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Design of a Scalable Framework for Lunar Habitats

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Abstract

The last decade has signalled the crystallisation of a common, global agenda to revisit mankind's exploration and habitation of the moon. Government agencies and private companies are presenting a common front to deliver critical missions and programs such as the Lunar gateway, working towards a permanent presence on the lunar surface. As an outcome of ESA's Open Space Innovation Program, our paper presents a scalable, holistic design and architectural framework for long term human habitation on the Moon, embedding key solutions for environmental protection and mitigation, construction methodology and assembly of a scalable architecture, life support and an overall mission architecture. Our approach differs from existing lunar concepts (i.e. static masterplans that predefine settlement layouts), devising a system that enables continual reconfiguration in response to future, unpredictable social societal needs, technological and operational advancements. The novelty of the proposal will focus around the reconfigurability, reusability, and accommodation of various growth scenarios of a lunar base. This design principle extends to the proposal's approach to system engineering, life support, modular construction techniques, and in-situ resource utilisation which are directly embedded into the architectural framework to ensure seamless expansion.

The proposal is led through a human centric, design-based approach, prioritising long term self- sufficiency, sustainability, and well-being of future lunar settlements. Formulation of solutions accommodate for a constantly evolving programmatic brief, taking into consideration the physiological, psychological, and social needs of a wider inhabitant demographic. The system is comprised out of several interdependent architectural components; an ISRU-based modular construction system for radiation protection, tensairity-based, pressure-retaining inflatable modules for habitation, a modular interior fit-out system, and hard-shell modules for vertical circulation. The system thus exists as a "kit-of-parts", serving as a comprehensive atlas of architectural elements and life support systems for further testing and development, with any advancements feeding back into its central design principles. Design reviews involving participation of multidisciplinary industry experts and partners were held several times throughout the design development of the project, ensuring robust scientific basis for design concepts and strategies.

Keywords: architecture, scalable, habitat, reconfigurability, design, kit-of-parts

1. Introduction

The last decade has signalled the crystallization of a common, global agenda to revisit mankind's exploration and more permanent habitation of the moon. Multiple government agencies such as ESA and NASA as well as private companies are collaborating to bring about critical missions and programs such as the Lunar gateway and the Artemis program, consisting of a series of missions aimed at landing the "first woman and next man on the Moon by 2024". These programs are utilized as anchor points that drive key developments and activities in envisioning lunar habitats, building upon the ESA's vision for an international "Moon Village".

1.1 Literature Survey – State of the Art

Over the past fifty years, architects and urban designers who are leading the discourse and research have conceived a new branch of the architecture field - Space Architecture. Existing habitat proposals made by space architects can be categorised into three classes: Class I - Pre-integrated, Class II Prefabricated - space/surface assembled and Class III - In situ derived and constructed [1]. An extensive bibliography of Lunar habitat concepts can be found in Benaroya's "An Overview of Lunar Base Structures: Past and Future"[2].

More recently, lunar habitation concepts have advanced from hybrid inflatable-plus-regolith shielding strategies, pioneered through ESA-led industrial studies

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and later further refined in projects such as LIQUIFER Systems Groups' REGOLIGHT solar-sintered interlocking blocks; towards increasingly holistic frameworks that integrate ISRU, modularity, and prefabrication as central construction methodologies. Building on these technical foundations, proposals such as SOM and ESA's *"Moon Village"* [3] and visionary schemes such as Vogler's "*Moon Capital"* [5] extend the discourse into the domain of lunar urbanism, addressing not only the architecture of survival but also the sociotechnical infrastructures required to support permanent, self-sustaining communities on the Moon.

Parallel challenges and difficulties can also be found when designing and planning for extreme and remote environments on Earth. Analog habitats in remote and extreme environments, such as polar stations, oil rigs, and submarines, provide vital testbeds for human space habitation, enabling trials of mission planning, logistical deployment, equipment interfaces, and long-term survival strategies under harsh conditions. Coincidentally, construction systems used in existing polar research stations and bases fit within Smith's [6] classification of lunar structures.

For example, Antarctic research facilities such as India's *Bharati* station [7] and the British Antarctic Survey's *Halley VI* [8] demonstrate how modular, relocatable systems, whether through containerised construction or hydraulically jacked, mobile structures, enable resilience against extreme environmental dynamics while minimising logistical burdens. Beyond engineering, these stations highlight the critical role of human-centred design: from personalised private quarters and adaptive social hubs to carefully selected interior finishes, each element underscores the necessity of architectural strategies that safeguard psychological well-being alongside survival in polar frontiers.

1.2 Aim and Vision

Our vision is to develop a scalable, holistic design framework for permanent human habitation on the moon, embedding key solutions for environmental protection and mitigation, construction methodology and assembly of a scalable architecture, life support and an overall mission architecture. This approach differs from a conventional masterplan – where outcomes are defined based on a static plan of how a city should be laid out. The aim is therefore, to enable multiple city layouts and configurations which can be constantly redefined and reconfigured, catering for an ever-changing programmatic brief that considers the physiological, psychological, and social needs of a wider inhabitant demographic as well as future advancements in technology.

The novelty of the proposal will focus around the reconfigurability, reusability, and accommodation of various growth scenarios of a lunar base. The system thus exists without a set masterplan, but rather a "kit-of-parts" that we can deploy to create a lunar habitat.

The scalable framework shall also serve humanity's interest towards becoming an interplanetary species, enabling future space related endeavours such as space industrialisation through ISRU (In-situ Resource Utilisation) and the facilitation of future exploration missions.

Figure 01. Aerial View of Proposed Lunar Habitat Framework, (Hassell, 2023)

2. Design Methodology

2.1 Formulation of Design Brief

As a starting point, the framework must define the initial set of parameters, programmatic requirements and functions needed to sustain a thriving settlement on the lunar surface. The departure points for the formulation our design brief was the examination of key references such as the "NASA-STD-3001- Space Flight Human Systems Standard" [9], "Human Integration Design Handbook"[10], ESA's "ECSS-E-ST-10-11C Standard for "Space Engineering – Human Factors Engineering"[11] and "The Lunar Base Handbook"[12],

extracting guidance for high level spatial requirements and relationships in space habitats.

Additionally, an investigative exercise was conducted to draw potential parallels with earth-based structures that are of a similar nature in size and functional program. These structures normally operate in extreme environments, comprising of typologies such as offshore oil rig platforms, submarines, Arctic, and Antarctic bases, which share a commonality in challenges and interfaces between the internal and external environments. Another similarity can also be found in their ability to shrink or grow in population size, depending on factors such as seasons or functionality of the overall base. The results of the work were distilled into a set of commonalities between functions and sizes that informed future spatial provisions.

2.2 Site Selection

The success of humanity's long-term settlement on the lunar surface is highly contingent upon site selection of the base. Building upon precedent lunar base proposals, our study will also select the Lunar South Polar Region as a suitable baseline for a permanent habitation.

The evaluation criteria in selecting a higher granular area for the habitat will be based on 4 main parameters:

- Illumination (i.e. for Solar power generation)
- Slope and Terrain
- Uniformity and continuity in size and area (for potential base expansion)
- Access to volatile regions (i.e. Proximity to permanently shadowed regions (PSR) - potential sites for water-ice mining)

Satellite imaging has been the primary source for verification to justify the final site selection of the habitat. Maps, imagery, and data used for analysis were mainly obtained from the Lunar and Planetary Institute Regional Planetary Image Facility's Lunar South Pole Atlas, and data on large PSRs were obtained from the Permanently Shadowed Regions Atlas, which lists PSRs with areas greater than 10 km2 as well as the Lunar Orbiting Laser Altimeter (LOLA). LOLA is an instrument mounted on the Lunar Reconnaissance Orbiter (LRO).

Investigative analysis and results of the key identified parameters from Gläser et al. (2014)[13], Gläser, (2018)[14]. Gawronska et al, 2020 [15]. Li et al, 2018[16] and Mazarico, et al., 2011 [17] have led to the selection of the south polar area cluster 1 (Connecting Ridge, C1-0 and Connecting Ridge, C1-1) is the chosen habitat site for our study. In essence, the justification behind the selection can be summarised in the matrix of figures extracted in Table 01.

As highlighted by the figures in the table, Cluster 1 sites have a high yearly illumination average as a function of its large, illuminated area and large relatively

Cluster, Site	Maximum Average Illumination [%]	Maximum Solar Visibility [%]	Size of Cluster [m2]	Size of PSR [m2]	Distance of PSR [m]	Maximum Slope PSR [°]
Connecting Ridge, C1-0	88.0	92.1	135,200	5,200	100	12.8
Connecting Ridge, C1-1	81.3	86.0	26,800	9,600	70	13.7
Connecting Ridge, C2-0	71.6	75.1	4,400	5,600	60	11.5
Connecting Ridge, C2-1	78.1	82.0	11,600	22,800	80	17.1
Shackleton, S0	85.5	89.4	21,600	58,400	370	17.0
Shackleton, S1	84.3	89.8	120,400	4,400	30	11.1
Shackleton, S2	73.9	78.8	31,200	1,200	80	6.0

Table 01. Table Excerpt - List of clusters at Hinshelwood, Peary and Whipple craters with favourable illumination conditions at two meters above ground (column one). Shown are the maximum average illumination and solar visibility of each cluster in percentage (columns two and three), the size of the cluster and the PSR in square-meters (columns four and five), and the closest distance between the cluster and the PSR in meters (column six) and the maximum encountered slope within the PSR in degrees (column seven). (Gläser et al, 2014)

flat area. This would allow for the scale of construction needed for power generation via solar arrays, while ensuring sufficient distances away from potential landing sites.

Mazarico, et al. have also investigated distances and traversal slopes of PSRs that surround Cluster 1, highlighting small pockets of PSRs within approx. 7km from the site and approx. 14.1 to a larger PSR (> 10km2 in area).

Cluster 1 can also be divided into two lobes. A detailed examination of illumination maps of the Connecting Ridge C1 reveals a suitable location for large solar arrays, positioned in areas that maximise illumination time experience by the larger lobe (in red). The smaller lobe on the top right could potentially be utilised for the landing pad, maintaining a considerable distance away from the main habitat. This would also minimise risk of debris and collateral lunar dust generated from EDL (Entry, Descent and Landing) or take-off activities.

The map captured in Figure 34 represents a potential high-level configuration of the habitat within the Connecting Ridge C1-0 site. Nearby PSRs and two relatively flat areas corresponding to the locations of

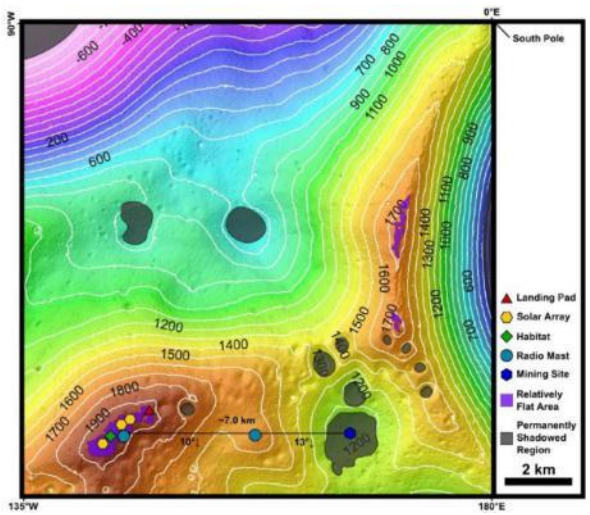

Figure 2. Topographic Contour Map of the Lunar South Polar Ridge (McCanaan, et al, 2019)

Cluster 3 (SR1, SR2 and SR3) have also been included as potential expansion sites, if solar power generation become a limiting condition on the habitat or other infrastructure.

2.3 Habitation Strategy

Our proposal builds on Smith's classification for lunar-base structures (Smith, 1993)[6], which was Later codified into NASA's technology development roadmaps. The classification consistently aligns with the "techno-sociological" development roadmap presented by Harper and Connell (1990)[4]. Smith defined three major types of surface construction for a permanent presence on the lunar surface: Class 1 structures will mostly be "artificial environments that provide life support and amenities to promote health, well-being, productivity and crew acceptance of living in a "radically different environment for very long periods of time" while Class 2 Structures look at structures that will enable inhabitants to "spend their lives and eventually bear and raise children" on the moon. The last classification is geared towards permanent settlement with self-sufficiency and growth capabilities at its core.

The aim for the proposed scalable framework is to embed resilience and a level of compatibility with future systems and designs, enabling straightforward interfaces between the old and the new. This would mean allowing various habitat classes to integrate within the chosen site. As a departure point, we are proposing a hybrid Class 2 and Class 3 Structure as the initial seed module for a scalable architecture framework. Our approach combines the advantages provided by ISRU as our primary means for passive bulk shielding whilst utilising the high-level precision afforded by prefabricated, deployable pressure-retaining modules from Earth.

2.3.1 Principles for Growth and Scalability:

The initial population seed and its scaling is a function of the crew capacity of the planned spacecrafts. (i.e the Crew Dragon has a capacity of 4-7 Seats, the Orion Spacecraft as a capacity of 2-6 seats, Dreamchaser has capacity for 3-7 Crew, Boeing Star Liner holds a crew up to 7 people). We have included intermediate population thresholds and expansion scenarios to accommodate up to 144 inhabitants. The "144" upper limit for occupants has been derived from Dunbar's number, "a suggested cognitive limit to the number of people with whom one can maintain stable social relationships". [18] When the population passes this threshold, we believe it is imperative to establish a new base to undergo the phases of growth and evolution.

Upon reaching a lunar population of greater than 144, the system should identify a new location and implant a new "seed". The subsequent bases should be connected to the core base but be completely self-sufficient in its own existence.

2.3.2 Scalability Strategies

Due to the specific environmental factors and reduced gravity present on the moon, along with the significant expenses involved in transporting goods and materials to space, achieving scalability within the habitat will not be a simple linear function of its constituent parts i.e. expansion of the floor area or volume. Our proposal aims to move beyond traditional convention of "copy-pasting" as a means of growth. Majority of precedents suffer from the necessary differentiation and flexibility required for an organic growing system of a Lunar habitat.

Our scalability strategy can be distilled in two main approaches: a centralised vs a decentralised approach.

A decentralised approach would involve a direct repetition of habitable modules to increase function and capacity, whilst a centralised approach would involve introducing a new module typology and size to aggregate the increasing requirements of a particular spatial program. Each approach within the framework can be adopted in the expansion and contraction of a permanent lunar base – dependent upon varying population thresholds and their associated community dynamics.

Another benefit of the centralised approach is the provision of variety in the type of spatial enclosures available to host the different programmatic functions of a growing base. For example, the spatial usage and behavioural dynamics of a kitchen that caters for 4 people is vastly different to one that can cater and feed 144 inhabitants. When appropriate, the centralisation of functions can also unlock new economies of scale and efficiencies for spatial programs, outweighing the potential mass & weight savings gained simply from module repetition.

2.3.3 Organisational Principles

Like many successful cities on Earth such as Barcelona, New York, or Paris; a grid is deployed and overlayed to create structure within the lunar settlement. The grid acts as the underlying logic that helps to standardise / systematise necessary variation for a growing system.

Our framework utilises an octagonal grid, which creates an inherent "courtyard" without any octagonal cell being unused. This also offers the necessary porosity for access to any given habitation module and cluster in the case of emergencies.

Building upon the scalability approaches of centralisation and decentralisation, the framework must also adopt a set of organisational principles or rules in the placement of habitable modules. Each module can be dedicated to one or more programmatic functions which

are then connected to adjacent modules under a shared protective shell, thus creating a cluster of modules. Each cluster could be functionally homogeneous in the case of greenhouse where a cluster is dedicated to a specific function or heterogeneous where each module within a cluster is of different function but together create a small ecosystem for living, working and leisure (Figure 03)

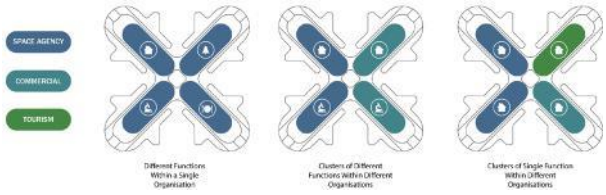

Figure 03. Two degrees of flexibility by the system, whereby different permutations of occupancy and function can occur. In each cluster one or more functions as well as organisations can be accommodated.

2.3.4 Circulation Logic

Due to the environmental challenges associated with living on the moon, our framework needs to offer a fully enclosed, closed-loop network of circulation that allows any habitant to move from any point to another without being directly exposed to the external environment.

Any growth within the base must ensure continuity to the circulatory system of the predecessor state of the habitat.

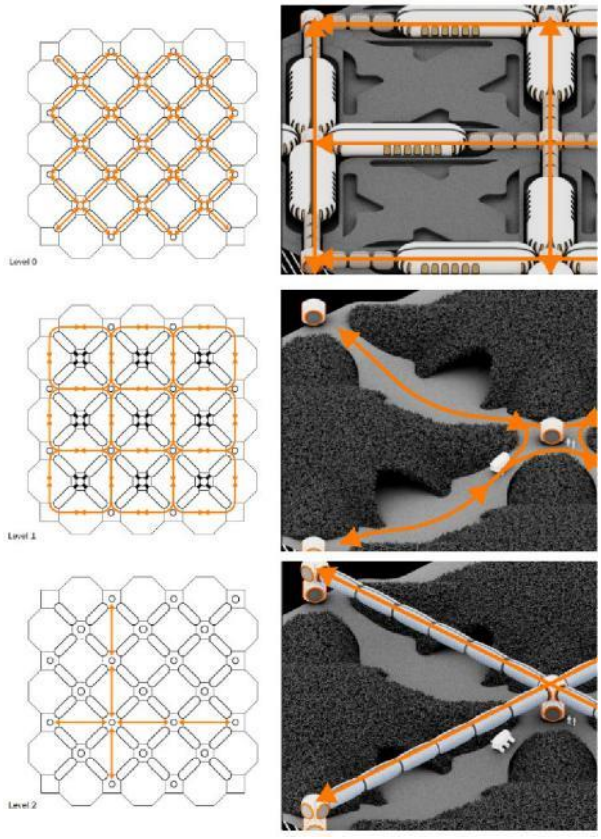

Figure 04. Multi-layered circulation system shown on plan and axonometric view.

We propose a layered circulatory system over three levels of the base, connected vertically through a series of towers at every key grid intersection. Primary circulation between habitable modules happens at the lowest ground level of the base, which require as many circulation loops as possible to ensure minimal interruption to the circulation flow within the habitat in the event of a catastrophic failure or stranded modules. This "slower" circulatory system is fulfilled through a network of connected modules, where each module has at least two exits/entrances; suitable for covering smaller distances/journeys within the larger settlement. (Figure 04).

The middle or "ground" level circulatory layer, rover and suit-port access to the external environment is embedded within the tower module.

Across greater distances the lower ground system is no longer the most efficient option as journeys require traversing through other modules inhabited for various functions in between destinations. In that sense, the absence of a corridor might cause unnecessary interruptions. To overcome this, we propose a faster, more direct circulatory system for longer distances across the habitat at the upper ground level, acting as an express highway between the vertical towers.

Expressways are used in a "shuttle" manner and users are expected to spend very little time traversing the circulation route. This is reflected in the design as they do not possess the same levels of protection as the primary habitation modules. In the event of a major radiation event, inhabitants should rely on the "slow" circulation that exists throughout the habitat modules under the protection regolith shell.

3. Architecture Framework Components

3.1 Protection Shell

Due to the lack of a magnetic field, survivability within the lunar environment is highly reliant on minimising exposure to harmful solar and cosmic radiation. The primary method of protection against radiation must therefore be achieved artificially, ideally through ISRU derived techniques and methodologies.

Over the last decade, significant advancements have been made for continuously 3D printed, monolithic shell structures as a protection layer for habitats on the Moon & Mars. Constrained to the material availability on the construction site, continuous 3D printing requires a high degree of precision with a low degree of tolerance for error for the shell to be pressure-retaining and watertight. Furthermore, the embodied energy required within the construction process is locked within the static design and does not offer any flexibility for future repairability, re-use or configuration. Each Protection shell would be fixated to the form of their initial design without the ability to grow or to be reconfigured.

Our proposal presents a radically alternate solution driven by numerous concerns of scalability, sustainability and maintenance within a framework that is to grow to accommodate 144 people.

A modular or discrete approach of constructing shell structures can also be adopted – offering its own set of advantages and constraints. Our framework builds upon this approach towards a novel aggregation methodology, aiming at the reduction of "building block" typologies as well as assembly through low precision. Embodied energy in the production of these "blocks" is therefore retained and can be easily adapted for future re-configurations and re-use.

The base "building block" module for the protection shell design within our framework is therefore centred around interlocking "tetrapod" based aggregation system.

3.1.1 Shell Design

Driven by material properties and characteristics of ISRU based structures, the shell has been designed through the principles of compression only structures. Form finding techniques and structural analysis of design iterations for the shell design was conducted by Format Engineers, ensuring feasibility and integrity throughout the design process. Tests, design iterations and simulations were used to inform and optimise the resultant parameters and geometries of the final shell structure design.

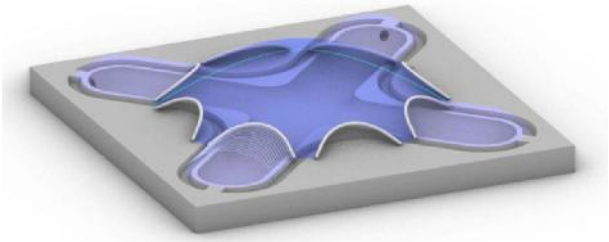

Figure 05. Ideal cross-section profile. Geometric Base for Structural Optimisation

Within the construction process, an inflatable formwork is required to maintain the optimal compression-only geometry. "Tetrapods" are then "launched" and placed consequentially on top of the formwork, slowly aggregating to create the necessary depth and layers for radiation protection. When interlocking layers and sufficient depth create stasis and equilibrium, the inflatable formwork is removed for future placement of habitable modules.

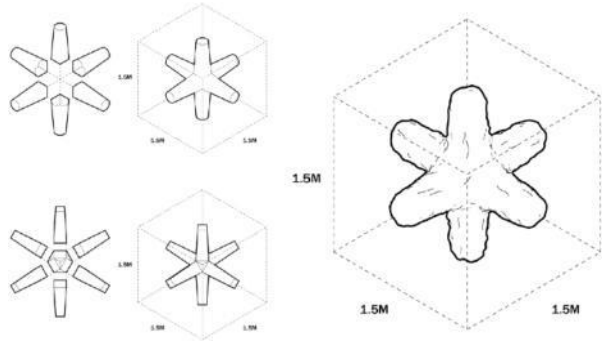

Figure 06. base Module "Tetrapod" Aggregate geometry breakdown.

The construction sequencing, assembly and aggregation of the tetrapods was simulated and investigated through a Houdini FX, a 3D procedural software for modelling, animation and visual effects. These tools have in-built physics engines and capabilities to accurately simulate the construction build up at a high fidelity and granular level.

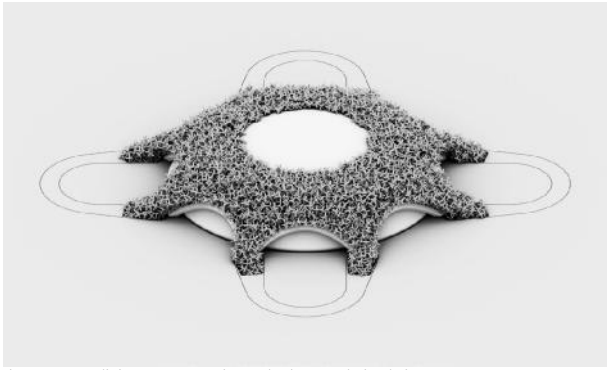

Figure 07. Houdini FX – Aggregation – Physics Based Simulation

3.2 Inflatable Design – Pressure Retaining Habitation Module

Our proposal reduces the reliance for high precision fabricated elements from earth to create pressure retaining volumes on the lunar surface.

The primary advantage of inflatables for the creation of habitats is their ability to generate enclosed spatial volumes with minimal surface materials. Furthermore, Inflatables generally comprise of foldable and collapsible flexible membranes which has immense space and volume saving benefits in an industry where the transportation of mass and volume often dictate economic and financial feasibility of missions. Structures can be compactly stowed and stored, which enables both the use of smaller launch vehicle fairings and the "ability to package multiple" structures [19]. Structurally, they can also constitute a set of "lightweight solutions with a relatively high structural efficiency" [20]. Due to the lack of a liveable atmosphere in extra-terrestrial environments, any habitats designed and deployed in space will already possess an imperative to provide an internal artificial pressurised environment – which is the structural basis of any inflatable.

The use of inflatables for space-based applications can be dated back to 1950s, ranging from conceptual designs of space stations to structural and MMOD testing of expandable habitats and airlocks. More recent success and applications can be seen through adoption in the Bigelow Expandable Activity Module (BEAM) on the

ISS on April 2016 [21] and further development for Sierra Nevada's "Large Inflatable Fabric Environment (LIFE)" modules. [22]

3.2.1 Structural Concept – Tensairity

To compensate for the "limited load bearing capacity" of inflatable elements, Luchsinger et.al (2004a) developed a structural system that combines "tension, air and integrity" in a similar manner to a tensegrity structural system. Its anatomy consists of two synergistic components; a "traditional building elements such as cables and struts" to take up external loading combined with a pressurised "air-inflated beam" that "pretensions the tension element and stabilizes the compression element against out-of-plane buckling". [20]

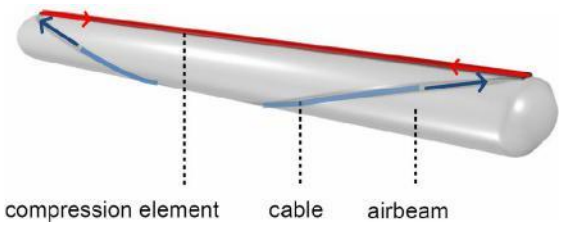

Figure 08. Tensairity Structural Diagram

Tensairity systems are inherently well-suited for space habitats, as their pressurised volumes already necessitate internal atmospheres. The additional inclusion of tension and compression elements in tensairity systems also provides structural redundancy mechanism, mitigating excess fabric loads from large spans and reducing the risk of catastrophic failure from minor pressure fluctuations.

To further investigate volume reduction strategies, the habitable module design builds upon Lars De Laet's research for a deployable tensairity structure. De Laet (2011)[20] explores and develops several mechanisms for a deployable tensairity structure, concluding with the fabrication, testing and evaluation of a prototype for "foldable truss system".

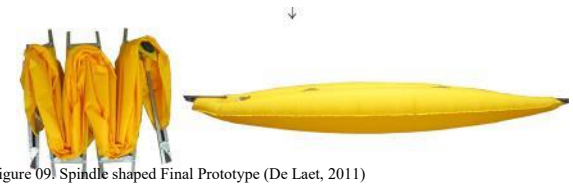

Figure 09. Spindle shaped Final Prototype (De Laet, 2011)

Internal cables within the hull also serves a dual purpose, acting as a vertical restrain on the hull that acts against the natural behaviour of inflatables to form a spherical volume. In doing so, the internal connection cable restricts the height and shape of the internal volume, which allows a greater efficiency for volumetric and programmatic planning of our habitable modules.

3.2.2 The Habitable Module Design:

These tensairity principles and mechanisms have become the basis of our design, which were further designed and developed to meet the provisional spatial and programmatic needs of each module.

We therefore propose a hybrid, - a pill shaped, "fusiform" geometry that combines both the benefits of rectangular volumes and hemi-spherical ends for efficient spatial and volumetric planning. The proposed global geometry is also conducive toward the desired, natural morphology of a pressure vessel - made up of a continuous exterior surface which does not possess distinct seams that are found in rectangular volumes (i.e., caused by enclosing walls).

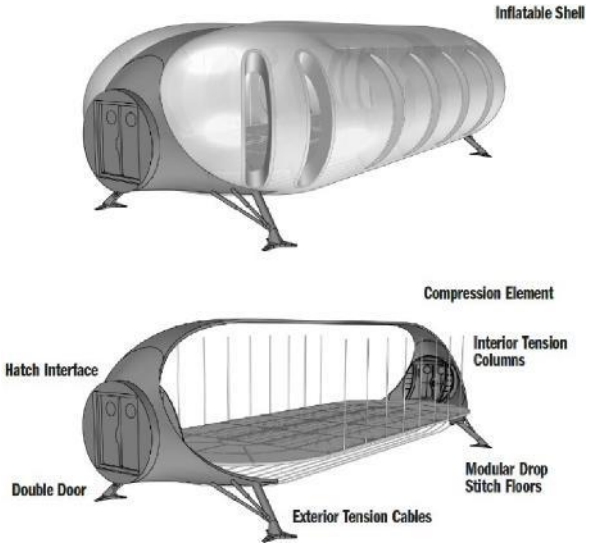

Figure 10. Proposed Inflatable Shell Elements - Habitable Module - Annotated

Each habitable module essentially acts as a tensairity air beam. The internal inflatable volume acts as the stabilizing hull for the system. A deployable compression element is supported by hard-shell elements on both ends of each module. The module's structural support, footing/ground connection, and access hatch are hosted within each hard-shell element. Hosting these kinetic components within a high-precision, prefabricated element decouples the risk of failure from potential interfaces with the inflatable membrane. As prescribed by the functional requirements, the footing of each habitat lifts each module off the ground, capable of making any necessary level/topography adjustments through its internal mechanism.

Tension forces within the tensairity system of our habitable module is distributed through a series of underside cables spanning between each hard-shell element. Stability of the module is also reinforced through a series of tension cable columns that ties the top compression element with the bottom cables.

Departing from Litteken's (2019)[19] review of the current state of the art for "Habitable Softgoods Inflatable

Design...", the materiality of our proposal draws from the inflatables technology development and testing conducted as part of NASA's TransHab Program. Our inflatable "shell" membrane design will also adopt a similar composition of material layers divided into five primary layers: Liner Layer, Bladder Layer, Restraint Layer, Micrometeoroid/Orbital Debris (MMOD) Protection Layer, Thermal Protection Layer and the Atomic Oxygen (AO) Protection Layer.

Windows and openings are vital architectural elements in both terrestrial and extraterrestrial habitats, serving not only operational needs but also supporting crew well-being. On the ISS, the Cupola provides psychological benefits which help offer perspective, grounding, and opportunities for activities such as photography, whilst also enabling external observation. In lunar habitat design, windows can facilitate visibility for extravehicular operations and foster visual connectivity between modules. To meet space-specific performance criteria, material selection becomes critical: transparent, flexible polymers integrated into inflatable membranes represent a promising solution. Early studies on radiation-resistant transparent polymers (Giori & Yamauchi, 1977)[23] suggest viable pathways for development, with terrestrial analogues such as ETFE already demonstrating architectural applications on Earth.

3.2.3 The Habitable Module Typologies

To accommodate the programmatic requirements and fit-out scenarios needed to sustain an expanding base, we are proposing several module typologies that vary in size and function. Each typology has been designed to accommodate an upper and lower limit of occupants and potential activities.

The Habitable Module is the primary inflatable volumetric shell, capable of accommodating most programmatic functions within the lunar outpost. The hemispherical ends of each pill has a radius of 3.75m with a floor to ceiling internal clearance of 3m. A provision of 500mm has been included to account for the layer composition of the membrane.

Two typologies of the Habitable Module exist within the scalable system, varying in their longitudinal dimension. The 4-Grid Pod module has an internal extrusion length of 8m whilst a 7-Grid Pod has an internal extrusion length of 14m. The smaller variation accommodates for more private/intimate configuration of spaces, whilst the larger module accommodates a greater number of occupants which can enable the aggregation of programmatic functions.

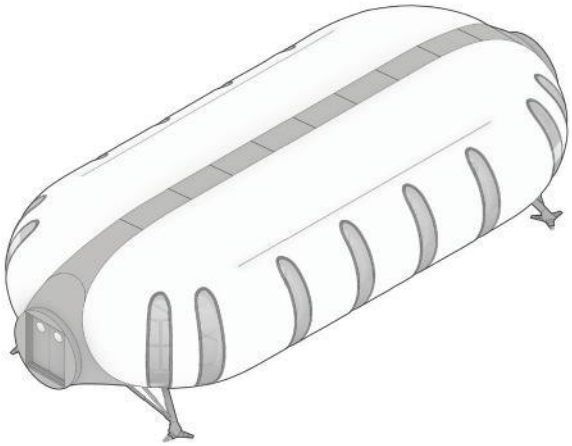

Figure 11. Proposed Inflatable Habitable Module - 4 Bay - Axonometric

Connectivity between the various module types is enabled through the Connector Module. The module has been designed to have minimal width whilst accommodating for bi-directional circulation at any given time. This optimisation of form also acts as a space saving mechanism during launch and transfers. Additional storage functions can be incorporated within each connector volume, occupying excess space that is created from the billowing of the internal pressurised volume.

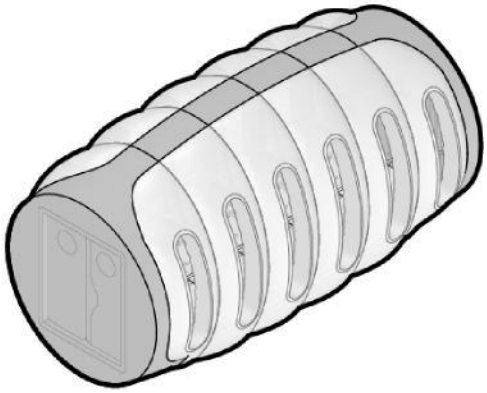

Figure 12. Proposed Connector Module - Axonometric

The third typology of inflatable volumes within the framework exist as an anomaly both in form as well as intended use. These volumes span over one entire grid cell, which does not allow for the attachment of adjacent habitable volumes. Large multi-Story volumes cater for a total centralisation of a programmatic function, such as a greenhouse or multipurpose gathering/ceremonial spaces. It also provides an alternative, grandiose internal spatial quality which contrasts from the monotonous repetition experienced within the primary habitable volumes.

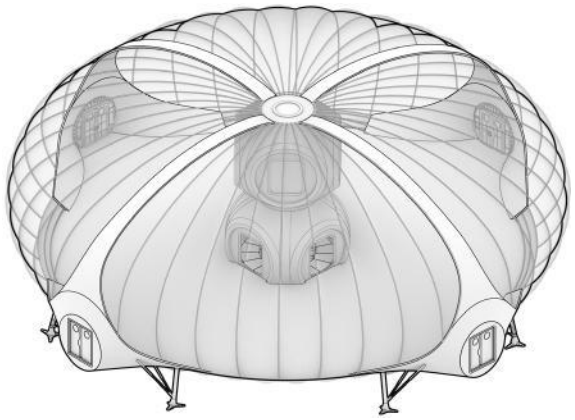

Figure 13. Proposed Greenhouse Module - Axonometric

3.3 Interior Fitout

Figure 14. Proposed Greenhouse Module – Axonometric

Modular design principles are also adopted in the framework's interior fitout strategy. The flexibility and adaptability afforded by the system is ideal to respond to the ever-changing needs of an expanding lunar settlement.

The International Space Station (ISS) was designed based on modules to allow users to use either "central facilities" for conducting their research or building bespoke equipment. The investigation-specific equipment is typically allocated a sub-portion of an International Standard Payload Rack (ISPR) based on a unit of space Mid-Deck Locker Equivalent (MLE). MLE has dimensions roughly based on the Space Shuttle's Mid-Deck Storage Locker (MDL) with an internal volume of 0.06m3 (2.0 ft3) and dimensions 43.2cm (17in) width x 50.8cm (20in) depth x 25.4cm (10in) height. [24]

In our proposal, the modularity of the interiors is based on the grid of units 50cm width x 75cm depth x 30cm height (Figure 15), which was determined to 1) fit MLE in order to extend the functionality of the equipment build for experiments on the ISS; 2) to accommodate furniture and functional spaces of everyday life like working areas, tables, beds,

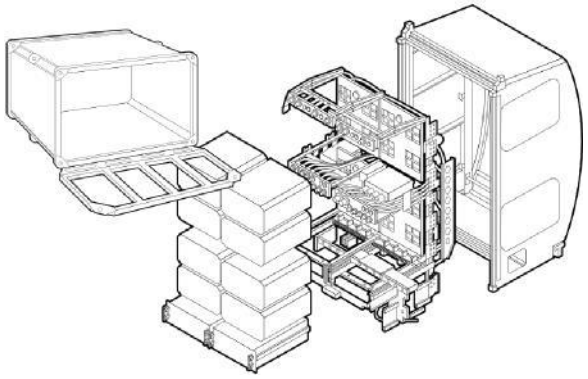

Figure 15. Technical diagram of ISPR. Standard Payload Racks Research payload within the U.S., European, and Japanese laboratories typically are housed in a standard rack, such as the International Standard Payload Rack (ISPR). Image: NASA

lounge furniture; 3) to fit technical partitions between the spaces. This formulates the base grid undelay for a given module.

Future adaptations and reconfigurations within a given habitable module are achieved through several design and spatial organisational principles. Structural elements within the central area of each pill are placed on the perimeter and there are no fixed partitions, thus ensuring maximum economic clear span. Any fitout elements within the hemispherical ends revolve around offsets of inherent the module's arches and radius, primarily accommodating loose furniture and fittings.

Internal partitions are to be demountable and reusable. To enable flexibility of the spaces, the internal partitions are modular, following inherent grid underlay.

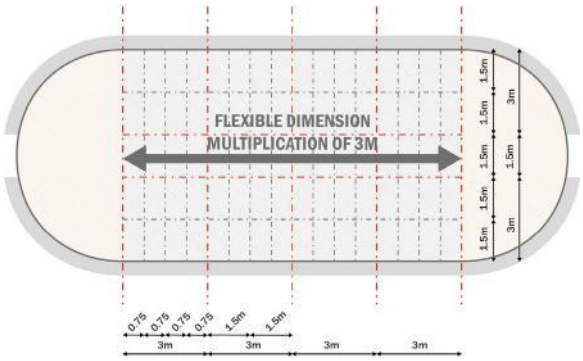

Figure 16. Floorplan, Organising Grid of 4-bay Habitable Module

3.3.1 Circulation Principles

A flexible floor plan allows various circulation possibilities depending on spatial and functional needs.

A minimum clear span of 1.5m within the grid underlay is always designated as circulation route.

As the location of the exits is fixed due to the standardisation of the Habitable Module and its hatches, any inhabitant must have access to both exits in an emergency.

Despite this constraint, Figure 17 shows various types of circulation arrangement, limited by the position of the

exits. The linear circulation path would be the shortest route between the exits, resulting in an equal division of the total width of the inflatable. As a result, the equal segments can easily be subdivided to make room for smaller rooms such as private bedrooms. A peripheral corridor is introduced on one side of the Habitable Module to accommodate programs requiring larger spatial enclosures, i.e., sports grounds and large laboratories. The oblique circulation allows for a more centralised space, allowing the placement of a greenhouse or a secondary corridor as required in medical facilities.

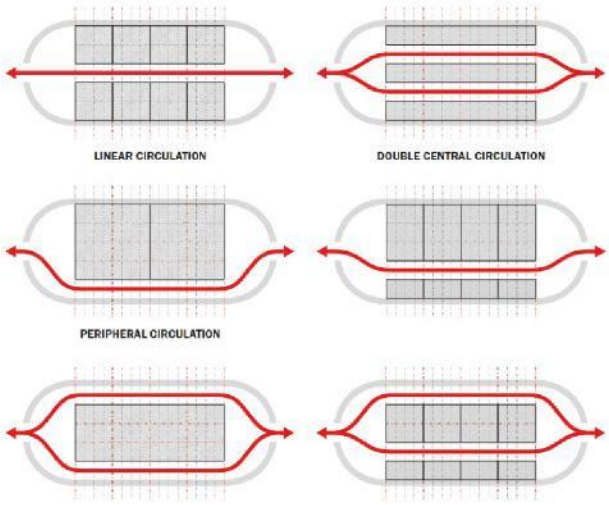

Figure 17. Types of circulation arrangements in the Habitable Module.

3.3.2 Spatial Partitions

For the integrity, ease of transportation and use of minimum materials, the system of the internal spatial partitioning: floor, walls and ceiling within The Habitable Module is made of drop-stitch panels (also known as spacer fabrics), which are comprised of 3-D woven pre-forms, stiffen and reinforced when air-inflated.

3.3.2.1 Floors

To maximise the usable area of The Habitable Modules, the floor is raised 700mm from the lowest point of the internal volume. Underfloor space is designated for the distribution of services and life support systems.
The floor panels are modular and readily removable to allow quick access to the underfloor services. They sit on the T-shape beams following the module grid. The panels in the semicircular area follow the offset of 3m from the radius of the floorplan perimeter. Access ports are also embedded within each floor panel, integrating service terminals for hot/cold water, water recycling, electricity; vents; handles to elevate the panel; anchoring system for Base Unit Racks. The standard panel size is 3000mm x 1500mm x 100mm, which can host 12 Base Unit Racks.

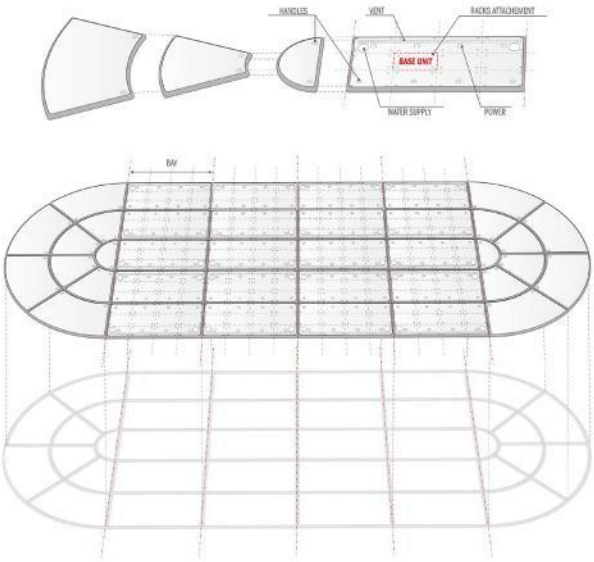

Figure 18. Diagram of flooring system.

3.3.2.2 Walls

Walls provide inhabitants with acoustic and visual privacy. Similar to the floor system, the wall elements are modular, made up of drop-stitch panels, which have been sized based on the aggregation of the base grid cells: 50mm x 1500mm x 1500 mm. The wall panels contain an integrated fixing system allowing customisation of the partitions and reconfigurability of the space (see Figure 156). The fixing system size is also based on the Base Unit, consisting of four anchors per Base Unit. Each standard wall panel can fit up to 15 Base Units.

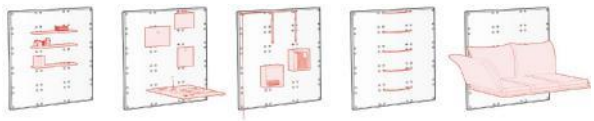

Figure 18. Diagram of flexible wall system and examples of furniture arrangements.

3.3.2.3 Ceilings

To create a homogenous space and maximise volume, the ceiling is embedded in the surface of the Habitable Module. It consists of modules sized according to the grid, which can be extended lengthwise. Channels integrated into the surface of the inflatables allow discrete distribution of services and anchors without occupying the internal volume. These services include fire detection devices, sprinkles, mounting anchors for cables, walls, and lighting.

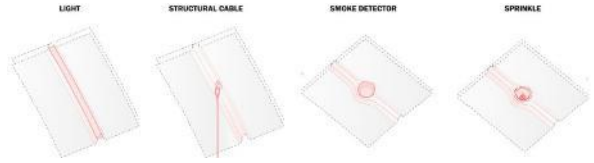

Figure 19. Diagram of flexible ceiling system and examples of channels uses.

3.3.3 Spatial Fitout Scenarios

To demonstrate the flexibility and capability of the proposed interior fitout system, we have generated several spatial fitout scenarios that reflects the spatial requirements identified in early programmatic brief investigations. The fitout system is tested within the various Habitable module typologies, showcasing how it can cater and function within an expanding base.

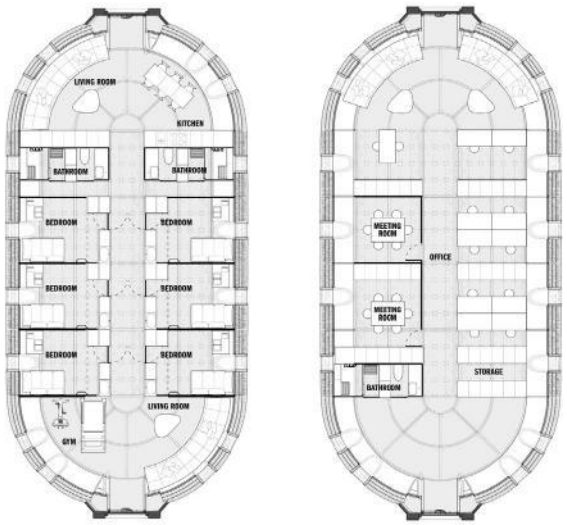

Figure 20. Example spatial fitout scenarios within the habitable module, left showing a scenario as private quarters and right showing fitout scenario for an office.

3.2 Expressways & Towers

As described in earlier section "2.3.4 Circulation Logic" Expressways are effective methods of travel for large distances between neighbourhoods and/or clusters. Cantilevering across several towers, they are outside the radiation protection zone of the framework as the habitants are expected to use these modules for a very short amount of time (Figure 161). Expressways are positioned strategically across the framework to achieve as the shorter alternative to most common routes taken at the ground or lower levels.

Each tower is made up of a 3-storey stack of high precision prefabricated "intersection modules", positioned at the grid intersections. This enables access to 3 different circulation layers within the system. The lowest level of this module acts as the primary vertical access to the tower, whilst maintaining connectivity across the network of habitable modules within the lower levels. The second module provides access to the "ground" level, which integrates suit-ports and hatches for rover access. This is the primary mode of access to the external lunar surface. Lastly the upper-ground connection module enable access to the expressways that act as the spine of the circulation system within the emergent masterplan.

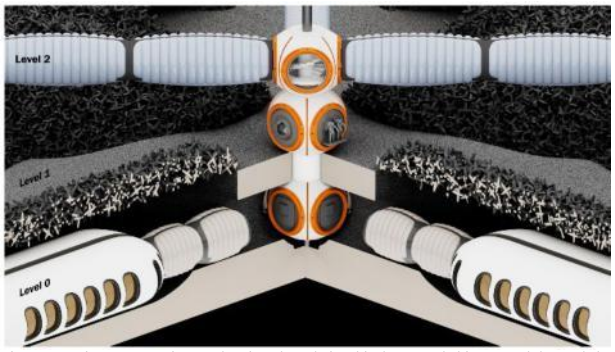

Figure 21. Pie axonometric cut showing the relationship between habitats, modules and the circulation.

At the top of each vertical tower sits an array of solar sails for decentralised energy distribution. Due to the unfolding nature of the array, they are named as Solar Sails. They offer a great degree of compactness in their initial payload to the Moon, afforded by its own internal folding mechanisms into cylindrical modules / towers. These modules are then unfolded into open sails from which array of solar panels unroll (Figure 164). In the case of an extreme radiation event the sails can fold again to minimise damage. Each sail is responsible for feeding energy into the 4 adjacent clusters of habitats. This way the overall energy distribution becomes decentralised and in the case of a sail malfunctioning, a given cluster can depend on any of the other 3 sails that is adjacent to it. As we are situated on the south pole of the moon, the sun path revolves around the base. Maximising solar gain for the solar sails will require the ability to synchronise rotation to the predominant sun direction. (Figure 22).

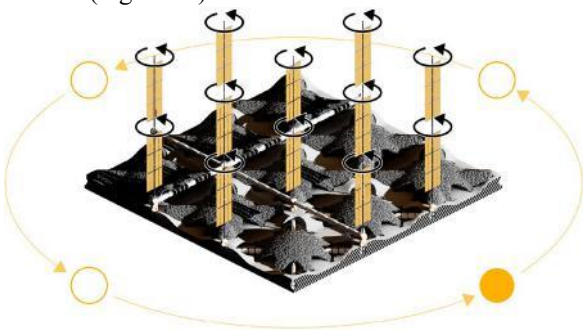

Figure 22. Moon's Revolution Around the Earth Changes the Sun's Reach Angle to the Moon in a Full Cycle of 27.3 Days

4. Supporting Infrastructure and Life Support Systems

Key life support assemblies, sub-assemblies, and infrastructural systems include subsystems addressing:

1. Power Supply & Energy Storage
2. Environmental Control and Life Support System
3. Communication and Navigation Systems
4. ISRU Avenues for Space industrialisation
5. Emergency Planning and Scenarios

The systems engineering, capacity and scenario modelling of these systems were conducted as part of our collaboration with Cranfield University, distilling an indicative set of design parameters to include in our overall proposal. This section aims to address the spatial implications that are associated with the provision of these requirements. A schematic level investigation on the integration of these systems within the various components of our design was conducted, which is represented as the maps and diagram below:

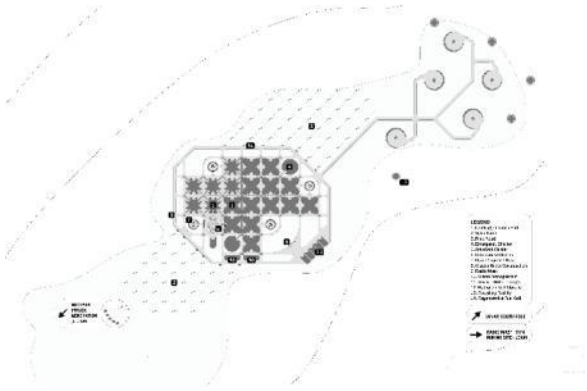

Figure 23. Schematic Design - Supporting Infrastructure Masterplan at 1:2000

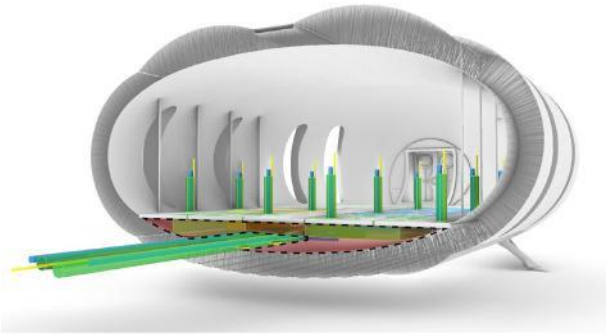

Figure 24. Schematic Design - Closed Loop Life Support Systems for Habitable Modules – Habitat underbelly for ECLSS.

Situated within the underbelly of each habitable module are the various sub-assemblies and systems required for life support. This is similar to raised access floor systems for buildings on Earth. Access points through the floor panels are strategically set out according to the grid subdivision to enable flexibility.

The central conduit is the primary distribution mechanism to disseminate excess across the greater infrastructure network. Each module however needs to be able to function as a closed loop system.

5. Growth Scenarios

The proposed framework has been envisioned as a system of nested "kit-of-parts," designed to facilitate a multitude of scenarios in terms of growth and expansion. Our design intent deliberately avoids prescribing rigid configurations of elements and components for any specific growth scenario. Instead, we prioritize the flexibility and adaptability of spaces, recognizing that the future demands of lunar colonies cannot be fully anticipated within a 20/30-year timeframe.

5.1 An evolving Identity

The framework should also account for the element of time in the lifespan of a lunar outpost. As the base gradually accommodates more inhabitants and expands its architectural and life support infrastructure, it will experience a transformation in its core identity and purpose. Consequently, design solutions need to be examined in tandem with the different growth phases, guaranteeing their feasibility and effectiveness throughout the projected lifespan. Initially, we envision five primary phases for the Lunar Base:

Phase 1 – Lunar Research Outpost

The first iteration of the habitat shall serve a skeleton crew of 6 to establish a permanent research outpost on the Moon. The facility shall enable the exploration and study of the Moon.

Phase 2 - Extended Lunar Research Outpost

Additional modules will be implemented as part of the core research outpost – enabling support for 12 crew members to comfortably live and work within the designated duration of a mission.

Phase 3 – Lunar Technology Proving Ground With a crew of 36 inhabitants, the third iteration shall incorporate spatial typologies oriented towards community interactions and building. Larger typologies such as a sports/multipurpose hall should be included to allow larger events to take place within the habitat. The base shall also evolve to allow industry to set up permanent access to experiments and prototyping – a proving ground for new technologies.

Phase 4 – Lunar Resource and Manufacturing Centre

Phase 4 of the lunar habitat will evolve to support/sustain prolonged large-scale operations in the collection and processing of lunar resources. With a crew of 72, the habitat should service a larger, more stable influx of space tourists – potentially including spaces tailored for hospitality and entertainment. Habitat functions must now be broken into specialised teams to cater for the various needs/functions of the habitat. Here we start to see emergence of specialised roles and the need to establish a hierarchy in organisational structures.

Phase 5 – Lunar Village Spaceport – Docking Station for Deep Space Exploration

The final iteration – a Lunar Village Spaceport will become the permanent docking/port/harbour for deep space exploration. The habitat shall have infrastructure and restocking/production facilities to enable/prepare for longer duration/deep space missions. In addition, the habitat should also have dedicated infrastructure and service crews for space tourism activities. The base will support a permanent crew of 144, excluding the influx of tourists. Smaller modules clusters should be able to serve smaller community congregations or emergent "neighbourhoods" within the settlement. Reconfiguration of the settlement may be required to consolidate functions and unlocking of efficiencies. The introduction of circulation hierarchies based on footfall and frequency of travel must also be defined, enabling distinction between more "private" areas of the base with more "public" clusters.

Additionally, to exemplify the inherent design merit, feasibility, and resolution of the proposed scalable framework, three potential growth scenarios for an expanding lunar base were developed. Each scenario embodies distinct overarching identities, showcasing the evolutionary stages of the lunar base as it transitions from a modest habitat for six individuals to a thriving community accommodating 144 inhabitants.

The three key scenarios included:

Scenario 1: Tourism-Driven Expansion

In the initial scenario, the growth and expansion of the lunar base have been meticulously optimized to accommodate a maximum influx of tourists and support various associated tourism activities. Modules dedicated to accommodation, such as hotels, are strategically clustered together, while adjacent modules cater to leisure activities like sports, restaurants, and spa facilities. A critical consideration in this configuration is

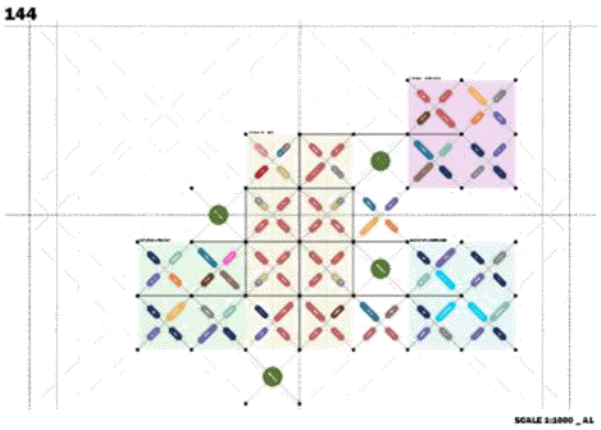

Figure 25. Lunar Base Layout Scenario - Tourism-driven expansion for 144 inhabitants.

the inclusion of service personnel within the base, requiring specific provisions for their well-being and spatial requirements. To ensure controlled access and avoid unwanted interference, agencies and traditional astronauts are situated in separate or adjacent clusters.

Scenario 2: Commercial-Driven Expansion

When envisioning a commercial-driven expansion, the layout of habitable modules is carefully designed to promote collaboration and accommodate a diverse range of businesses and activities. Given the anticipation of emerging industries and the evolving lunar environment, these modules are arranged in a manner that fosters dynamic interactions. In this scenario, accommodation is centralized along a central spine or neighbourhood, while surrounding clusters form distinct commercial neighbourhoods. Each neighbourhood possesses a unique identity based on its primary focus, such as manufacturing, co-working spaces, or isolated private entities.

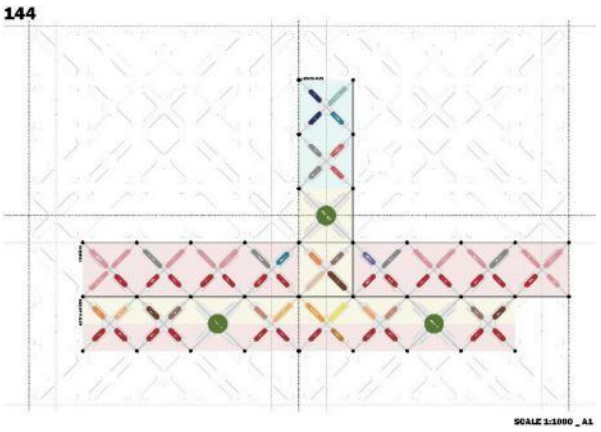

Figure 26. Lunar Base Layout Scenario - Commercial-driven expansion for 144 inhabitants.

Scenario 3: Research and Education -Driven Expansion

The final explored scenario focuses on the growth and expansion of the lunar base as a dedicated research and academic campus. Drawing inspiration from renowned terrestrial university campuses like MIT and Cambridge,

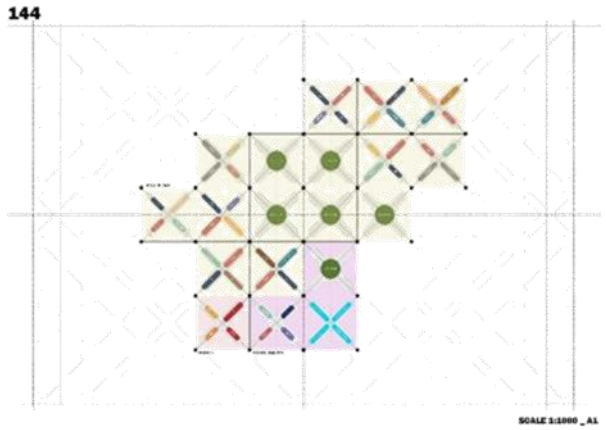

Figure 27. Lunar Base Layout Scenario -Research/Academia-driven expansion for 144 inhabitants.

existing master planning principles were carefully analysed to extract their overarching configuration and design principles.

6. Discussion

6.1 Peer Review and Design Validation

Preliminary technical input and subject matter expertise within the relevant engineering domains were provided by Cranfield University. The team provided the necessary initial literature review and background calculations that help inform the design approaches within the framework.

At key milestones of the design development, our team also held a number of open symposiums bringing together industry experts and key organisational representatives to critique our proposal and strategies. The first symposium was held on August 26th, 2021, which was attended by:

- **Aaron Parkhurst** – *Lecturer in Biosocial and Medical Anthropology* at University College London
- **David Cullen** – *Professor of Astrobiology & Space Biotechnology* at Cranfield University
- **David Jeevendrampillai** – *Honorary Research Fellow of Anthropology* at University College London
- **Beth Healy** – *British Medical Doctor* – Experienced a year in Concordia Station
- Undisclosed Architect – *Embassy Designer* at Foreign & Commonwealth Office
- **John Eager** – Ex-*Head of Polar Operations* at British Antarctic Survey
- **Brady Peters** – *Assistant Professor* at John H. Daniels School of Architecture – University of Toronto
- **Vittorio Netti** – *Lecturer for Space Technology* at SICSA/University of Houston

Figure 28. Roundtable Discussions conducted during Symposium 01

Discussions were centred around themes of population thresholds, programmatic functions, spatial and amenity provisions and organisational structures for the lunar base – drawing upon lived experience and expertise of attendees who have previously experienced living in extreme conditions. Anecdotes were also shared to challenge initial assumptions around social dynamics, behaviour and the use of space within the differing habitats.

A second symposium was held on May 25th, 2023 – with a primary objective to review and critique a more developed version of the framework, ensuring that no critical elements were overlooked. The symposium was attended by:

- **Aaron Parkhurst** – *Lecturer in Biosocial and Medical Anthropology* at University College London
- **David Cullen** – *Professor of Astrobiology & Space Biotechnology* at Cranfield University
- **David Jeevendrampillai** – *Honorary Research Fellow of Anthropology* at University College London
- **Aled Deakin Roberts** – *Founder and CTO of DeakinBio, Doctor of Philosophy* – Manchester University
- **Kate Jeffrey** – *Professor of Behavioural Neuroscience* at University College London
- **John Eager** – Ex-*Head of Polar Operations* at British Antarctic Survey
- **Lars De Laet** – *Assistant Professor, Department of Architectural Engineering* at Vrije Universiteit Brussel
- **James Solly**– *Director* at Format Engineers
- **Anna Talvi** – *Microgravity wear PhD Candidate, Director* at Microgravity Technologies, University College London
- **Malica Schmidt** – *PhD Candidate, Centre for Nature Inspired Engineering, Chemical Engineering, Guest Researcher - Aerospace Microbiology Research Group - Institute of Aerospace Medicine* at University College London, German Aerospace Centre (DLR)
- **David A. Green**– *Senior Lecturer of Human and Aerospace Physiology, Doctor of Philosophy* at European Space Agency - European Astronaut Center (EAC)
- **Hanna Lakk**– *Researcher - Space Architecture and Infrastructure* at European Space Agency, ESTEC

The symposium was structured around specific themes and aspects of the proposed framework:

- Activity Aim, Programmatic Brief, Site and Environmental Conditions, and Urban Scale Masterplan Principles for Growth.
- Initial Site Works, Grid Development, Systems Engineering, Infrastructure for Life Support Systems.
- Design of the Habitable Modules - Structural Principles, Module Typologies, and Internal Spatial Planning.
- Interior Design Fit-out Components - Kit of Parts, Functional Fit-out Scenarios based on Programmatic Brief, Masterplan Configuration - Growth Scenario.

- Design of the Protection Shell Element and Overall Construction Sequence.
- Design of Circulation Components such as vertical owers and expressways.

Figure 29. Hassell Team presenting the Urban Scale Masterplan principles and Habitable Module Design. during Symposium 02

Each section had a corresponding banner showcasing the design development, drawings, diagrams, and visualizations, which became the basis for Detailed discussions, in-depth analysis and examination of the concepts and design elements. Feedback and suggestions were later incorporated into the final framework proposal.

Our framework proposal aimed at achieving TRL (Technology Readiness Level) 2. Future iterations of the proposal would need to incorporate a greater integration and scope for a wider technical/engineering team to support feasibility and performance.

7. Conclusions

The proposal sets to design a scalable design framework for permanent lunar habitation, integrating environmental protection, construction methodologies, life-support systems, and mission architecture within a human-centric paradigm that prioritises flexibility, reconfigurability, and long-term well-being. The framework aligns spatial design with self-sustaining infrastructural systems, enabling not only habitation but also lunar industrialisation through ISRU and the support of future exploration missions to Mars and beyond.

At its core, the framework establishes a network of modular “kit-of-parts” systems, allowing settlements to expand and adapt dynamically rather than conforming to a fixed base arrangement. Conceived as a living atlas of architectural and infrastructural elements, it can be continuously updated with new discoveries and technologies, ensuring future lunar communities can evolve their built environment to meet changing programmatic, physiological, and sociocultural needs while minimising resource expenditure.

Figure 30. Aerial View of Proposed Lunar Habitat Framework, (Hassell, 2023)

8. References

[1] Howe, A. and Sherwood, B., 2009. Out Of This World. Reston, VA: American Institute of Aeronautics and Astronautics, pp.180-181.

[2] Benaroya, H, 2002, “An Overview of Lunar Base Structures: Past and Future,” AIAA-Paper 6113, Oct

[3] Inocente,D*, Koop, C, Petrov,G, Hoffman,J, Sumini,V , Makaya,A, Arnhof, M, Lakk, H, Lamaze,B, Cowley,A, Binns,D, Landgra,M, Messina,P, Haigneré,C, 2019, ”Master Planning and Space Architecture for a Moon Village”, 70th International Astronautical Congress (IAC), Washington, DC 21-25 October 2019.

[4] Harper, L. D, and Connell, K. M. (1990), “The Lunar Outpost: Testbed for Colonization and Extraterrestrial Evolution,” AIAA Paper 90-3850 Sept.

[5] Vogler, A., 2014. Moon Capital: Life on the Moon 100 Years After Apollo. Architectural Design, 84(6), pp.30-35.

[6] Smith, A, (1993), “Mechanics of Materials in Lunar Base Design”, Applied Mechanics Reviews, edited by H, Benaroya, Vol 46, No.3, 1993, pp 268-271

[7] ArchDaily. 2020. Indian Research Base / Bof Architekten. [online] Available at: <https://www.archdaily.com/404279/indian-research-base-bof-architekten?ad_medium=gallery> [Accessed 15 June 2020].

[8] Broughton,H*, Howe, A. and Sherwood, B., 2009. Out Of This World. Reston, VA: American Institute of Aeronautics and Astronautics, pp.363-370

[9] NASA. *NASA-STD-3001, Volume 1: Crew Health, Revision C*. Washington, DC: National Aeronautics and Space Administration, September 15, 2023. Accessed [16.11.2022].https://standards.nasa.gov/sites/default/files/standards/NASA/C//nasa-std-3001-vol-1-rev-c-signature.pdf

[10] NASA. *Human Integration Design Handbook, Revision 1*. Washington, DC: National Aeronautics and Space Administration, 2015. Accessed [16.11.2022]. https://www.nasa.gov/wp-content/uploads/2015/03/human_integration_design_handbook_revision_1.pdf

[11] ECSS. *ECSS-E-ST-10-11C: Space Engineering — Human Factors Engineering*. Noordwijk, The Netherlands: European Cooperation for Space Standardization, July 31, 2008. Accessed [Month Day, Year]. https://ecss.nl/wp-content/uploads/standards/ecss-e/ECSS-E-ST-10-11C31July2008.pdf

[12] Eckart, P., 1999. *The Lunar Base Handbook: An Introduction to Lunar Base Design, Development, and Operations*. New York: McGraw-Hill. ISBN 0072401710.

Or 2006 2nd ed.: Eckart, P., 2006. *The Lunar Base Handbook*, 2nd ed., McGraw-Hill, New York.

[13] Gläser, P., Scholten, F., De Rosa, D., Marco Figuera, R., Oberst, J., Mazarico, E., Neumann, G. A., & Robinson, M. S. (2014). Illumination conditions at the lunar south pole using high resolution digital terrain models from lola. Icarus, 243, 78–90. https://doi.org/10.1016/j.icarus.2014.08.013

[14] Gläser, P., Oberst, J., Neumann, G. A., Mazarico, E. and Robinson, M. (2018). Illumination conditions at the lunar poles: Implications for future exploration. *Planetary and Space Science*, 162, pp. 200–208. DOI: 10.1016/j.pss.2017.07.018.

[15] Gawronska, A.J., Barrett, N., Boazman, S.J., Gilmour, C.M., Halim, S.H., Harish, McCanaan, K., Satyakumar, A.V., Shah, J., Meyer, H.M. and Kring, D.A., 2020. Geologic context and potential EVA targets at the lunar south pole. *Advances in Space Research*, 66(5), pp.1247-1272.

[16] Li, S., Lucey, P. G., Milliken, R. E., Hayne, P. O., Fisher, E., Williams, J. P., Hurley, D. M., & Elphic, R. C. (2018). Direct evidence of surface exposed water ice in the lunar polar regions. Proceedings of the National Academy of Sciences of the United States of America, 115(36), 8907–8912. https://doi.org/10.1073/pnas.1802345115

[17] Mazarico, E., Neumann, G.A., Smith, D.E., Zuber, M.T. and Torrence, M.H. (2011). Illumination conditions of the lunar polar regions using LOLA topography. *Icarus*, 211(2), pp. 1066–1081. DOI: 10.1016/j.icarus.2010.10.021.

[18] R.I.M. Dunbar, 1992, "Neocortex size as a constraint on group size in primates", Journal of Human Evolution, Volume 22, Issue 6, Pages 469-493, ISSN 0047-2484, https://doi.org/10.1016/0047-2484(92)90081-J. (https://www.sciencedirect.com/science/article/pii/0047248492900081J)

[19] Valle, Gerard & Litteken, Douglas & Jones, Thomas. (2019). Review of Habitable Softgoods Inflatable Design, Analysis, Testing, and Potential Space Applications. 10.2514/6.2019-1018.

[20] Laet, L. D, 2011, 'Deployable Tensairity Structures', PhD Thesis, Vrije Universiteit Brussel, Brussels

[21] Bigelow Expandable Activity Module (BEAM). Bigelow Aerospace. NASA. https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Investigation.html?#id=1579, [Accessed 09 March 2022]

[22] Sierra Space. (n.d.). LIFETM Habitat | Inflatable Space Station Design. [online] Available at: https://www.sierraspace.com/space-destinations/life-space-habitat/. [Accessed 09 March 2022]

[23] C. Giori, T. Yamauchi (1977) " Space radiation resistant transparent polymeric materials" - NASA, Science and Technical Information Office.

[24] NASA (2000). ISS User's Guide-Release 2.0. pp. 19- 22. [PDF] Available at: https://www.nasa.gov/sites/default/files/atoms/files/o49797075.pdf (Accessed 16.11.2022).

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Design of a scalable framework for lunar habitats

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