HiveMars: Design of a Hybrid-class, scalable Settlement on the martian surface

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Utilization of in Situ resources is a fundamental capability to be developed for the construction of permanent and semi-permanent structures on Mars and the Moon. Nevertheless, direct human contact with regolith would jeopardize crew health. New design strategies that address such problems need to be explored and developed. This paper presents a feasible design for a hybrid class 2 / class 3 outpost that includes ISRU structures integrated with prefabricated inflatable and solid elements, both for pressurized and infrastructure elements. The Architectural Design Thesis Laboratory of the Polytechnic University of Bari conducted research on this topic, and, under the name of archi.mars, the group designed a permanent and self-sufficient settlement: "HiveMars". The proposal explores a concept for the integration of ISRU-enabled and prefabricated structures to create a scalable infrastructure capable of supporting human life on the surface. To reduce mission costs and launch load from Earth, eight different automated rovers will prepare the site area before the crew's arrival. Following the site exploration phase (identified in the Hellas Planitia, in the martian southern hemisphere) the automated surface assets will proceed with the material collection, processing, and construction of the main infrastructures, including Landing pads and roads. The first habitat nucleus is composed of three self-supporting, inter-connected domes, built with Martian regolith using additive manufacturing, and outfitted with an inflatable, pressurized core that hosts the pre-integrated ECLSS systems and the internal infrastructure. A pre-integrated dome on the top of the prefabricated core ensures the right amount of natural light while protecting the internal habitat from radiations and micro-meteoroid impacts.

I. Nomenclature

NASA	=	National Air and Space Administration
ISRU	=	In Situ Resources Utilization
SLS	=	Space Launch System
WAVAR	=	Water Vapor Adsorption Reactor
MOXIE	=	Mars Oxygen In-Situ Resource Utilization Experiment
PLGA	=	Polylactic-co-Glycolic Acid
DCM	=	Dichloromethane
$2 - Bu$	=	2-Butoxyethanol
DBP	=	Dibutyl Phthalate

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II. Introduction

The priority of the first human outpost on Mars will be to protect the health and safety of the crew and to support life through good design practices for habitability and human factors. This project aims to provide both the living and working environment for eight crew members during 670 – sol mission duration. The project is focused on the architecture of Martian habitats to be built through automated surface assets which will support the site preparation for human crews, collecting resources and construction materials from local resources. The project, named Hive Mars, presents a feasible design that aims is to reduce the launch mass and cost of future human surface missions, considering extensive usage of in-situ resources and current and near-future technologies to guarantee crew self-sustainment for a Martian settlement. Hive Mars is based on three case studies: the Marsha Space Habitat by Ai SpaceFactory group, winner of the NASA 3D-Printed Habitat Challenge 2015 [1]. This project proposes the use of a recyclable biopolymer composite to manufacture the habitat's inner structure and to use processed local regolith for the external shell. The second case study, the NASA Design References Architecture 5.0, is the most recent version of the Martian mission Architecture conceived by NASA. The architecture proposes three different missions in three different sites. In the preliminary phase of the project, consequentially to the definition of the geological, biological, and human factor objectives, a monolithic, class 1 habitat is proposed as the main outpost, while all the exploration activities make use of pressurized and non-pressurized vehicles to conduct medium and long-range research missions. This project also considers the use of in situ resources for the production of consumables such as oxygen, water, and propellant [2]. Finally, the last chosen case study is the Mars habitat created by the Hassell+Eckersley O'Callaghan who participated in NASA's 3D-printed habitat Challenge. To address the radiation problems, the group designed an external shell manufactured in Martian regolith with autonomous robotic rovers to protect a hybrid class 1/2 habitat [3]. The three different case studies have been chosen for their relevance to the topic and the different approaches, achieved through the use of the latest innovations in the field of additive manufacturing using ISRU.

III. Mission Architecture

To bring all the necessary assets on the surface and eight astronauts to begin the crewed phase, the launches of various heavy-lift rockets will be required. For this mission, architecture has been chosen SpaceX Starship for the cargo mission and NASA SLS Block 1B for the crewed part of the mission. The proposal is focused on a mission not only to set foot on Mars but also to enable scalable colonization of the red planet. Before showing the outpost proposal, has been defined a mission architecture diagram that represents the launch, travel, and landing phases. The diagram 2 shows the mission timeline and launch sequence that ties each launch to a specific launch window, to exploit the minimum traveling time between Earth and Mars to enhance crew and cargo safety and reduce the interplanetary travel unknowns. The mission consists of two phases and will last a total of fifty-three months [2].

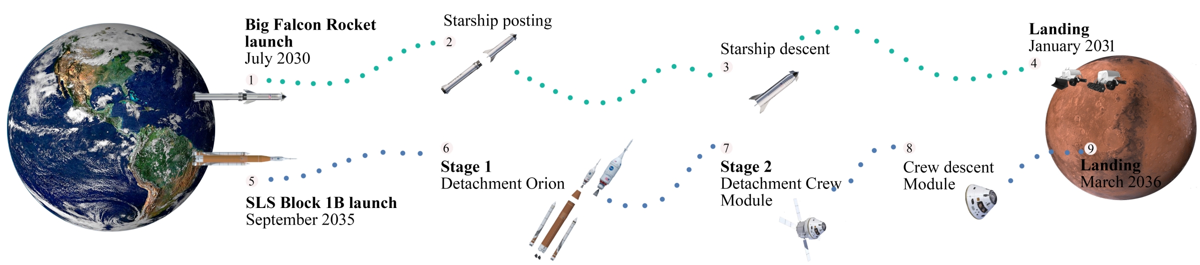

Fig. 1 Mission Architecture Diagram

A. Cargo Mission

The take-off of the first spacecraft is set for July 2030 with the SpaceX Cargo Starship departing from the LC-39A launch pad. The vehicle will transport six specially designed Rovers of the Bee family, such as the explorer, the flattener, the excavator, the transporter, the 3D printer, the processor, and the bee lifter. The goal will be to collect raw materials, such as regolith, and ice, and process them, through chemical processes, into refined materials suitable for construction, together with all the prefabricated assets to be integrated with the 3D-printed structures. The journey will last about two hundred and fifty-one earth days and will include the landing of the specially designed machinery in January 2032.

B. Crewed Mission

The infrastructure deployment and the first habitat core construction (second phase) will last approximately 5 years. After that time, the third and last phase will begin: in September 2035, the SLS Block 1B will depart from the Kennedy Space Center LC-39B pad. The SLS will fly the first crew of eight members to Mars in approximately two hundred and thirteen days. Upon their arrival, the mobile assets on the surface will have already built the first habitat core, consisting of two cylindrical habitats and an unpressurized vehicle storage area, including all the functions necessary to sustain life, including the work area, crew quarters, and leisure spaces. The mission will last at least 680 sols, around two Earth years, the time necessary to perform the exploration activities and carry out all the main scientific objectives of the first human exploration phase.

IV. Surface Assets

Surface assets are assets used to move, store, protect, secure, and monitor a long-duration mission on Mars. These assets are brought from Earth in the first phase of the mission and are intended for exploration, site preparation, material collection, and construction.

A. Mobile Assets

On top of the habitat and infrastructure design, the design team focused on the construction sequence, outlining appropriate surface elements to support the construction. This role is performed by the Bee Family Rovers which include all the autonomous and semi-autonomous mobile assets, based on a common chassis to ease the maintenance operations. The design of each machine is inspired by Epigenetic-based insects [4], belonging to the Apidae family, a particular genetic characteristic that allows insect with the same DNA to evolve in different physical features, designed to fit their role in hive societies. Each of the Bee Rover assets plays a different role in the construction process. The Bee Family Rover consists of eight machines. In order of arrival, we find:

- Spider Explorer, designed to explore and analyze the outpost area to define the site conditions and resources localization .
- Bee Flattener, which main task is of leveling the construction area to avoid unevenness in the ground that compromise the structural integrity of the habitats.
- Bee Excavator, will collect the regolith for the construction from the top layer of soil.
- Bee Transporter, used to move the construction material around the building site.
- Bee Processor, that has the task of processing the regolith into building material
- Bee 3D Printer, is a printer with a three-axis mechanical arm capable of building the outer shell of the housing modules through additive manufacturing process
- Bee Lifter, is used to lift, transport and place the prefabricated assets.
- Archimars Pressurized Rover, to be used by the crew for the exploration activities and transportation between the different outpost areas.

B. Infrastructures

A complex outpost needs a robust infrastructural system that can support surface development. This system is composed of different elements designed for tasks such as energy production and distribution, material processing, and storage. Most of these elements are technologically too complex to be manufactured in situ and they will be prefabricated on Earth. Since that these surface elements are fundamental for the settlement self-sustainment, proper redundancy and tolerance need to be assessed, to overcome unknown danger and malfunctions that can jeopardize the life-sustainment capabilities of the human-rated systems. These elements will be mostly located in two different areas at a distance from the habitat: the ISRU and Power production area, which are described in the Masterplan section of this paper.

- Energy production area: where solar panels and kilopower reactors are located.

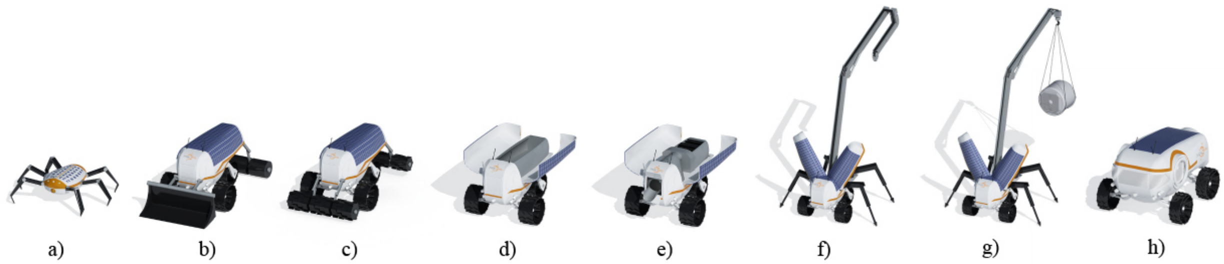

Fig. 2 Bee Rover Family: a) Spider Explorer; b) Bee Flattener; c) Bee Excavator; d) Bee Transporter; e) Bee Processor; f) Bee 3D Printer; g) Bee Lifter; h) Archimars Pressurized Rover

- ISRU area: entrusted to prefabricated elements which allow production, processing and storage of water, oxygen and manufacturing materials.

C. Prefabricated habitat elements

Some of the components for the construction of the pressurized habitat need to be manufactured, assembled and tested on Earth to ensure the precision and safety suitable for hosting human life. These components, brought from the Earth, are:

- Deployable inner modules: inflatable/deployable elements that host human activities, including work, leisure and crew quarters.
- Hatches, suitlocks and payload airlocks: deployable cylindric elements which connect deployable module with one another or with the external module environment.
- Window modules: prefabricated and preassembled elements that allows external light and view.
- Skydome elements: light-transmitting structure that enclose the external shell at the top.

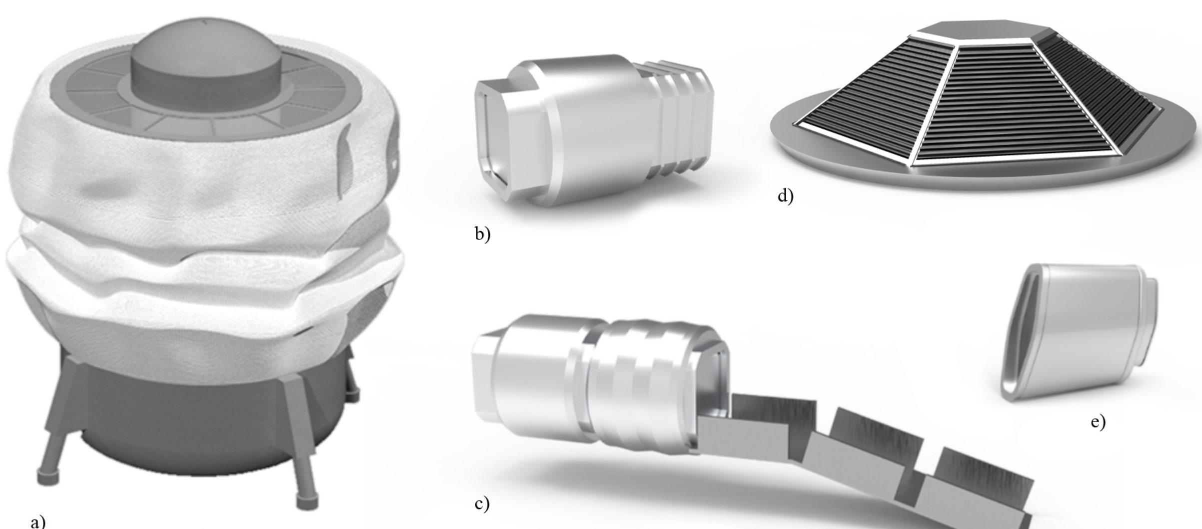

Fig. 3 Prefabricated surface elements: a) Deployable inner module; b) Airlock; c) Suitlock; d) Skydome; e) Window

V. In Situ Resources Utilization

All the elements that aren't brought from the Earth are built using in situ resources, exploiting the local regolith and ice deposits.

A. ISRU for Crew Sustainment

To live on Mars, crew members will need oxygen to breathe, water, propellant, and energy to power their habitat. Instead of bringing everything they need from Earth, they will use in situ resources to produce them. This way is self-sufficient, economically, and environmentally sustainable. Per day, one crew member needs approximately 3.52 kg of water for drinking and about the same amount for cleanliness and approximately 0.84 kg of oxygen [5]. To fulfill these needs, different strategies have been assessed using established technologies considered by NASA and ESA for long-duration missions, such as Sabatier process [6], Water Vapor Adsorption Reactor (WAVAR) [7], Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) [8].

B. ISRU for construction

The use of local materials for the construction of the entire settlement has a fundamental role in the HiveMars proposal. The use of the principal Martian resource, regolith, together with other surface minerals such as basalt, sulfur, ice can be processed to obtain processed materials to be used during construction. The production of the material in situ is closely linked to construction technologies that see new applications and new experiments already on Earth [9]. Additive manufacturing and the use of local materials can reduce the amount of material transported from Earth, construction costs, time, and even environmental impact reducing greatly the cargo capacity and number of launches needed to build on the planetary surface. To ensure the achievement of the mentioned benefits for this kind of construction, the habitat module has been designed around additive manufacturing technology capabilities.

C. Additive Manufacturing of Regolith

As stated before, the construction of the external structures of the settlement involves mostly the use of the Martian regolith. Powders are characterized by distinct morphologies and highly inhomogeneous sizes, where the dust particles are rough, but mainly rounded. The printable ink consists of three main components: the powder, the elastomeric binder, and a mixture of solvents. The powder, previously examined, occupies 70–75% of the volume of the mortar while 30–25% of the volume is occupied by PLGA, an elastomeric polymer based on organic acids. Instead, the mixture of solvents, easily available in situ, includes the majority of the volatile solvent dichloromethane (DCM); lower amounts of 2-butoxyethanol (2-Bu), a surfactant that mitigates and cancels the electrostatic and steric interactions between suspended particles and dibutyl phthalate (DBP), a plasticizer that improves the flow properties of dissolved PLGA and further inhibits the interaction of the particle during the flow [10]. After thickening, through evaporation of the excess DCM, a 3D printable consistency is obtained at a linear deposition rate of 1–150 mm / s. All the elements used for the preparation of the regolith mortar can be recycled. The polymer, PLGA, can be synthesized from biologically derived lactic and glycolic acids. It could be used to process and recycle unrelated organic wastes, such as urine and plant waste, into PLGA and similar elastomer-derived bio-waste. Optionally, the 3D printed elastic structures could potentially be transformed, by sintering, from solid form into gas, water, hydrocarbons, and into diatomic oxygen and hydrogen by electrolytic methods. Finally, the sintered regolith structures could be pulverized into primordial regolith powders [11], which could be used to create new regolith inks for 3D printing. The entire process of transforming the regolith into Martian mortar or cement takes place inside the Bee Processor rover and subsequently transferred to the Bee 3D Printer rover which performs the printing of the external structure. The printer technology uses the "additive" principle of depositing the material on layers [12]. The rover is equipped with a mechanical arm adjusted through a numerical control mechanism and it performs two types of movements: a circular one, along the x and y axes, and a vertical one, along the z-axis, following the deposition of the various layers. The nozzle, located at the upper end of the arm, has a diameter of 0.14m and is heated to melt the regolith mortar.

D. Shielding with regolith

The habitat structure consists of an external Class 3 shell and an inflatable Class 2 internal structure. The external structure refers to historical models of the Nubian dome and takes the shape of a dome with an ogival section truncated at the top. It reaches an external diameter of 15m and a height of 13m for the central dome while the two lateral ones have an external diameter of 13m and a height of 11m. The thickness at the base of the ogival dome reaches the size of 1.5m and narrows as the highest point is reached, become thinner to 0.50m which is equivalent to a minimum thickness required in the design of planetary habitats. This thickness favors adequate protection of the inflatable living module, placed in its internal volume, from the Martian severe weather such as sandstorms, meteor showers due to the weak magnetic field and shielding from solar and background radiations which are extremely harmful to the humans, especially for long exposure time [13]. The ogival profile of the wall thickness is interrupted by the presence of joints placed along the lines oriented at 120° from the center of the main dome. Each joint follows an ogival arched section and in the central part, has a circular passage that allows the correct positioning of the prefabricated modules such as the airlocks, windows, and Hatches. Between the domes, there is a joint of suitable thickness that allows each dome to be detached to avoid collision between the independent external shells during seismic events, although less frequent than those on earth. In particular, the shell presents a smooth surface on the inside while the outside is modeled onto a parametric tridimensional texture that allows better thermal management and protection against micrometeoroid impact. The choice of an external textured finiture responds to two determining factors such as the self-shading of the structure itself and the ability to retain the dust that is deposited on it. Over time, this dust stiffens the structure and also increase the wall thickness, resulting in additional protection.

E. External Shell Construction Sequence

The construction of the dome structure begins with the excavation of a 1.6m circular hole that will host the habitat foundation; the typology chosen is the continuous foundation with a circular bed, lower than the ground level, in which the internal shell will sit. Subsequently, the Bee 3D printer will proceed to print the base of the external shell starting from the foundation level. The first interruption of the printing takes place in correspondence with the ground-level hatches placed inside the side connections. the Bee Lifter rover transports and places the airlocks undeployed. The rigid section of the hatches and airlocks works as a support for the upper layers. A second interruption occurs at the level of the windows, directly transported from Earth, and placed in position using the Bee Lifter. In particular, the window frame consists of two polycarbonate panels, one in contact with the external casing and one internal; a shutter, which protects against micrometeorites and debris and, in addition, favors control of external lighting that reaches the internal environment; bulletproof glass panels that are attached at the rear and in the front of the latter. The printing of the ogival dome continues after the placement of the first three openings, interrupting in correspondence with the upper ones, positioned in correspondence with the second and third floors. The upper part of the dome is truncated because the printing technique would not allow adequate structural support to close the shape. Furthermore, once the construction of the envelope has been completed, this shape allows the placement of the undeployed inflatable module from the upper cavity using the Bee Lifter rover. Once placed, a truncated-pyramidal skylight is placed to seals the external shell. This element is inspired by the ISS dome and provides greater illumination of the internal environment.

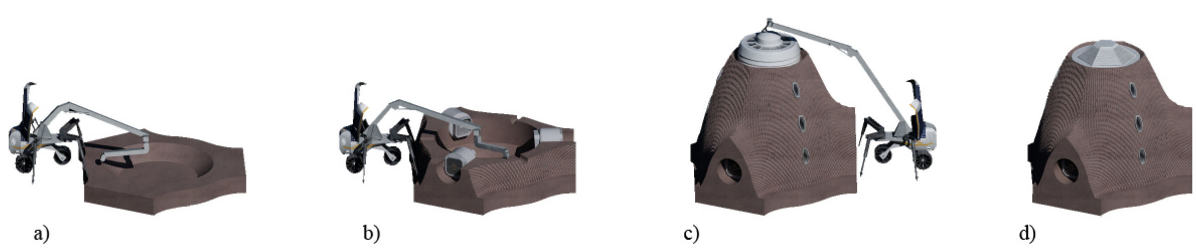

Fig. 4 External shell construction process: a) Foundation printing; b) Airlocks deposition; c) Deployable module deposition; d) Skydome installation

VI. Pressurized habitat

Once the class 2 protective structure has been defined, it is possible to establish a class 3 housing module that is part of the infrastructures brought from the Earth. It is important to understand the formal choice of the external inflatable module, the deployment phases of the internal structure, and the specific function it assumes. A long-term stay requires a habitat capable of reducing the mass and costs of launching and at the same time capable of guaranteeing large pressurized spaces to allow all human activities to be carried out. The choice for the habitat inside the regolith structure, therefore, fell on an inflatable habitat. Its advantages are remarkable: it is lighter than a rigid aluminum structure; it also allows greater flexibility of the internal layout and greater internal volumes; allows automated outfitting and easier assembly; manages better the thermal and structural stresses, while keeping the weight low [14]. Assuming that an inflatable habitat is more advantageous for site preparation before the arrival of crew members, the form factor becomes a fundamental choice to address in the design process. Cylindrical, semispherical, and toroidal shapes have been considered. Different studies and evaluation mockups built on earth Earth have shown that the toroidal shape is ideal for a small habitat. Compared to the semispherical shape, the torus has important advantages: it is characterized by a ratio between mass and surface which is more advantageous for transport from the Earth; it has inherent stability; needs less gas for inflation. With the same external volume, the torus has a larger internal habitable volume than that of the sphere. The torus is safer thanks to its "segmentation into separate pressure compartments". In the case of the Hive Mars human settlement project, having an ogival section of the dome, neither the torus nor the sphere was suitable. Considering all the advantages of the torus, including its characteristic of having a central distributive core, and considering the shape of the sphere more narrowed upwards, to fit as much as possible the space available inside the external shell, an egg-like shape has been chosen. This shape is the best to deal with the pressure delta between inside and outside in a reduced gravity condition. It is also able to exploit all the volume available inside the dome, covers more space in height and width, allowing better management of the internal environment.

A. Habitat Construction Sequence

Once the undeployed inner module is lowered from above into the dome, the inflation begins. Integrated air pumps the pressurization needed to reach the final shape of the inflatable module, using filtered martian atmosphere in place of the precious oxygen mix. In the first phase of the deployment, the telescopic central core deploys vertically; in the second phase, the module inflates. after the deployment is complete, a flooring system characterized by a mobile octagonal floor, deploy radially from the central core. At first, two of the three cores scroll upwards; then the mobile floors open and then the wings of the ground floor, which unload the weight on a system of beams deployed from the central core. The unfolding of the structure continues with the opening of the movable floors, then of the wings, and then of the pillar on the first floor. Upon the arrival of the crew, it will be possible to outfit the internal space, through 3D printed and prefabricated elements transported from the Earth. To move the furniture between the floors, the elevator in the central core will be used. When is not in use, the elevator platform is stored in the service module on the bottom, while allowing the deployment of a helical stair system mounted between the same tracks that allow the deployment of the structural pillars. The result is a large habitat characterized, by an internal steel structure on three floors connected by the distribution core, which occupies the entire volume of 780 m3 of the external inflatable egg, functional for daily leisure of all activities of four crew members.

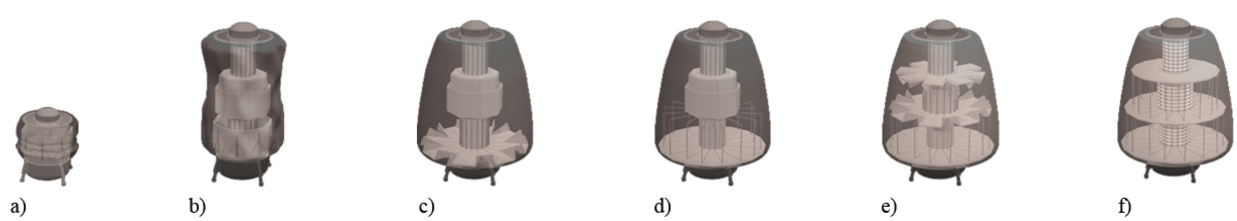

Fig. 5 Inner shell assembly sequence: a) Deployable module is installed; b) Central core extension; c) First floor deployement; d) Substructure deployment; e) Second and third floor deployment; f) Inner module fully deployed;

B. Intenal layout

The layout of the interior space revolves around the crew activities. It derivates from decades of human experience in minimal habitat design and the ISS experience. Designing for human factor means to affect human performance in a dangerous environment through design solutions that need to enhance the focus and the mental health of astronauts. The primary purpose of the design of the internal environment is therefore to ensure, together with the aspects related to

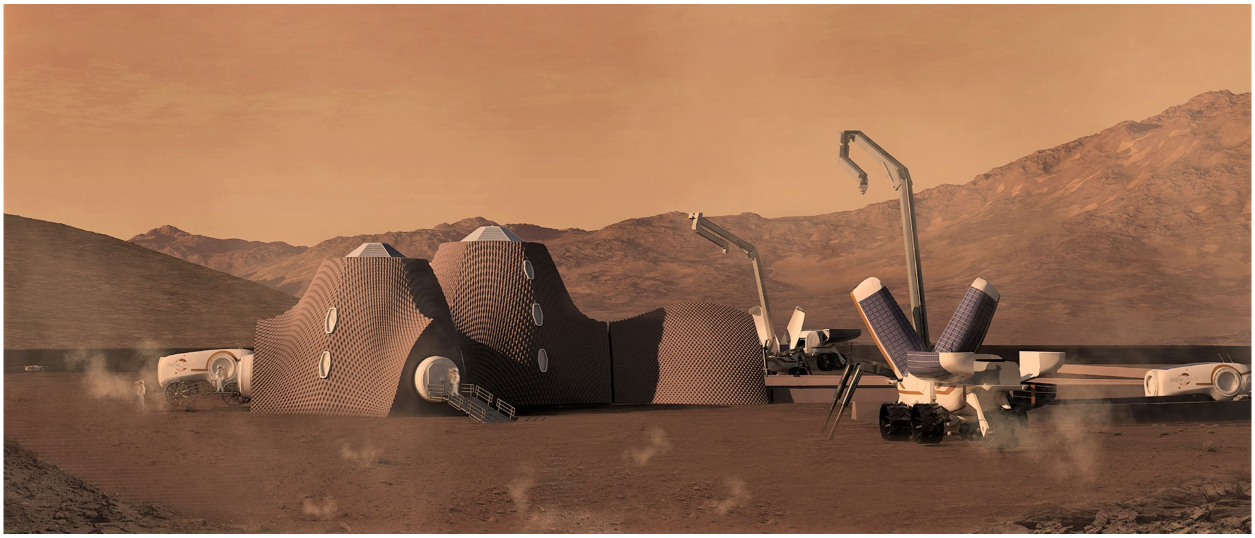

Fig. 6 External view of the Habitat Core in Construction

the safety of the crew, all that concerns the physical, psychological, and social health of the inhabitants. The living module of Hive Mars is a deployable structure on three levels. The internal arrangement of each area, in particular, and the arrangement of each living module, in general, derives from the presence of three connecting airlocks arranged on axes of 120° from each other. Each floor has an increasingly smaller walkable area from bottom to top, given the egg shape of the external inflatable module. Each of them has three windows arranged on 120°axes from each other, which do not so much perform the function of illuminating from the outside, but rather that of offering people a view to the outside, partly freeing them from the sense of isolation. The function of illuminating the internal environment is instead performed by a circular skylight dome mounted on the top that closes the core system. This skylight, thanks to a system of automated shutters, opens during certain hours of the day to radiate the internal module from above. The light, therefore, filters from above through the skylight, illuminates the second floor, and partially reaches the lower level from the gap between the inflatable module, the floors, and the internal structure. Each functional area is made accessible and connected vertically by a helical staircase placed at the center of the structural core. On the external walls of the core is placed a continuous hydroponic cultivation system, characterized by columns of 3D printed vases and a system of led grow lights, to produce part of the food, perform experiments and stabilize the internal hygrometry. The plants have also a proven benefic effect on the crew mental health [15]. The Ground floor is 70 square meters of space, suitable for carrying out work, research, meeting, and care activities. The area, initially empty, will be outfitted by the first crew of four. The instrumentation rack outfitting is the first step. Subsequently, on this floor, A 1m3 delta 3D printer will be installed to print all the furniture and partitions wall. The doors, such as the other elements, are prefabricated. the rest of the furniture will be gradually arranged within this area until the configuration of the planned distribution of spaces is obtained. The Medical area is positioned north-east, to the south-east laboratories for scientific research, to the north-west, there is the Local Mission Control Center. The First floor has an area of 60m2, characterized by a distribution corridor around the core that leads to the common areas, represented by the living room to the north-east and the dining room with the galley to the southwest, and the private quarters, i.e. the four bedrooms of the first crew members. The area, therefore, is dedicated to feeding and sleeping, but also personal and private activities. The floor is served by two complete bathrooms. The second floor is the area of 45m2 is, a single open space that is configured for relaxation, leisure, and physical activities.

VII. Masterplan

The HiveMars project takes into consideration the entire infrastructure, not only the habitat module. This section will be described the different areas that characterize the system, and their roles in the mission structure. The arrival of the first Cargo Starship is scheduled for January 2032. Once the landing has taken place, all the machinery necessary for the preparation and exploration of the site are deployed on the surface before the arrival of the crew, that will happens three years later. First of all, the Spider Explorer survey the designed construction area to provide detailed information

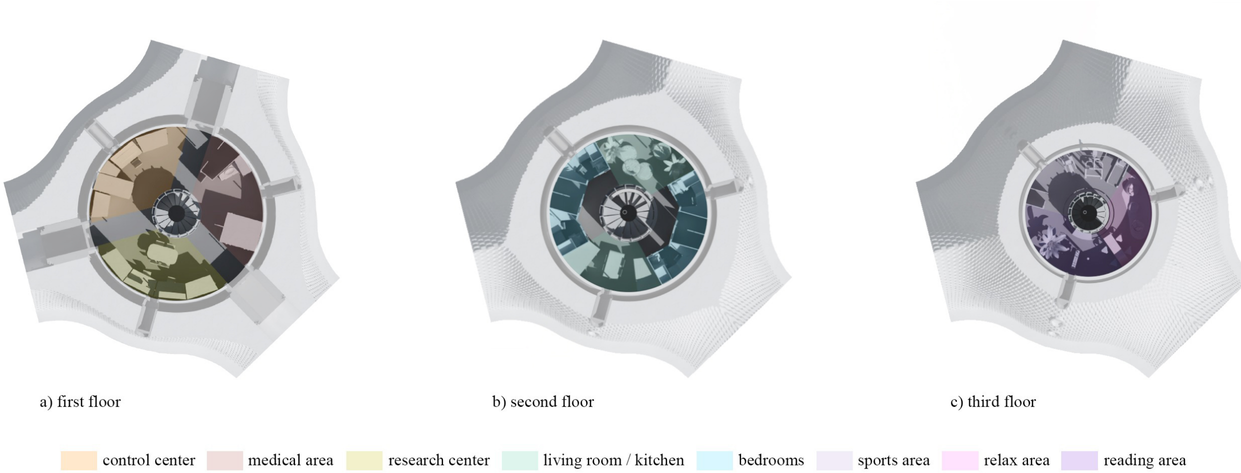

Fig. 7 Internal layout: a) first floor b) second floor c) third floor

Fig. 8 Interior views: a) First Floor; b) Third Floor

about the site to the construction rovers, such as the presence of water in the subsoil. Subsequently, the Flattener rover will level the terrain and free the area from the rocks that can‘t be processed. In the second phase, the Bee Excavator and Bee Transporter rovers will dig the foundation's area and collect the regolith for the transport to the ISRU area, where it will be processed, and where the activities of water extraction, production of oxygen, and propellant take place. Once the regolith is processed, it‘s transferred to the 3D Printer rover, which will print the protective wall of the primary landing pad, the rover pathway, and the shell of the habitat. the Kilopower reactors and solar panels are so placed robotically within the energy production area, and the electric cables are laid down until the habitat area, at 300m of distance. Just after the construction of the first habitat module, the site will be ready to host the first crew which will land on Martian soil with the SLS BLOCK 1B vehicle in 2036. Upon its arrival, the astronauts will found the Archimars Pressurized Rover waiting at the landing pad to take them to the habitat. The first nucleus consists of three multifunctional units, one main and two secondary, and an unpressurized hangar to protect the vehicle during sandstorms and solar events.

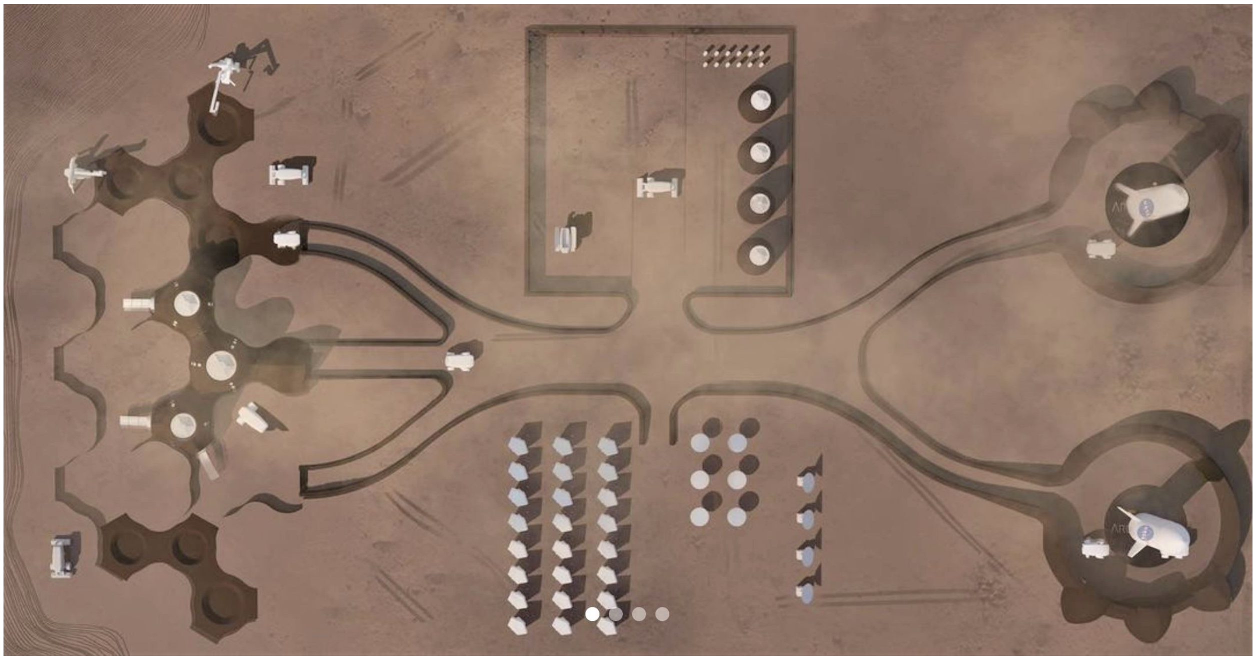

Fig. 9 Outpost Masterplan: a) Habitat Area; b) ISRU Area; c) Power production Area; d) Landing Pad Area

A. Landing Area

The first area to come in contact with the human spaceships will be the landing pads. The area chosen as the landing area must comply with some technical and physical requirements such as the adequate solidity of the ground considering an underlying paved surface, the scarce presence of rocks on the ground to avoid any accidents during the descent of the vehicle, the conformation preferably flat, less than 10% slope, the low ground level to allow the spacecraft, which uses the Martian atmosphere for its deceleration, to descend in complete safety. Each of the two landing pads will be 100m in diameter and surrounded by a protective wall of printed 3d regolith. The wall is critical to stop the sandblasting effect on the structures of the Starship propulsive landing. The whole landing area must comply with a distance of at least 500m from the habitat area, and served by the main road to minimize the dust circulation end enhance crew safety. The landing pad will need to sustain more launches with minimal maintenance time. Within the area, it is necessary to consider the presence of other buildings such as maintenance bay and emergency shelters for radiations, micrometeoroids, and sandstorms or to store the unloaded cargo.

B. ISRU Area

As human capability for long-range missions evolves, the In Situ resources utilization and manufacturing will become increasingly important. The ISRU area is dedicated to the collection, processing, and storage of materials produced from the mars soil. Breathable air, clean water, metals, rocket propellants, building materials, and more. All these elements can be extracted through chemical and mechanical processes such as electrolysis. The selection of the Area is based on the presence of ice and some other basic mineral elements, such as basalt. Other elements such as propellant can be extracted directly from the atmosphere rich in carbon dioxide or even from the regolith itself. From raw materials such as ice, regolith, sulfur, and basalt, through processing methods like sintering, hot pressing, and liquefaction, other materials would be produced, such as glass and fiberglass, polyethylene, plastic, iron, and steel. The energy production will be progressively excavated like lithic mining sites on Earth.

C. Power production Area

The energy production area is dedicated to servicing the power needs of Habitat and the ISRU Area. The most important power source is the Sun from which ultraviolet rays propagate and constantly hit the surface of Mars. Through lightweight, super-efficient photovoltaic panels. Solar power will be used as the main source of the outpost, refilling the accumulators of the outposts. The panels will need constant cleaning and maintenance, which will be mostly done robotically. The actual transformation efficiency is about 30%, but it will grow in the next future. Furthermore, solar panels have a fairly long useful life, especially considering that on Mars they would be subjected to much milder weather events and more favorable temperatures. which turns them into a long-term renewable energy source. A considered solution to integrate panel production is the use of multiple Kilopower reactors. The kilo power uses a solid core of molten Uranium-253 to provide a constant flow of energy, at any hour, that can protect the outpost from malfunctioning events and prolonged sandstorms. It is a very reliable solution with a high Technology Readiness Level (TLR) [16]. Some form of algae bioreactor has been also considered.

D. scalability

The configuration of the single habitat module allows three points of connection, corresponded with the three airlocks placed at 120° from each other, disposed of radially. This arrangement makes it possible to connect the single unit with others, of different sizes and shapes until a hexagonal shape is achieved. The hexagonal geometric figure allows the outpost area to be divided into modular tiles, favoring a future expansion of the outpost while procedurally increasing the hosting capabilities of the system. The ISRU and energy production areas will grow consequentially until the reach of the minimum safe distance from the habitat and landing pad areas.

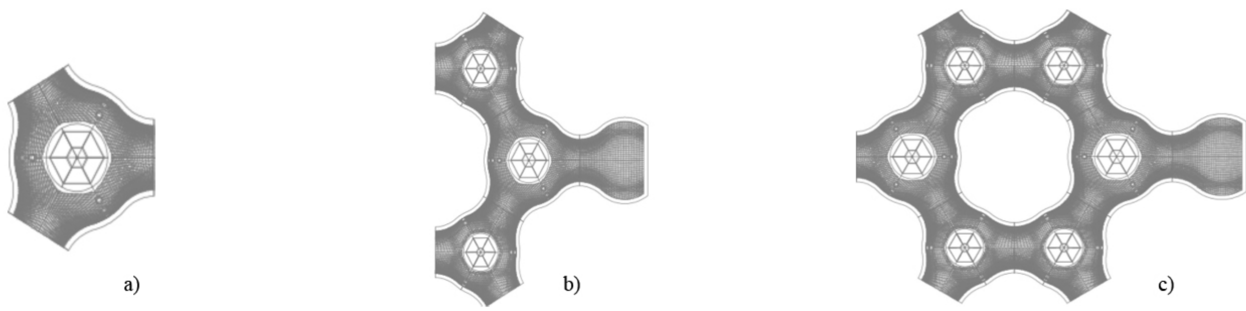

Fig. 10 Module Scalability: a) Single habitat; b) Functional Unit; c) Full Outpost

VIII. Conclusion

This paper has introduced Hive Mars, a proposed design for a Hybrid-class, scalable settlement for the martian surface, from its base concepts to the technological solutions that characterize its construction methodology. The priority for the design of this habitat is to protect the health and safety of the crew, ensuring sustainable productivity through good construction and design practices. The project presents specific solutions to reduce mission costs and complexity, addressing each development phase in detail. The construction process is left to eight highly autonomous rovers. The mobile assets play the fundamental role of dealing with the whole construction process, from the in-situ sourcing of the materials to the site preparation and habitat maintenance. Local resources are not used just as a construction material but are also process to produce water, energy, oxygen, and propellant. The habitat section consists of 3d printed self-supporting domes, outfitted with prefabricated inflatable modules that together protect the human life conditions from the dangerous conditions of the red planet. The habitat has been designed so that allows a high level of modularity and safety in the internal distribution: each habitat is provided with 3 accesses that can be connected to other modules, to a pressurized rover, or the martian surface. The design concept is based on the manufacturing capabilities of the different elements: While the high precision needed for pressurized internal shells requires prefabricated module on earth, the external radiation/micrometeoroid shielding can be safely manufactured in situ with limited robotic capabilities.

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