D.N.A. - Designing New Abodes on the Moon: Pioneering the First Permanent Lunar Station

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ABSTRACT

The realization of the first permanent lunar settlement is going to mark a historic moment that will reverberate throughout history. As we embark on this endeavor it becomes clear that the design of an outpost on the Moon must transcend mere functionality and instead be conceived as an iconic work of art, paying homage to humanity's unwavering quest for the unknown.

Grounded in these principles, this research is centered around the design of an architecture, drawing inspiration from the most fundamental essence of life itself: human DNA. Within its complexity lie the secrets of our existence and the capacity for growth and adaptation. Drawing a parallel with the first human settlements that emerged within caves, the structure embeds itself entirely within a lava tube to leverage the natural protection of lunar soil. Symbolically mirroring the intertwined double helix of our genetic code, the architectural form of the station emerges.

INTRODUCTION

Designing a habitat in space presents several technical challenges due to the inhospitable environment which cannot sustain human life. A space architecture project should address these obstacles and provide safety against hazards such as low temperatures, low pressure, and radiation (Häuplik-Meusburger 2016). With the D.N.A. project, the aim is to address these technical challenges while also placing particular emphasis on the importance of a strong and meaningful concept, enriching the project with symbolic connotations that transcend the technical aspects of space architecture. This paper focuses on key elements, including site selection, the concept of operations, architectural and interior design, and computational design. The goal of the research is to develop a human settlement on the Moon that goes beyond mere technicality and embraces the human element, symbolizing humanity's need to explore the unknown while leaving a cultural and symbolic legacy.

SITE SELECTION: LACUS MORTIS PIT

Location characteristics. The selected location for this project is Lacus Mortis pit and its accompanying lava tube, situated at 44.96°N, 25.61°E (NASA/GSFC/Arizona State University 2023) within Lacus Mortis (Giguere 2022). These pits are a result of collapses and essentially function as a natural incline, providing easy access to the subterranean tunnels. Lava tubes serve as optimal sites for lunar settlements due to various advantages. The lunar environment is subject to high radiation, temperature fluctuations, and micrometeoroid bombardments, all of which can have profound effects on human health and on the structural integrity of habitats. However, research has demonstrated that lava tubes provide shielding against radiation (De Angelis 2002). Moreover, large temperature variations are reduced due to the sealing of the tunnels, which enhances heat conservation (Hong 2015). This location is extremely interesting to explore from a planning point of view, as it could be the ideal site for the first lunar settlement, which could grow over time due to the large size of the tunnel. In addition, having a settlement within it would facilitate the mapping and study of the lunar subsurface, promoting scientific advancement.

Morphology. Lacus Mortis Pit exhibits an elliptical shape with its major axis oriented in an east-west direction and a depth reaching up to about 100 meters. The west wall of the pit is almost vertical, while the east wall slopes gradually from the rim down to the bowl-shaped floor. This morphology creates a kind of ramp, potentially facilitating access to the interior of the pit. The western end of the pit has indentation that could correspond to the entrance of the cave (Wagner & Robinson, 2022). The lava tube that is assumed to be accessible from the base of Lacus Mortis pit is roughly cylindrical in shape, with flattened dimensions reaching 90 meters wide and 70 meters high. As one enters the lava tube, it gradually narrows, with dimensions of about 60 meters wide and 45 meters high after a descent of 500 meters. The internal slope of the cavern is also relatively slight, making it suitable for uses without excessive ground handling.

CONCEPT OF OPERATIONS

Plan of the mission. The planned settlement features a modular system, with prefabricated modules built on Earth, packed, and then shipped to the Moon. The mission will involve several launches from Earth, each of which will bring specific equipment to the lunar surface. The first launch will include shipping the equipment necessary for constructing an infrastructure, comprising landing pads, roads, and energy production facilities. This initial phase will be crucial as it prepares the site for subsequent steps. During this part of the mission, temporary accommodation for the astronauts will be required, which could be rovers suitable for their living quarters. Other launches will follow to transport the modules and elevators. Once the modules arrive, they will be transported inside the lunar tunnel, connected to each other, and secured to the tunnel using stretched cables.

Master plan. The chosen site, Lacus Mortis pit, and its associated lava tube, offers invaluable advantages, including natural inclines and natural radiation shielding. These advantages play a significant role in shaping the design solution. The master plan (see Figure 1) consists of different zones, each designated for specific functions: observation zones, enabling residents to visually explore outer space; energy production areas, crucial for sustainable lunar operations; in-situ resource production zones, vital for on-site construction; landing zones, facilitating arrivals and departures; and habitation zones, providing lunar pioneers with a safe and comfortable home.

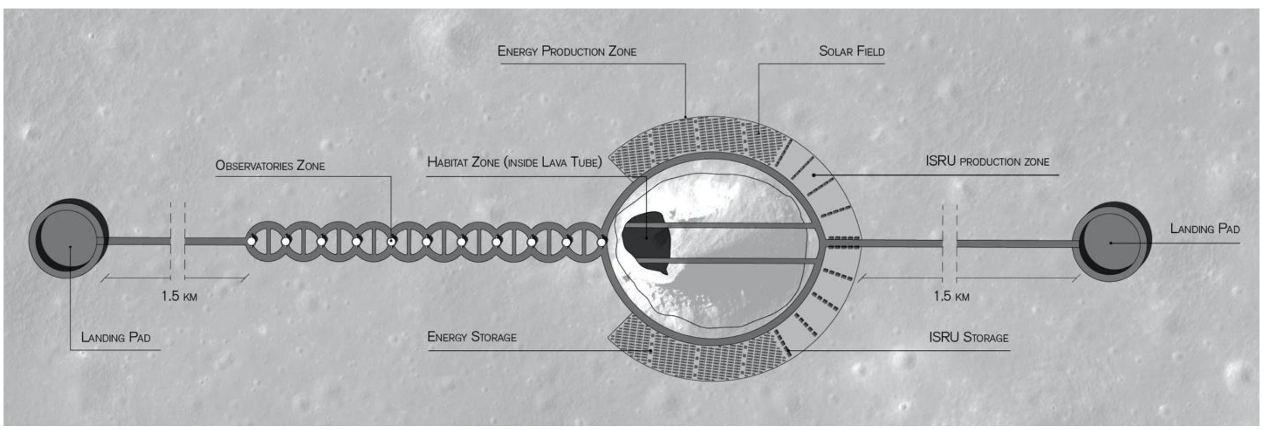

Figure 1. Master plan.

The lunar habitat is designed with modularity as a core concept, featuring prefabricated modules deployed on-site. The mission progresses in phases, with the initial phase focusing on on-site preparation and infrastructure. The master plan consists of distinct and autonomous loops, each equipped with essential functions. Immediate habitation for pioneers is prioritized, while modularity enables seamless expansion over time.

A NOVEL DESIGN CONCEPT: DNA

The concept. The need to transcend mere functionality highlighted the urgency of finding a strong and meaningful architectural concept that could be filled with symbolism and a human element. This aspect is sometimes overlooked in aerospace projects that primarily focus on technical and functional considerations. The intent pursued with this research is to find a symbolic connotation for the lunar settlement and its potential for growth. Humans are about to inhabit a completely new environment, and it is essential to design a project that conveys the essence of humanity. The inspiration for this concept draws from the essence of life itself: human DNA. It embodies what underlies human growth and evolution. With this project, we are effectively bringing human DNA to the Moon, both in an architectural and social sense. This symbolizes the leap that humanity is poised to take and the imprint that we, as humans, wish to leave on this new outpost. Furthermore, the DNA double helix structure is well-suited for a settlement located inside a lava tube due to the horizontal configuration of both elements. In this way, symbolism aligns with functional requirements.

Architecture. The Moon station is comprised of individual, self-contained modules designed to facilitate gradual development. This setup allows the initial residents to find immediate shelter while offering the potential for expansion over time by duplicating the modules and extending horizontally throughout the entire tunnel. These modules are arranged to assemble the spiral structure (see Figure 2).

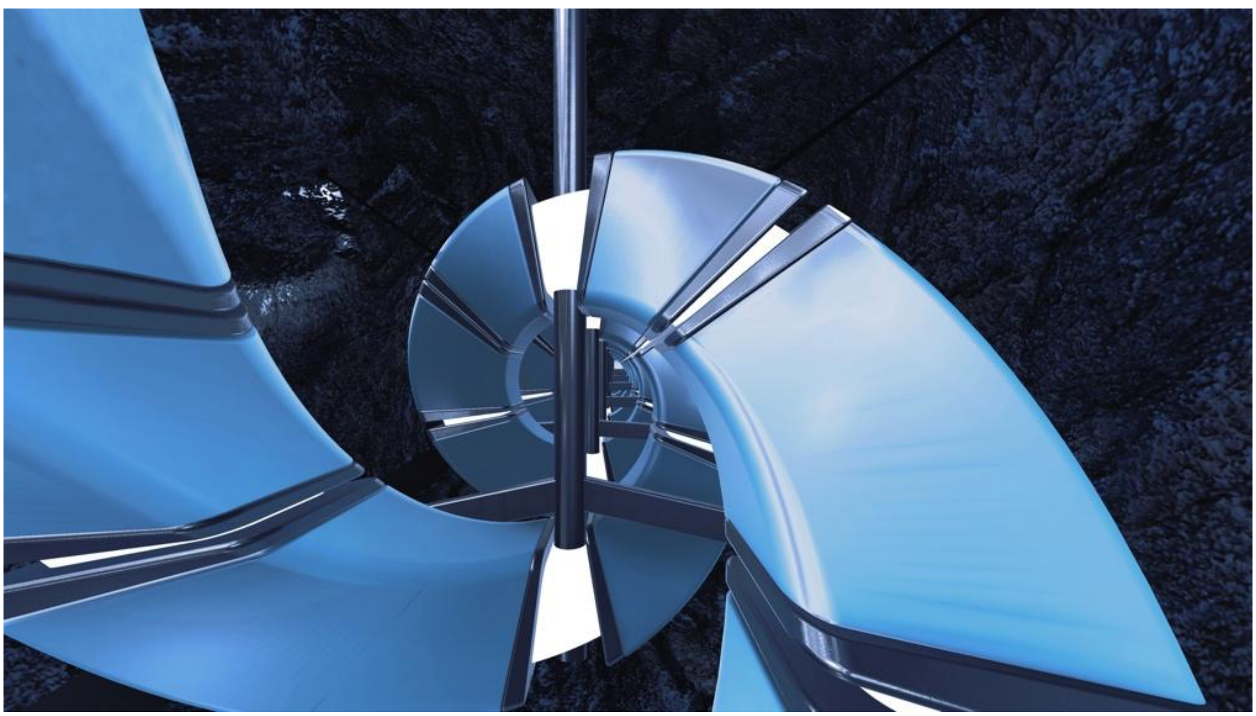

Figure 2. D.N.A.'s rendering.

The interconnection of the modules is facilitated by strategically placed airlocks, which not only secure airtight seals but also enable circulation within the spiraling structure. Situated within a lunar lava tube, access to this habitat is provided through a network of vertical elevators. These elevators are positioned to traverse both helices at 50-meter intervals in correspondence of the airlocks that join the modules. The entrances to the elevators are situated on the lunar surface and are designed not only for practicality but also to serve as observatories. Two distinct pathways have been integrated within the lava tube, each following the contours of the spiral structure. These pathways serve a dual purpose, enabling both exploration and easy access to the vertical circulation areas within the habitat. In this way, every element of the habitat is carefully engineered to maximize its functionality. Essentially, the modular spiral structure's internal circulation is made possible using airlocks, while access to the spiral itself is accomplished through vertically inserted elevators.

Functions. The two spirals are composed of a series of inflatable modules, each of which accommodates a range of distinct functions and has multiple levels (see Figure 3).

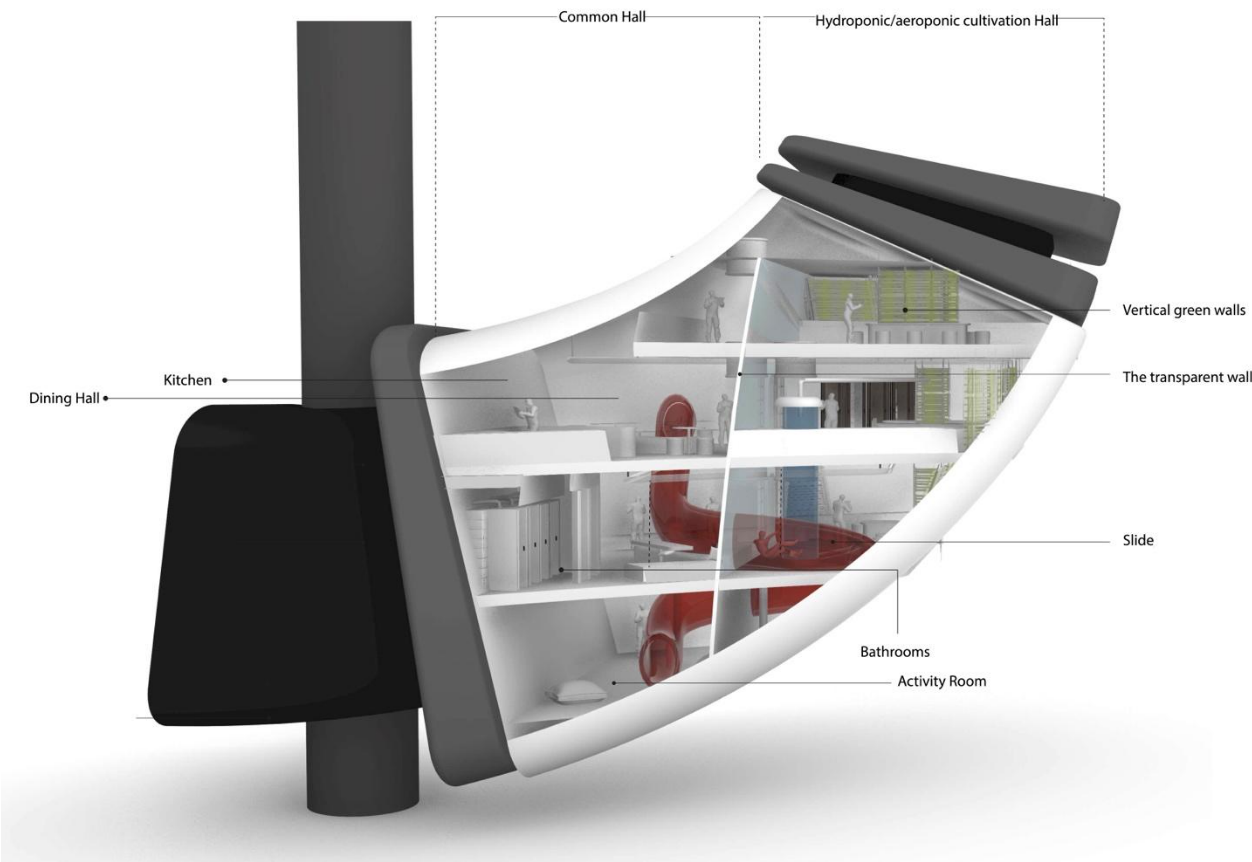

Figure 3. D.N.A.'s interiors.

Designing a space station for Moon-based operations requires careful consideration of specialized functions. Within the lunar station's design, key functional areas include staff accommodations (70 sqm), customized for the resident staff, emphasizing simplicity and comfort. Accommodations for guests (42 sqm) provide a place to stay for professional and commercial astronauts. The control room (40 sqm) houses essential life support control equipment. The common hall (150 sqm) functions not only as a dining area but as a hub for social interaction and knowledge exchange for both staff and guests. The hydroponic/aeroponic cultivation hall (80 sqm) ensures on-site, cost-effective food production while creating a visual contrast with the common hall. A gym (60 sqm) addresses health challenges associated with the reduced gravity of lunar environment. The infirmary (30 sqm) is equipped for various medical emergencies and strategically located for quick access. Lastly, laboratories (130 sqm), positioned near entry and exit areas, support data processing and sample analysis, optimizing sample transportation within the station (see Figure 4).

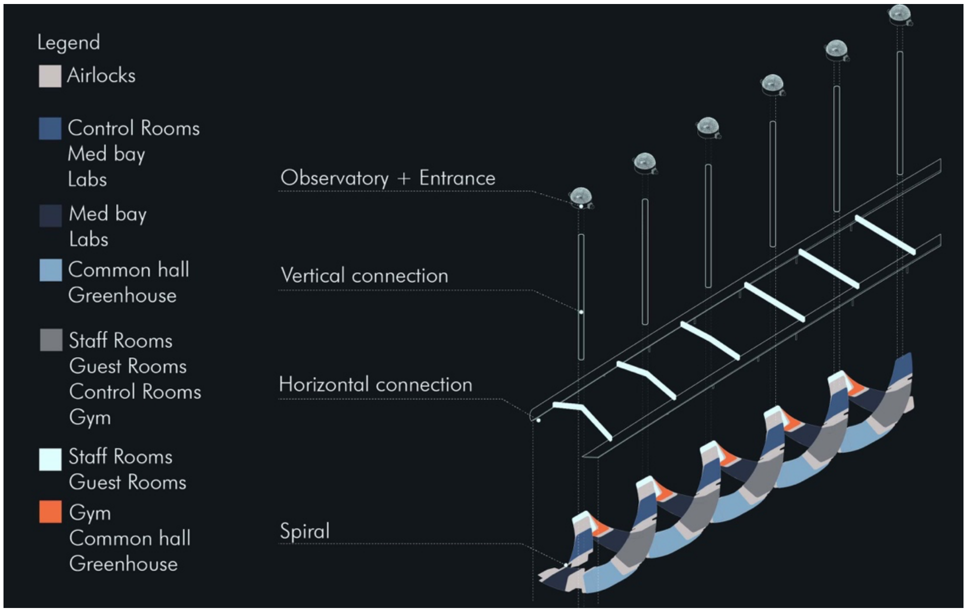

Figure 4. Function distribution.

This comprehensive design approach seeks to address not only the technical requirements of lunar living but also the psychological and social elements that enhance the well-being of those residing in the lunar environment. The spatial organization emphasizes the fusion of technological innovation and human comfort in a challenging lunar setting.

Interiors. The interiors are thoughtfully designed to prioritize functionality and the well-being of the lunar pioneers. The modules house various essential spaces, including staff rooms, guest rooms, control rooms, med bays, labs, common areas, cultivation halls, and gyms. Common spaces play a crucial role in fostering a sense of community and connection among the inhabitants. The transparent partition that separates the cultivation hall from the common area offers controlled isolation while providing a visual link to the greenery in the cultivation hall. This connection with nature significantly enhances the psychological well-being of the inhabitants.
One notable feature in the common area is a recreational slide, passing through the cultivation hall. This unique addition serves both entertainment and practical purposes, capitalizing on the Moon's reduced gravity to offer an extended and enjoyable experience. It contributes to the residents' physical and psychological well-being while encouraging shared experiences. Within the lunar modules, each function is carefully planned to maximize efficiency. The design integrates multi-functional spaces, optimizing the use of resources and making efficient use of the limited living space. Modular adaptability ensures that the interior layout remains relevant and functional as

technology evolves or new needs arise. The interiors aim to provide a balanced, efficient living environment, supporting the crew's physical and psychological needs.

COMPUTATIONAL DESIGN

The tool. Computational design played a vital role in the D.N.A. project's development. Employing algorithms to oversee the critical parameters in a space architecture project allows for the effective management of numerous variables, facilitating adaptability to changes (Keane 2005). As the project begins to take shape, new questions arise and adjustments to the original product are necessary. A potential solution to this challenge involves adopting a parametric and algorithmic approach to problem-solving. The rules followed by the model are established by the designer, and the program calculates the resulting alterations accordingly (Wassim, 2013). The D.N.A. 3D model was created using Grasshopper®, a graphical algorithm editor integrated within Rhinoceros®, a 3D modeling software. Grasshopper® features a graphical interface and follows a programming logic. It enables parametric control over models and offers generative design capabilities (Akos, 2015).

Building a parametric model. The D.N.A. model was built in Grasshopper®, using the 3D representation of the lava tube as the foundation. This established the geometrical constraints for the project. The lava tube has an approximate total length of 500 meters, with the width at the entrance at Lacus Mortis pit measuring 90 meters. As one progresses deeper into the lava tube, the internal section narrows, and the width at the end reduces to 57 meters. Similarly, the height varies as one moves away from the entrance, transitioning from 67 meters to 45 meters (see Figure 5).

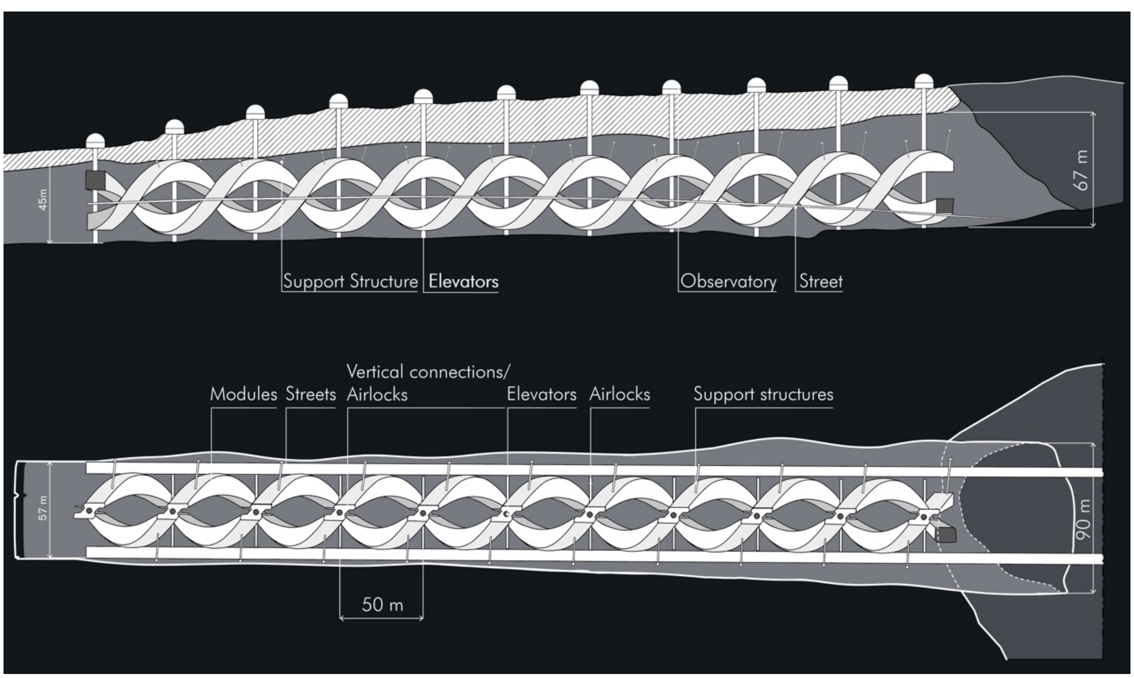

Figure 5. D.N.A.'s section and plan.

The initial step in creating the parametric model was to define the geometric parameters, encompassing the length, width, and height of the structure, based on the constraints presented by the lava tube.
The D.N.A. configuration of the design concept required the definition of two intersecting spirals. As the two helices are identical, the modeling approach involved designing the first spiral and subsequently duplicating and rotating it to create the other. Therefore, a baseline for the first spiral was established, specifying the distance between the loops. The baseline was then offset to create the rails for developing the solid structure. These rails served as the foundation for constructing a lofted surface, which was then extruded to form the internal space of the modules.
At this stage, the spiral comprised a single large module. However, modularity is a crucial aspect of the design, and a massive structure is not practical. Consequently, the spiral was divided into smaller, more manageable modules, with airlocks placed in between. This division was achieved by segmenting the initial baseline.
As previously stated, the resulting geometry was duplicated and rotated to create the second spiral. The next step in the modeling process involved establishing vertical connections (elevators) between the two structures, positioned at the locations of the airlocks between the modules. This was achieved by identifying the midpoint of each airlock and implementing a pattern to remove unnecessary points. This enabled the creation of connections between these points and allowed for surface extrusions, facilitating the generation of the connecting elements. Boolean operations were employed to ensure a proper junction between the different parts.
The lateral roads and the horizontal connections were also constructed using the same approach. The placement of the roads was determined by the width of the entire double-helix structure, while the horizontal elements intersected with the elevators, aligning their placement with the axis of these elements.
This modeling strategy enabled the project to be adjusted throughout its development. Each element is interconnected, so by modifying one or multiple parameters, the model responds to these changes in every part and recalculates the entire design.

Expansion. The modeling strategy developed within Grasshopper® offers significant advantages for potential project expansion. The modularity at the core of the D.N.A. project is a fundamental element of this approach, enabling the planning of lunar settlement growth and a more substantial human presence on the Moon. This is made possible by the ease of aggregating multiple modules and the incremental growth inherent in this project type.
Having a parametric model that can be rapidly modified by adjusting a couple of parameters allows for the control of the expansion process and a straightforward aggregation of multiple modules. Since the relationships between elements are already established, it becomes easy to add or remove modules and recalculate the settlement's configuration. For example, the D.N.A. model can be rapidly enhanced in terms of module quantity by increasing the length of the spiral. Other aspects,

such as the subdivisions of the modules, the placement of airlocks, and the number of elevators, will automatically adjust to the new parameters and expand to meet the updated requirements.

Future work. This research enables possible future work to develop and delve into more technical details, including material selection, deployment of inflatables and elevators, and structural analysis and optimization. The computational approach allows for a straightforward exploration of these aspects of the project. By integrating the existing script with plugins like Kangaroo, Karamba3D, and Crane, it is possible to cover the aspects not defined in this paper. Kangaroo, a live physics engine that can simulate the behavior of materials and objects, can be utilized to simulate inflation, and perform a form-finding process (Piker, 2013). Karamba3D is an interactive parametric Finite Element program that predicts the behavior of the structure considering the specific project parameters (Preisinger, 2013). The data needed to feed the program includes material properties, the internal pressure of 1 Atm, and the reduced gravity of the Moon of 1.62 m/s^2. Since the structure is inflatable, it will be analyzed as a shell and constructed with membrane materials, such as Kevlar, Kapton, or Nextel (Pedley, 2001). Crane simulates the folding of a structure (Suto, 2023), serving as a powerful tool for future development to demonstrate that the structure can be properly packed and transported to its destination, respecting the volume constraints of the launch vehicle. This process can be followed both for the inflatable structure and for the interior walls and floors. It is also necessary to verify the mass limitations of the transportable cargo, this is achievable thanks to the parametric framework of the model. The volume of the structure can be extracted from the Grasshopper® model and it can be multiplied by the density of the materials, giving as a result the weight of the entire system.
In conclusion, although the research primarily focuses on a conceptual approach to architecture, the conceived methodology facilitates the straightforward development of technical details.

CONCLUSIONS

This research introduces an approach to a lunar settlement that encompasses multiple elements. While the technical aspect of a space architecture design is crucial, the developed project does not solely focus on technicality. Instead, it seeks to integrate technical aspects with symbolism and art. The D.N.A. project represents an imprint of human presence in the challenging lunar environment. Given that the Moon has never been inhabited before, the intention with the D.N.A. design is to bring the very essence of the human element to this new environment, both conceptually and physically. The first humans will reside inside a structure whose shape symbolizes human life itself. The role of computational design was crucial in demonstrating how the design concept could be translated into something that is adaptable while still honoring the underlying philosophical principles. The analysis of the morphological features of the location and the development of an architectural and interior design project enabled the creation of a settlement that is conceived with a central focus on human needs while also accommodating the technical requirements dictated by the location's unique features. The chosen strategy for constructing the D.N.A. concept model allows for easy adaptability and use in various applications, not only in other space settings, such as in orbit or on Mars but also here on Earth. The outcomes of this research comprise a comprehensive and adaptable project with a robust conceptual foundation and the potential flexibility to be employed in diverse contexts.

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