L.A.D.E.
Lunar Architecture Design Exploration

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Executive summary

Since Apollo missions, robotic exploration of deep space has seen decades of technological advancement and scientific discoveries. Today, NASA's Artemis Program is envisioning a plan to drive humanity to live on the Moon. Indeed, the possibility of building a permanent settlement on the Moon is still a major challenge. In this framework, Alta Scuola Politecnica and Thales Alenia Space partnered to design a novel agile habitat through a holistic multi-disciplinary approach to allow crewed surface exploration missions.

Lunar Architecture Design Exploration (LADE) project's output is a mobile space architecture system that enables human presence on the Moon, allowing medium to long term missions. This module is the key movable part to build a more complex system of hybrid class II and class III shelters that aims at the construction of a lunar village.

The goal of the design effort is to allow the permanence of four astronauts on the South Pole of the Moon, next to Shackleton crater. The location is strategical for surface exploration goals and provides favourable environmental conditions for a future permanent settlement. To achieve this, a combination between a mobile habitat and a network of robotically constructed shelters will be necessary. The design of both systems aims at satisfying all habitability and mobility requirements in the harsh and extreme lunar environment, while exploiting ISRU, through the demonstration of 3D printing capabilities for micrometeoroids and radiation shielding purposes.

The presence of a sheltering system will concur with a series of minimum infrastructure requirements, which will be reached through a first robotic mission. The aim will be defining the first mission elements necessary to sustain a human settlement, including the construction of solid foundations, roads and landing pads, stabilising the soil, providing an energy production and storage sub-systems.

The iterative process of functions allocation within the module and its overall architecture have been guided by the principle of human-centred design. The different mission constraints led to the development of an adaptive system, able to change according to the astronauts' needs and provided with a combination of rigid pre-integrated elements and deployable spaces through pressurization.

The implementation of LADE's functionality into the Artemis mission architecture enables the shift from early exploration phases to a continuous human presence on the lunar surface.

Key Words
mobile space architecture, Moon, mobile habitat, human-centred design, adaptive system

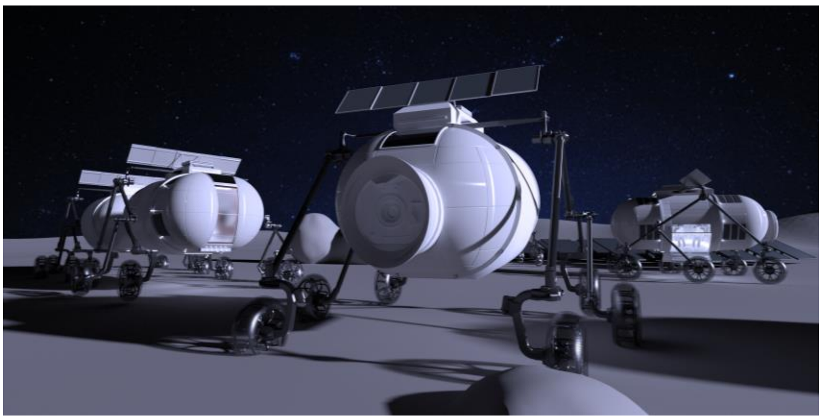
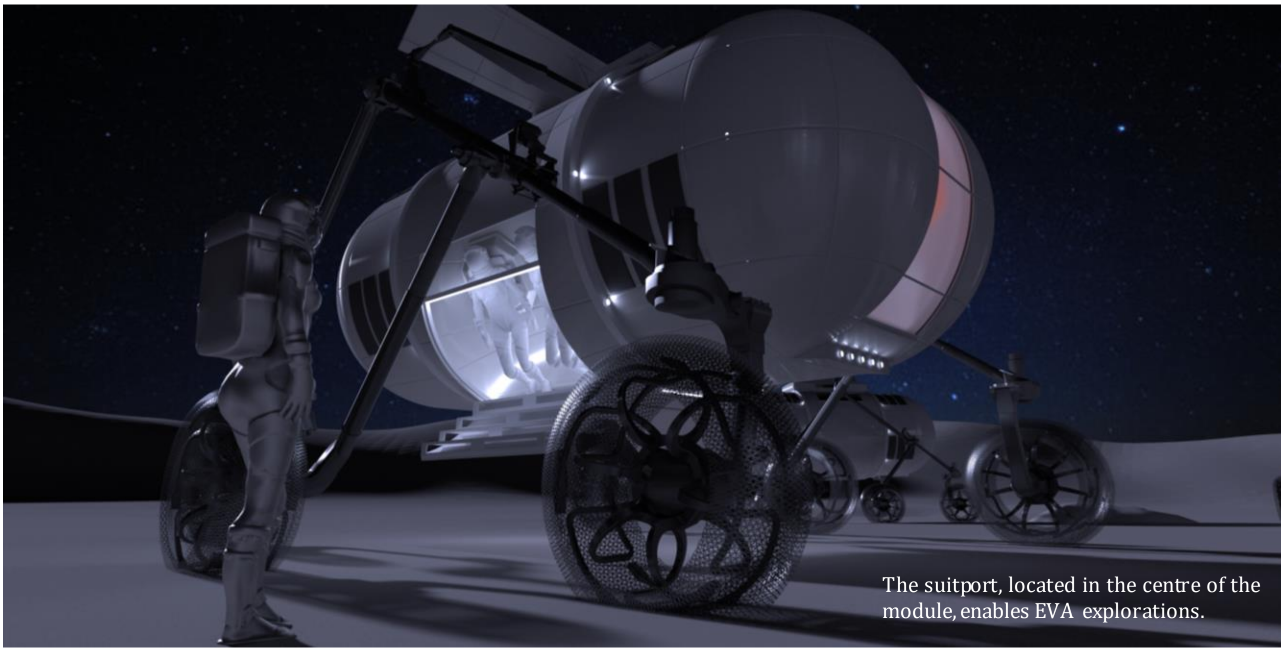
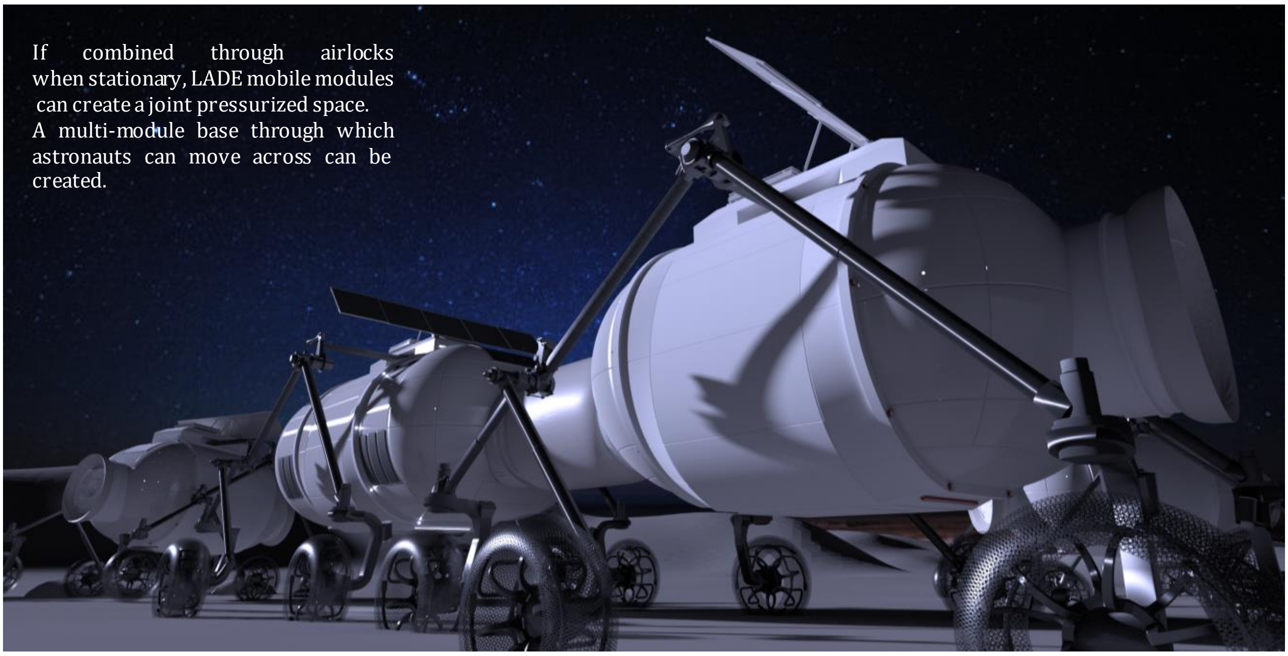


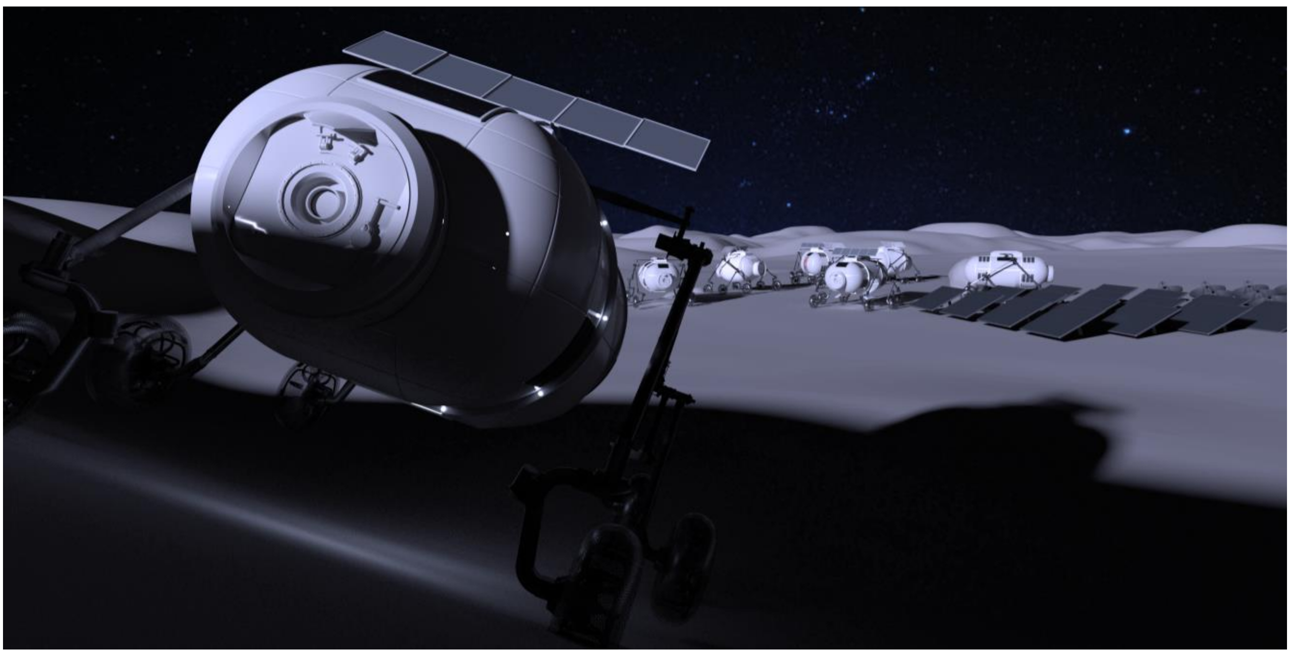
Figure 1. Render of the exterior of the mobile module (top and following page)



The suitport, located in the centre of the module, enables EVA explorations.



If combined through airlocks when stationary, LADE mobile modules can create a joint pressurized space.
A multi-module base through which astronauts can move across can be created.



Project description written by the Principal Academic Tutor

NASA's Artemis Program is envisioning a plan to drive humanity to live on our closest celestial body: the Moon.
The dream of designing and building a permanent outpost on the lunar surface to allow human explorers to live at 250,000 miles from Earth is becoming reality. Ad Astra team explored innovative architectural and engineered design solutions of an integrated agile and mobile settlement on the Moon that is based on the conditions unique to the lunar environment, such as reduced gravity, extreme thermal differentials, high-energy solar exposure, cosmic radiation, high velocity micrometeorite impact, abrasive-electrostatic regolith, zero atmosphere and constrained human living space and human factor design principles.
L.A.D.E., Lunar Architecture Design Exploration, represents a mobile habitat infrastructure for a sustainable lunar exploration.
Each LADE mobile module has been designed bio-mimicking bees, in terms of systems and sub-systems distribution and overall architecture. The module includes navigation, communication, energy production and storage systems as well as proper thermal, micro-meteoroids and radiation shielding and the possibility to perform EVAs through dedicated suitports. A deployable rocker-bogie system with superelastic tires, integrated with the module and solar panels, enables mobility on the lunar surface.
The key main aspects are: integration between mobility and habitability requirements, flexibility and agility during Extra Vehicular Activity (EVA) on the Moon, and multi-purpose missions thanks to a unique modular system.
The project allows connection and interconnectivity capabilities between L.A.D.E. modules.
LADE project has been developed by a multi-disciplinary team of Alta Scuola Politecnica students and supported by a multi-agent advisory board composed by Space Architects, Structural Engineers, Aerospace Engineers, Physics and Human Computer Interaction Professors affiliated to Politecnico di Milano, Politecnico di Torino and Massachusetts Institute of Technology, including former NASA astronaut Prof. Jeffrey Hoffman, and in collaboration with Thales Alenia Space, that is currently involved in the NASA's Artemis Program for the development of habitation modules for both cislunar orbit and lunar surface.
Ad Astra team applied a holistic design approach within a truly collaborative teamwork, in line with the main ASP objectives. Indeed, Ad Astra students have been challenged to develop critical thinking by stepping outside their respective disciplinary comfort zones in order to embrace curiosity and a broader visionary attitude towards new technological, scientific and design challenges.
Developing architectural solutions for the Moon, generated awareness and transformative thinking about terrestrial concerns and applications in terms of optimal use of resources in extreme environment on Earth, while meeting some of the UN Sustainable Development Goals of Agenda 2030.

Team description by skill

The LADE team is composed of 9 students and its multidisciplinarity turned out to be a point of strength of the project, because it allowed to combine different skills and competences from different field of study in all the steps of the project.

Angela studies Biomedical Engineering and she is specialized in the design and development of innovative technologies focusing always on psychological and physiological well-being. She combined her interest in engineering with the ability to design life-saving elements to ensure the survival, energy, and thermal and radiation protection of crew members.

Marco is the Aerospace Engineer of the team, he has some experience and knowledge regarding advanced technology in spacecraft and aviation. He applied his crucial knowledge to any part of the engineering process both in the theoretical research and also in the design phase especially in the energy, shielding and mobility part.

Lorenzo, Mechatronic Engineering student, combined his electronics and mechanics to transfer skill to manage the design, engineering, manufacturing and maintenance of mechatronic systems and devices, especially regarding the mobility system of the module, i.e. the rocker-bogie system.

Ana Carolina studies Civil Engineering, Structure and Infrastructure, therefore her role was important when defining the structure of the module and analysing the loads, taking into account the general balance of the structure.

Daniele, who focuses on Building Architecture, played a crucial role in developing the complex structure of the module thanks also to his experien ce in BIM softwares, which were fundamental to develop the design. Together with Alessandro, developed the prototype of the mobile module that was 3D printed through additive manufacturing.

Marta and **Michela** study Architecture, Built Environment and Interiors and this background gave them a capacity to understand the importance of the human relation with the space, focusing on how to improve the experience of the user while inside the module.

Giulia is enrolled in Architecture and Urban Design, which gave her an advanced training in the field of architectural design. She developed theoretical, humanistic, artistic and design competences which was able to bring into play on several scales of the architectural definition of the project.

Last but not least, **Alessandro**, Design and Engineering student, his knowledge was transversal because he worked on several aspects of the project understanding the context and the users' needs. His competences allowed him to work in the design phase together with the architects, because he is able to merge design and engineering skills.

Goal

The project goal is to design a habitable mobile module, which represents the key movable component in a complex system of shelters on the lunar surface. LADE positions itself in the initial phase of Moon exploration, human transportation, and technology exploitation for future applications, in the view of a permanent settlement on the lunar surface.

Therefore, born from the collaboration between Alta Scuola Politecnica, Thales Alenia Space, and MIT, LADE aims at developing technological solutions for mobile lunar habitats, being part of NASA's Artemis program. The goal is to realize a mobile and habitable module that can allow for mid- to long-term manned missions on the Moon, becoming the primary means of transport between a network of settlements, as well as allowing day-long explorative missions.

Understanding the problem

Since the Apollo missions, robotic exploration of deep space has seen decades of technological advancement and scientific discoveries. Today, over 50 years after the historic Neil Armstrong's landing, NASA's Artemis Program is envisioning a plan to drive humanity to live on the Moon.

The employment of this module will take place in the phase III of Artemis program, in which manned exploration missions will be carried out in the Moon south pole region. To allow such challenge to be accomplished, the project focuses on the human experience, providing both the functionality of a research site and the comfort of a habitable place. Furthermore, it is necessary to devise and bring in cutting-edge technology, exploiting the In-Situ Resource Utilization (ISRU) practice, designing innovative mobility and autonomous driving systems, and optimizing the closed-loop system towards a circular use of resources.

The context in which the project is framed requires also to deal with multiple problems and constraints, given by the lunar harsh environment (cosmic radiations shielding, protection from micrometeorite impacts, active control of the module stability while moving on rough terrains, etc.), self-sufficiency of the module (in terms of energy resources), limitations in the size of the module and the safeguard of the crew's physical and psychological needs.

In conclusion, LADE results in a complex and multidisciplinary project, not only for the context in which it is involved but also for the impact it can have on the future of Space Architecture.

Exploring the opportunities

The Moon is a treasure trove of science, and the knowledge acquired through a sustained human and robotic presence on its surface and orbit has the potential to unravel valuable information on not only the universe, but our home planet.

The study fields benefited from this new era of Space Exploration range from understanding planetary processes to application of novel technologies and resources to human missions with destinations even farther from Earth. Such plans are included in the Artemis program, post phase III, in which returning to the moon sets the stage for the next giant step: reaching Mars.

The project has, thus, the potential of revolutionizing the current paradigm of space exploration, which is centred on the use of robotic solutions instead of human crews for missions of long duration. We believe that our work, at least as far as it concerns the holistic methodology exploit to develop all the aspects related to the design of a habitable, efficient, and safe module for the exploration of the Moon's surface, will serve as a starting point for future research and feasible outputs in this sector.

Generating a solution

To bring humankind successfully to the Moon, the project envisions different typologies of mobile pressurized modules supported by a network of permanent shelter providing protection and supply. The aim is to provide a range of typologies of mobile modules to choose from, according to the specific mission. The concept idea is based on the presence of a primary mobile module in charge of navigation and paving the way, followed through computer vision by the secondary modules selected for the mission (i.e., dedicated to research or storage). LADE mobile modules can be combined through airlocks when stationary to create a joint pressurized space, thus creating a multi-module base through which astronauts can easily move across to perform their activities. This technology enables significant flexibility of the desired performances according to the missions.

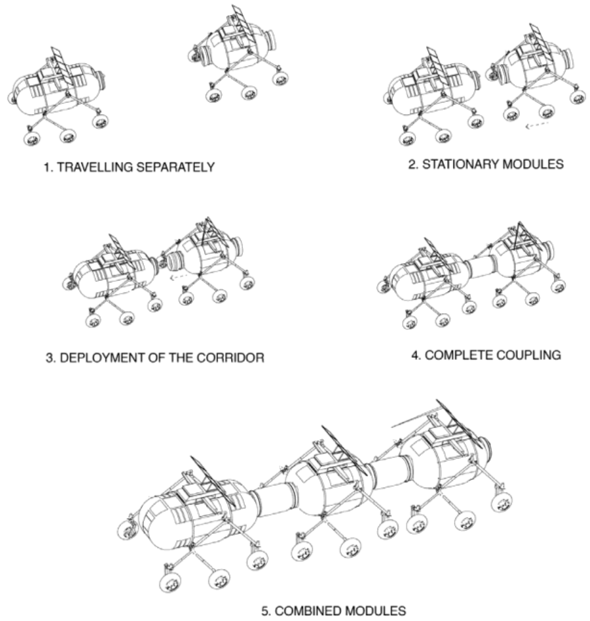


Figure 2. Phases of conjunction of the modules

As to the module structure, the structural system for the primary module was organized based on the functional needs and the payload constraints. In particular, the system has been divided into two main macro-elements: the mobility system, and the shell structure, containing the pressurized habitat space. The latter was topologically optimized exploiting static computational analysis performed with Grasshopper© software, resulting in a finalized geometry of the shell.

Regarding the locomotion system, the requirements to be fulfilled were the first to be defined, followed by the choice of the best system among the existing possibilities. Once assessed the rocker-bogie was the most efficient mobility solution, the system components were designed and dimensioned, particularly the wheels.

The shielding is an essential component of the module, responsible for preserving the astronauts' safety by limiting the hazard due to radiations, micrometeoroids, and harsh temperature variations that characterize the Moon's surface. To properly define and dimension it, different solutions from the literature and avant-garde materials were analyzed. Given the novelty of the materials chosen for the radiation shielding, a deeper analysis using NASA's software OLTARIS© was performed to determine the safest thicknesses.

Once defined all the previous elements, a power subsystem able to provide for the energetic needs of the mobile module was dimensioned. Also in this case, different commercial possibilities were investigated, resulting finally in a combination of rechargeable batteries and photovoltaic panels.

LADE project was born after a deep analysis and, afterward, interpretation of bees. The natural reference has been reshaped into a futuristic vision of a lunar swarm and its hive. The project envisions the shelters and the mobile modules as strictly dependent elements reciprocally essential to be and to work. The biophilic approach has been used also in the design of mobile modules whose functional distribution is inspired by the bee's body. When connected they resemble the head, the thorax, and the abdomen of the considered animal by their functions: navigation, communication, locomotion technologies and EVA system in the primary module, and research or storage in the secondary one.

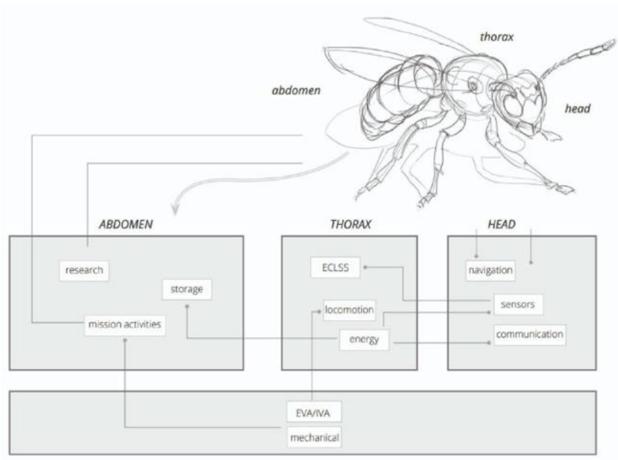


Figure 3. The biophilic approach visible in the functional distribution of the mobile modules

The internal configuration of the primary mobile module is defined by its main functions and therefore organized in three sectors: the cockpit, the center and the back. The cockpit is dedicated to navigation and control, hosting wide desks with displays, speakers, projectors, and sensors. Different human-computer interfaces systems are installed in this area of the module to support the performance of the astronauts and to enhance the quality of their work and their psychological wellbeing. In the central body of the module, the suitport enables EVA explorations. The system allows the astronauts to descend upon the suits directly from the internal corridor of the module through the bulkhead vestibule hatch, guaranteeing the absolute separation between the pressurized module and the non-pressurized space.

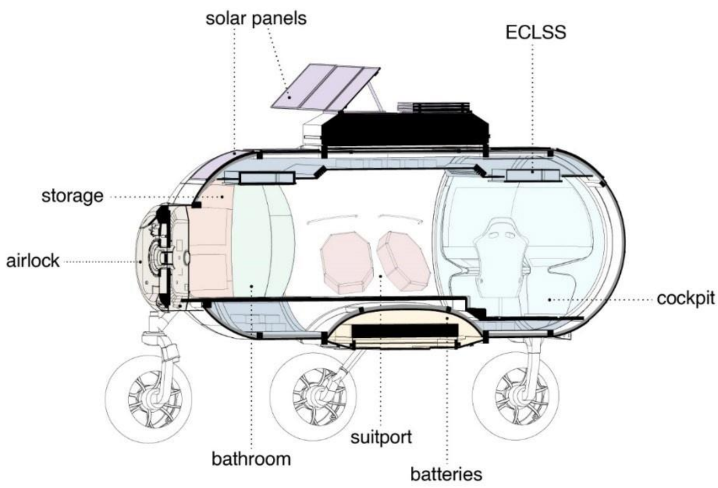


Figure 4. Perspective section of the module showing the functions with the colors

Finally, in the back of the primary module are located two more seats for the crew members who are not driving integrating storage boxes. Moreover, a circular bathroom is present, together with an equipped wall to store the tools for maintenance, the medical kit, food and cleaning tools, personal items, and the inventory management system. An airlock is present to connect the primary module with other ones guaranteeing a continuous pressurized space.

LADE, in all its forms, represents more than a design effort towards an innovative solution for surface exploration and habitability, it aims at setting a solid background to build upon a new chapter in the history of sustained Lunar exploration.

Figure 5. Render of the interior of the primary module

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