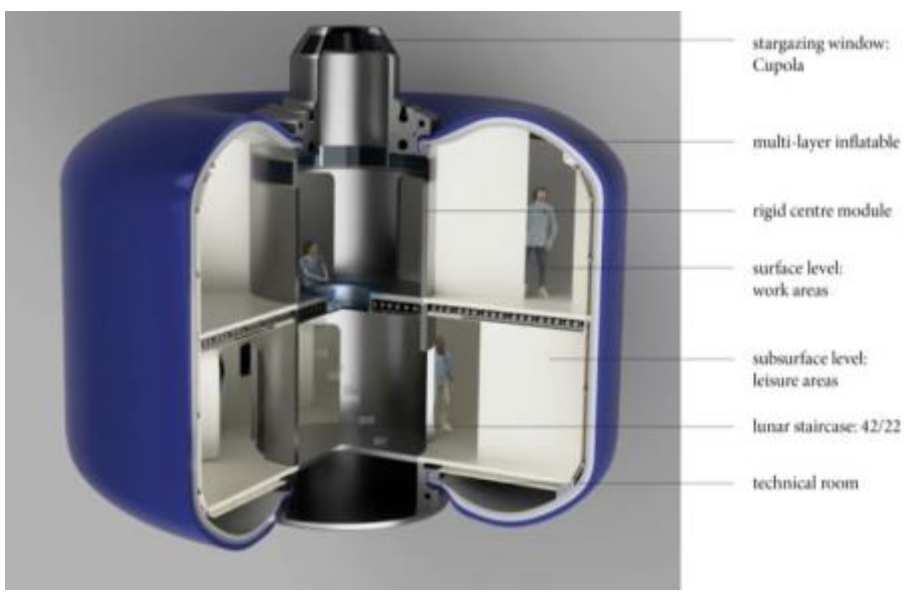

Figure 2. Spatial setup of the habitat. *The main part of the HAVEN habitat consists of a central rigid module and a multi-layer inflatable module.*

The inflatable shell is composed as seen in Table 2 [15]:

Layer	Material(s)	Size (cm)
Inner Liner	Nomex, flame and puncture resistant	1.5
Pressure bladder	Kevlar 29/BR 180 (alternating)	15
Restraint Layer	Kevlar 29 (tight webbing)	3
MMOD	Nextel/open cell foam (alternating),	9
Thermal Protection Layer	Aluminised Mylar layers	1.5

Table 2. Setup of the multilayer shell; interior to exterior.

By deploying the inflatable module, the habitable volume of HAVEN increases more than six fold, enabling the design of spacious living and working areas for a crew of eight, while the habitat in its packaged state still easily fits into the chosen launch system's cargo fairing (Table 3). [18]

Many of the technical and supporting systems, which are located in the rigid module, are pre-integrated and tested on Earth. This includes the aeroponic green walls and all the major installations; a vertical maintenance shaft for sanitary and electrical installations, as well as ventilation, runs in the rigid wall and ends in the technical room, which is located in the lowest section of the rigid component. Installations in the inflatable parts run in the floor space and can easily be connected to the pre-installed main systems of the rigid part.

		Dimensions (m)	**Habitable Volume (m^3)**		**In-flight storage capacity (m^3)**
Packaged Habitat *(packaging system: external folds)*	*diameter*	5.4	~ 187		~ 100
	height	8.2			
Deployed Habitat	*diameter*	12	*rigid module*	~ 80 m^3	n/a
	height	8.8	*inflatable module*	~ 515 m^3	

Table 3. Dimensions of the packaged and deployed HAVEN modules

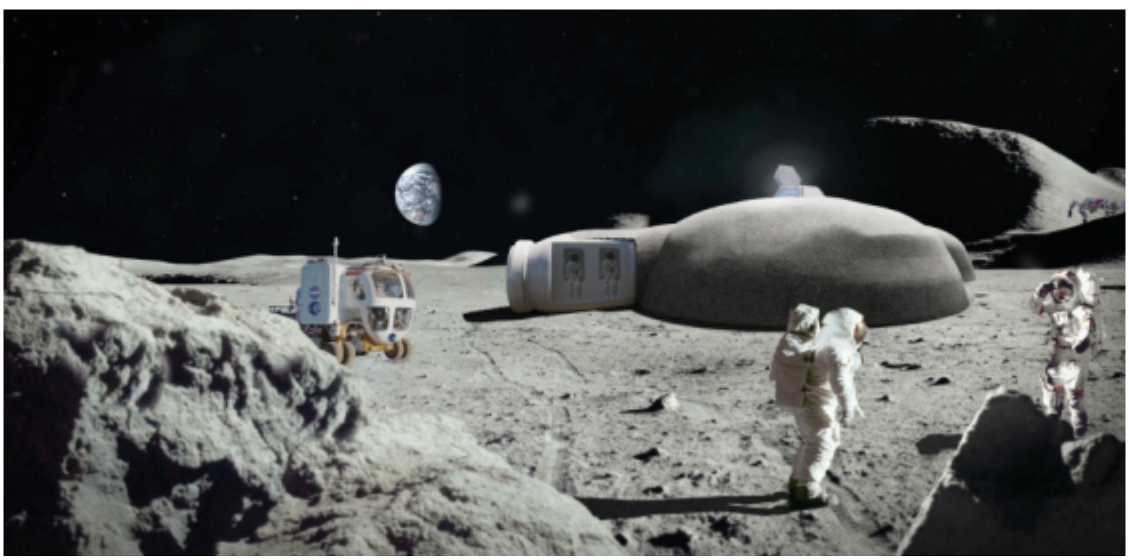

Figure 3. Visualization of the HAVEN long-term habitat on the lunar South Pole.

[15] The setup of the inflatable shell is based on the TransHab shell[16] and M. Arnhof's Design of a Human Settlement on Mars[17], and adapted for the HAVEN structure and location.

[18] The HAVEN missions aim to utilize the Block 1B configuration of the Space Launch System (SLS), which is set to play a major role in the establishment of the Lunar Gateway and the return of humanity to the Moon. The Block 1B launches will provide an 8.4 meter diameter fairing in 19.1 meters or 27.4 meters length. The internal cargo diameter lies at 7.5 meters.[19]

1. Excavation and Shielding

While the basic functions of terrestrial construction equipment are commonly used as a foundation when designing tools for lunar soil manipulation, conventional Earthen machinery is not applicable in an efficient manner on the lunar surface. Terrestrial devices achieve the breaking-up and excavation of soil and rocks through brute force and hydraulic systems, which is not be recommendable on the Moon, due to the extremely heavy payload and the fact that a terrestrial hydraulic approach would be impeded by the low lunar gravity. [20] Potential alternatives to conventional terrestrial techniques are the percussive and pneumatic approaches, of which a hybrid approach is used in the excavation oft he HAVEN site. This excavation phase prepares the site for the habitat placement and results in

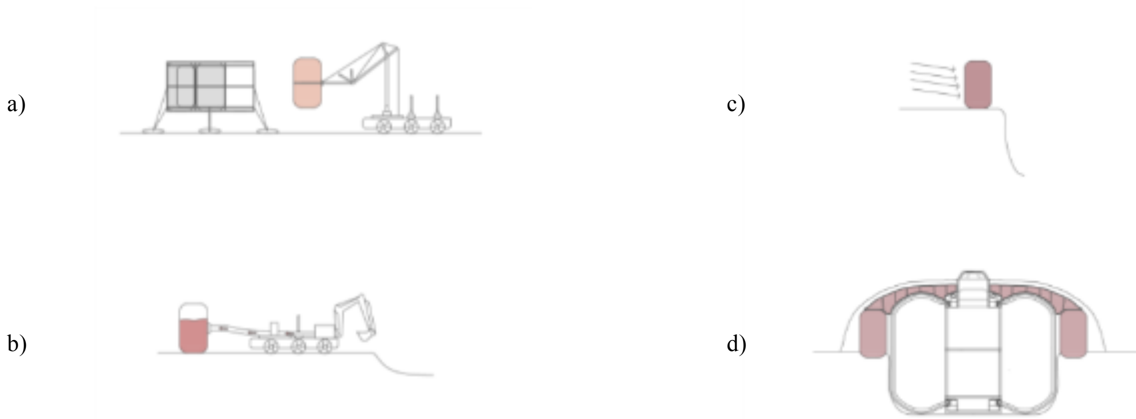

Figure 4 a-d. Placement of radiation shielding through regolith-filled lander tanks.

the subsurface location of a part of the habitat, which allows for additional, failsafe radiation protection in this critical area. Pneumatic excavation, which is based on harnessing gas momentum to move particles into a bin[21], can be simultaneously used to place the regolith shielding at HAVEN.

An overall regolith layer depth of 2.4 meters protects the HAVEN inhabitants from radiation. This consists of 1.8 meters of regolith, filled in lander propulsion tanks, topped with a less-tightly packed raised layer of 40 centimetres that covers the structure and protects the tanks' exteriors from external influences. Due to the angle of repose, which defines the steepness of this layer, a variable thickness with a somewhat larger offset at the bottom eventuates. [22] The top of the habitat is protected by regolith filled bags of 1.5 meters. The thickness of the side protection is defined by the respective lander tanks, but should measure at least the 1.5 meters of the top.

The use of empty lander propulsion tanks is a time and energy efficient version of creating regolith shielding. By using a mixture of percussive and pneumatic digging, the excavated regolith can directly be filled into the empty lander tanks during the excavation process, thus preventing the need for an external placement of the excavated material, which could prove harmful to the equipment, eliminating the need for sending additional bags or other habitat covers to the Moon, and preventing the energy-consuming task of, eg. sintering regolith around and on the habitat with special machinery. Thus, the discarded lander tanks find a second use in creating a safe and quickly constructed radiation shield.

As shown in Figure 4a, to create this ring of shielding, in a first step empty propulsion tanks are removed from the lander with a Lunar Surface Manipulation System (LSMS) [23], mounted on a Chariot Crew Mobility Chassis (CMC) [24] Regolith is then filled into the tanks during the pneumatic excavation process (Figure 4b). Thus, the excavated material is immediately safely disposed off, no additional machinery is needed, and the process can run simultaneously to the excavation process, saving time, payload, and money. The regolith-filled tanks are placed in a ring around the habitat to act as horizontal radiation shielding (4c,d). On top of the habitat, regolith filled bags act as shielding. An additional layer of lose regolith creates a barrier between the main part of the shielding and the lunar environment. This outer layer can easily be banked up with the LSMS mounted on the CMC.

2. **Functional layout and access limitations**

	Surface Level	Subsurface Level
Shared space/unrestricted access	• wardroom/galley, • training/instruction room • green gallery • airlock 2 • private communications cubicle • semi-private niche • hygiene unit • stargazing cupola	• crew lounge • workout area • sickbay/medlab • laundry room
Permanent crew only	• communications area • airlock 1 • greenhouse	• permanent crew quarters • hygiene units permanent crew • common space permanent crew • technical room
Guest crew only	-	• guest crew pods • common space guest crew • hygiene units guest crew

Table 4. Room schedule and access situation at HAVEN

Different areas inside the HAVEN habitat underlie different access restrictions, as shown in Table 4. This is necessary to optimise the co-habitation of the permanent crew and the guest crew.

While there are many shared areas where both crews are encouraged to mix and participate in common activities, certain spaces are accessible only to the permanent crew. These include not only crew quarters and hygiene units, but also areas with critical systems, like the technical room or the greenhouse, and the workspace of the permanent crew. This ensures undisturbed working processes and the necessary amount of privacy. In contrast, areas open to everyone encourage the two crews to spend time with each other outside the work and training hours. Thus, the very limited social circle of the permanent crew is enriched with a changing number of individuals and their experiences on a regular basis.

The HAVEN habitat furthermore offers a variety of different privacy situations. It is of special importance to offer the inhabitants of an isolated base a choice in how much privacy they want to integrate in their daily routines. Of equal importance is the manner of this privacy and to enable the crew to chose and flexibly adapt their levels and nature of interaction.[25]

In order to improve the privacy situation on a lunar base, mechanisms that emphasize the crew member's individuality should be increased. This can span from allowing personal choices in the decoration of certain areas to the individual selection of clothing. Ensuing the physical separation of private areas is another contribution to helping the crew deal with the minimized privacy.[26]

The privacy levels at HAVEN are not necessarily dependent on the area's access limitations, but often a result of these.

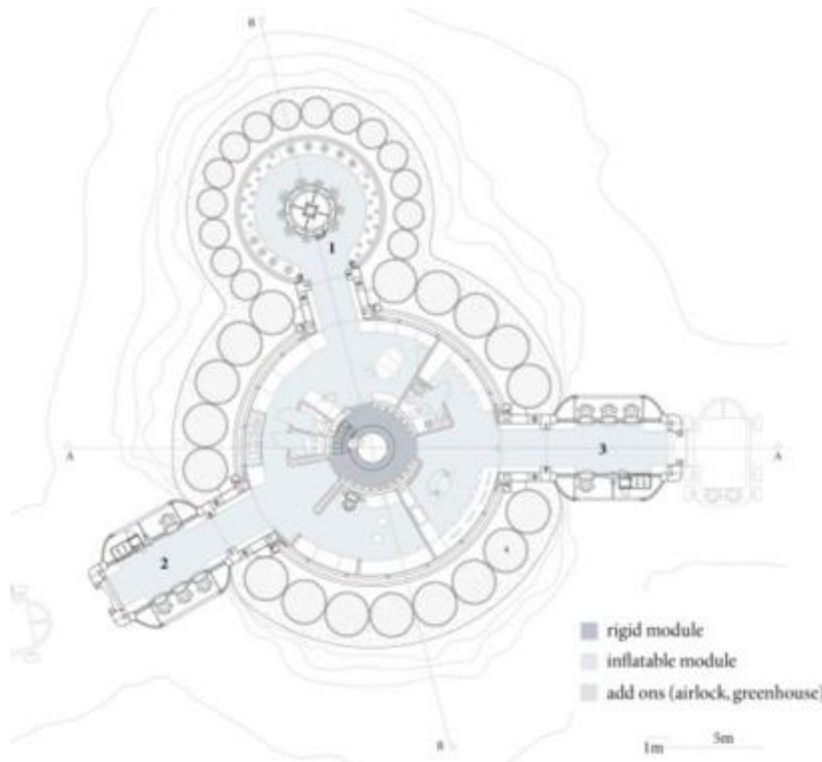

Figure 5. Surface Level. *(1) Greenhouse. (2) Airlock 1 (rover undocked). (3) Airlock 2 (rover docked). (4) Regolith-filled propulsion tanks.*

Furthermore, flexible options in the design allow the users to adjust the architecture to their current personal needs. This is achieved by changeable elements, such as sliding wall elements, which allow the fast modification of certain areas.

3. Surface Level

The surface level (Figure 5) provides entrance to the habitat via two egress/ingress airlocks (2,3), both fitted with four suitports[27] each, as well as a docking opportunity for a Small Pressurized Rover (SPR), a glovebox system and an extensible (telescopic) robotic arm supports to support work directly outside the habitat. In addition to internal storage space and charging stations, external lockers hold all necessary equipment for successful Extravehicular Activity (EVA).

Airlock 1, next to the instruction and training room is used as main egress/ingress route for non-scientific EVAs and arriving crews. Airlock 2, located in the restricted area next to the permanent crew's working and communications area, is only accessible to the permanent crew. This airlock is mainly used for research and exploration EVAs, as well as maintenance tasks.

One of the merits of having two separate airlocks is the aspect of redundancy in emergencies, which should be kept in mind during any space mission.

The HAVEN greenhouse (1) is an inflatable structure that is connected to the main habitat with an airlock. This allows closing-off of the greenhouse, to keep the atmospheric conditions ideal for farming purposes.

The greenhouse is not meant for the astronauts to interact with the plants or to use as a means of improving habitability (this purpose is fulfilled by the green gallery in the main part of the habitat). Its sole purpose is to grow enough fresh produce to supplement the crew diet and is therefore defined as a critical area with restricted access. However, apart from providing necessary sustenance in a fresh form, plants contribute a variety of many-sided benefits to life on a lunar base, many of which are important in raising the habitability levels. Greenery has a special value in maintaining emotional balance and avoiding depressions amongst the crew[29], which is why an extensive green

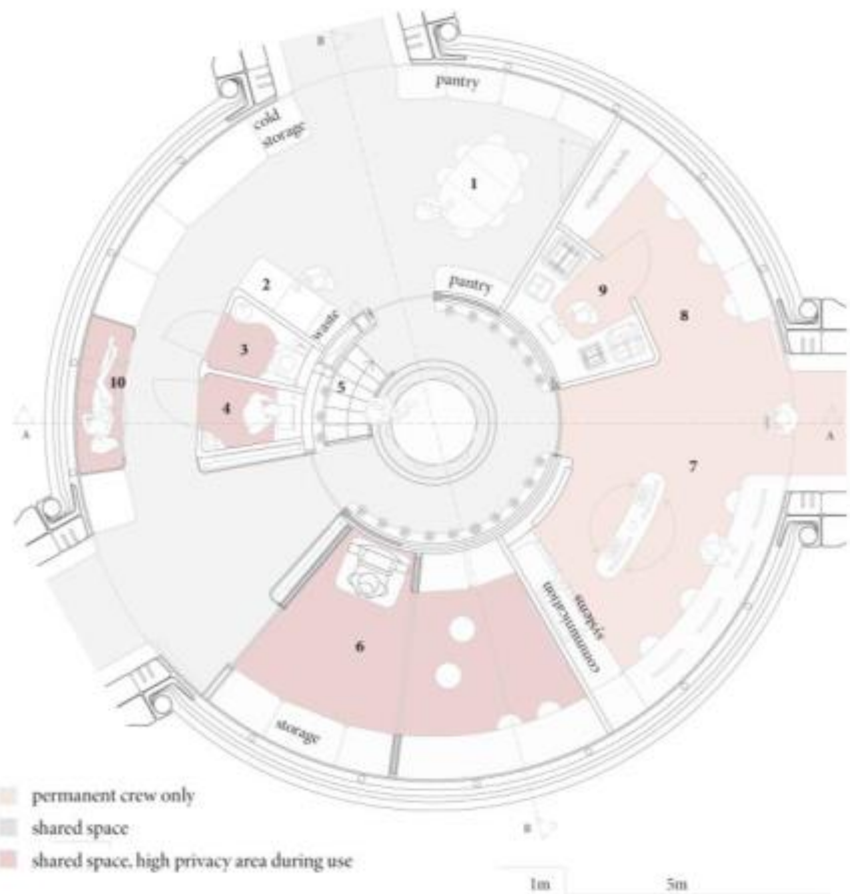

Figure 6. Surface Level, detail. *(1) Wardroom. (2) Galley. (3) Hygiene unit. (4) Private communications cubicle. (5) Green gallery. (6) Instruction area/workspace guest crew. (7) Communication and control center/workspace permanent crew. (8) Engineering/maintenance. (9) Additive manufacturing cubicle. (10) Semi-private niche.*

[27]The Suitport Extravehicular Access Facility is an efficient ingress/egress solution by M. Cohen, which minimizes the necessary pump-down volume and thus the required time and power.[28]

wall in the rigid part oft he habitat allows the crew members to interact with the plants.

As seen in Figure 6, this green gallery (5) lies at the centre of the habitat and connects the different work areas on this level, as well as the two levels themselves, and the stargazing cupola above. The gallery's floor breakthrough towards the crew lounge below allows view relations and the transmission of light from the stargazing window above. A green wall enhances the liveability in the habitat by acting as a buffer between the work areas and by allowing the crew to interact with the plants.

The galley (2) and wardroom (1) offer room for different crew sizes due to flexible furniture systems. A media screen can be rotated and adjusted to personal crew preferences. A bio-waste grinder attached to a chute next to the galley allows the crew to immediately dispose of their waste, which is then lead to a composting module in the subsurface level. Non-decomposable waste (eg. packaging material) is collected and transferred to a separate waste facility on the HAVEN compound for processing (eg. additive manufacturing resources). From a communication and control centre (7), which also acts as the permanent crew's main work area, the launch and landing processes, as well as any communication with Earth or other outposts, can be managed from. This area is adjacent to an engineering and maintenance area with a soundproof additive manufacturing chamber.

The instruction and training room (6) can also act as a private workspace for the guest crew. This large, open space can be divided into two smaller ones, depending on current needs, and offers enough free space for various kinds of trainings, including indoor 1/6 G exercises or 1/6 G medical training.

A small separated room (4) with noise insulation offers the possibility for private communications with Earth and a niche with privacy curtain (10) allows the astronauts to temporarily withdraw from the busy workspaces.

4. Subsurface Level

As the subsurface location of this level makes it especially well shielded, this part of the habitat contains the private quarters and leisure time areas (Figure 7). This also includes the workout space. A common crew lounge (7), which is open towards the green gallery and the stargazing window above, forms the centre of the living quarters.

The quarters of the permanent crew and guest crew, as well as the hygiene units of the two crews, are spatially separated to allow for more privacy between the permanent crew and the visitors.

Four crew quarters (1) offer individual living space to the members of the permanent crew.

On the other side of the habitat, four stacked pods act as quarters for the guest crew (8). Two small areas next to the respective quarters (2,9) offer the possibility for each crew to interact amongst each other and a semi-private setting.

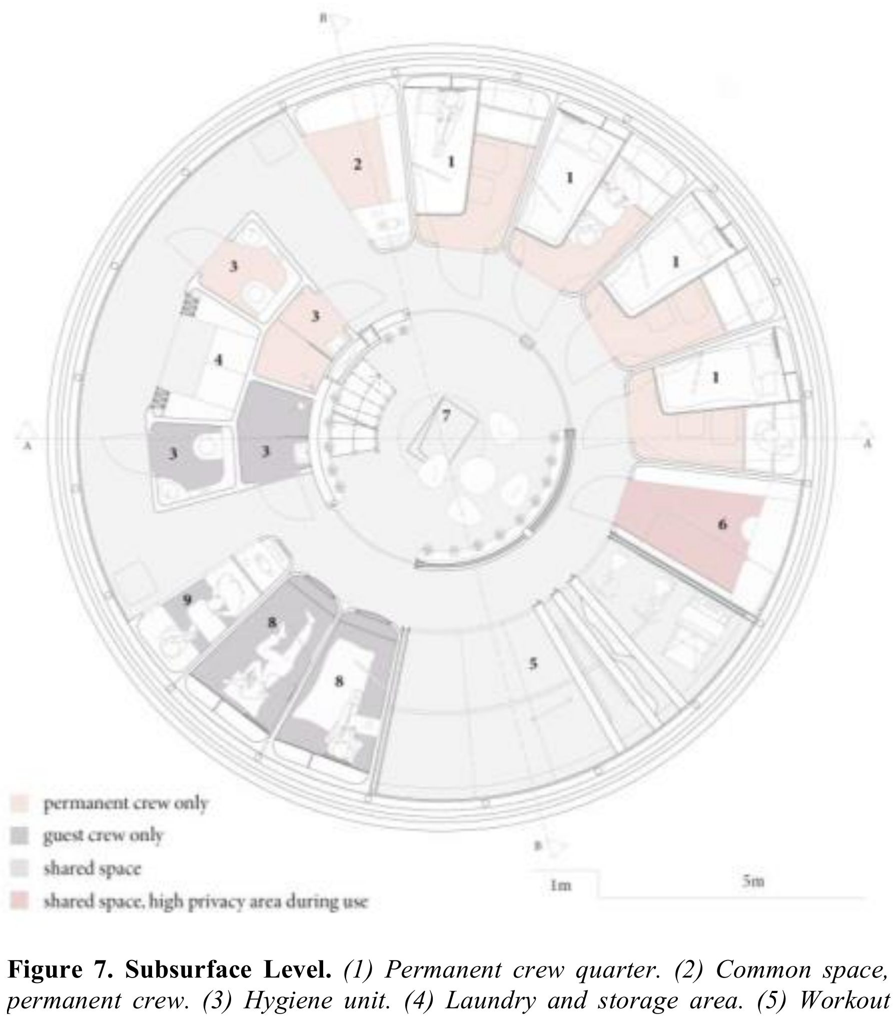

Figure 7. Subsurface Level. *(1) Permanent crew quarter. (2) Common space, permanent crew. (3) Hygiene unit. (4) Laundry and storage area. (5) Workout area with movable walls. (6) Sickbay/Medlab. (7) Crew lounge. (8) Guest crew pods. (9) Common space, guest crew.*

A workout area allows a flexible adaption by sliding 'workout-walls' along a floor-rail system. The area offers bouldering, wall bars, battle ropes, and various workout machines. This system enables the crew to create several smaller or one bigger workout area, adapted to the individual needs. It also allows the interim use of the area for other functions, when no workout takes place.

The subsurface level furthermore contains laundry facilities (4) and the sickbay (6), which can double as a medical lab.

5. Personal crew quarters

The distribution of the habitable volume at HAVEN is not equal between all astronauts – different sized crew quarters allow for a larger habitation space for those with longer stay durations. The members of the permanent crew are allocated private quarters of 11 m^3 volume, with a floorspace of 4.5 m^2, each; the short-duration visiting crews' private spaces are stacked, pod-like chambers with a volume of 4 m^3 each, at a floorspace of 2.8 m^2.

a) Guest Crew Pods

The personal quarters of the guest crew (Figure 8) differ from those of the permanent crew in shape, size and function. The guest crew is accommodated in private pods of 150 centimetres height. Two pods are stacked on top of each other for maximal spatial efficiency, the upper being easily accessible due to the low lunar gravity. The pods' entry hatches are made from glass that can be toned at the inhabitant's choice, thus allowing both a visual connection with the central lounge area or complete privacy inside the pod.

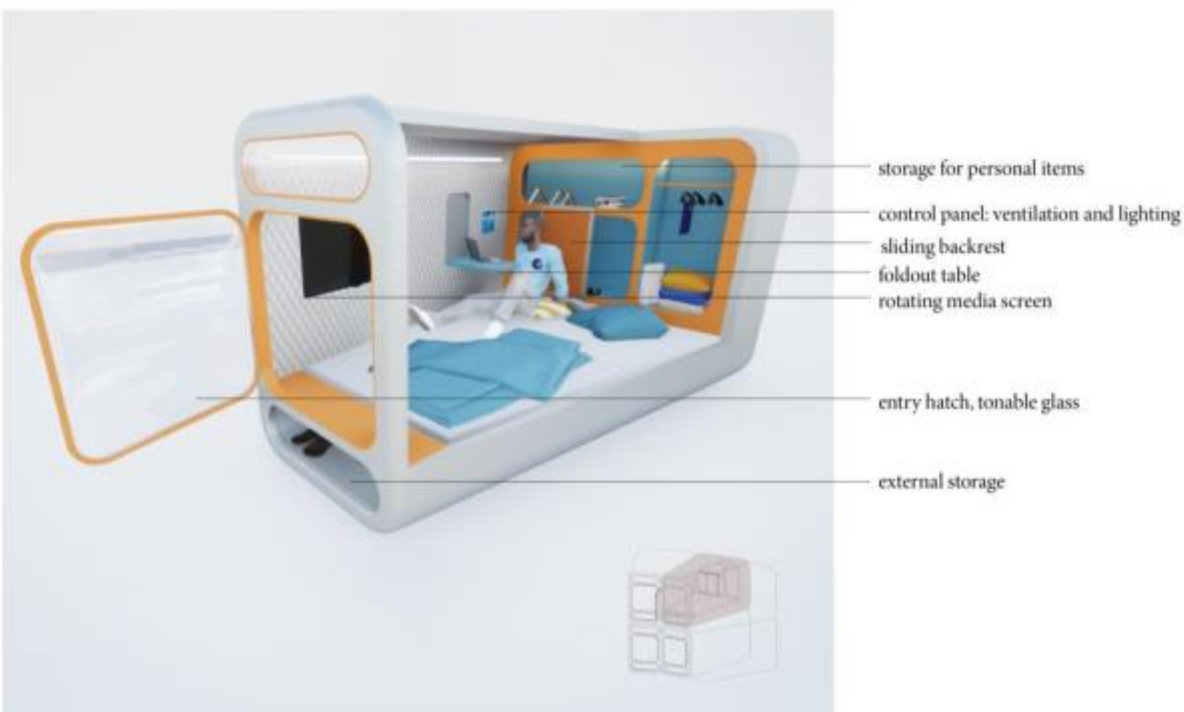

Figure 8. Guest Crew Pod

A small external storage niche enables the astronauts to place their house shoes or quick-access items during the day. Inside, the pod offers additional storage for objects the guest crew will need during their stay at HAVEN. A separate locker pod provides storage for luggage and larger items that are needed less frequently. A small foldout table and a rotating media screen complete the interior of the cosy pod. Over a control panel in the wall, the astronauts can individually control the ventilation and lighting situation of their pods. Comfort and privacy during a short-term stay on minimal space are the main objectives of the guest pods.

b) Permanent Crew Quarters

The somewhat larger volume of the personal quarters of the permanent crew (Figure 9) allows the inhabitants to move around in a standing position. Generous storage possibilities, as well as plenty of room for personal items and decorations, allow the crew to claim this space as their own.

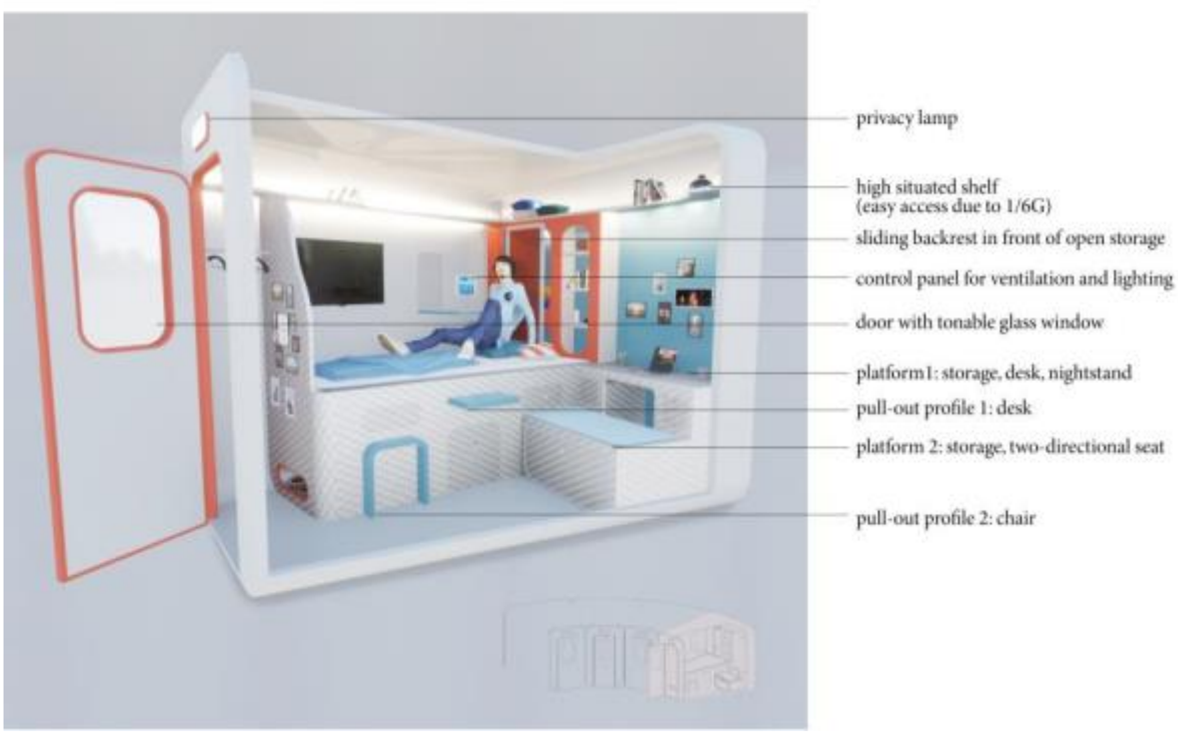

Figure 9. Permanent Crew Quarter

Similar as in the guest pods, a rotating screen and a control panel for ventilation and lighting are set within easy reach above the bed. Additionally, the permanent crew can control 'privacy lamps' outside their doors, which can give indication to their fellow crewmen of their mood, privacy needs, or availability.

The permanent crew quarters focus on providing a flexible room schedule, as seen in Figure 10a-c: simple pull-out profiles in the bed structure allow the flexible creation of a intimate space for two crew members. Thus, the crew quarters can be used as fully private area during the night (1), as a small private work area (2), or as space for intimate gatherings between two crew members (3) during the day. If the need arises, the bed can be extended to accommodate a couple (4).

Figure 10 a-c. Variations of the Permanent Crew Quarter.

V. Conclusio

Establishing a permanent lunar outpost will be beneficial for further human space exploration. The South Pole is a coveted region for this and a site on a ridge between Shakelton and De Gerlache craters was chosen as location for the HAVEN Lunar Port and Base. This design encompasses a whole compound, to act as an Arrival Port at the lunar South Pole, but focuses on the architectural design of the habitat itself, which consists of an inflatable torus with a central rigid module and regolith shielding in discarded lunar lander tanks.

The design for a lunar outpost with such arrival port functions opens up the interesting aspect of having to plan for the simultaneous occupation of crews with different objectives and mission durations. This versatile crew situation bears great potential for a more diverse social exchange on such an isolated base, but at the same time could cause conflict and interruptions in the workflows. The HAVEN architecture addresses this by offering spaces with different privacy aspects, as well as access restrictions to certain areas. At the same time the habitat's common areas encourage an exchange between the different crews. The levels of privacy in the various areas are not necessarily dependent on the access limitations, but often a result of these. Several areas allow the inhabitants to adjust the room schedule or privacy situation according to current needs. The versatile crew situation requires a balance between guidelines established by the architecture to protect critical areas and processes and flexible options left to the users to ensure sufficient privacy and possibility for communication.

Technical modules	**Design elements**	**Shape**	**Number**	**Functions**
	Rigid core	cylinder	one	• common space • lunar staircase • in-flight storage
	Inflatable module	torus with oblate sides	one	• work areas • wardroom/galley • crew quarters • hygiene units • workout area
	Airlock	capsule (rigid ends, inflatable centre)	two	• Suitports • SPR docking glovebox • EVA storage
	Greenhouse	inflatable sphere	one	
Spatial aspects	**Area function**	**Design Focus**	**Number**	**Access situation**
	Work areas	uninterrupted workflows	two	crew specific
	Wardroom/galley	encourage exchange	one	unrestricted/open to all
	Crew lounge/green gallery	encourage exchange, support relaxation	one	unrestricted/open to all
	Permanent Crew Quarter	flexible room schedule, personal storage, personalisation	four	user specific
	Guest Crew Pod	Maximum privacy/habitability on minimum space	four	user specific

Table 5. Summary of design aspects.

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