D-Shape Strategy Position Paper for Space Expansion horizon 2030 2050

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Abstract

Talking about vision of some possible developments of the 3D Printing technologies for space applications with horizon 2030 and 2050, we have to consider two main categories of conditions and constrains:

- the status of the human expansion into space and related status of astronautics
- the status of 3D printing technology and its possible evolution

The following thoughts are a basic conceptual draft for a position paper about 3D Printing techniques to be used for space colonization.

All of our concepts are driven by a deep humanist philosophical thought, so we designed our strategy starting from the needs and the interest of almost seven and half billion inhabitants of planet Earth and, in second priority, of all the forms of life living on our mother planet[1].

3D Printing techniques, with particular mention to the subset related to the building of habitations and structures targeted to guest human life, can higly contribute to the colonization and settling of the extraterrestrial space and resources, allowing the use of in situ resources, by methods cheaper and quicker, wrt the traditional ones.

Konstantin Tsiolkowsky: "Earth is the cradle of Mankind, but one cannot spend the whole life in a cradle".

1 Vision 2030 - 2050 and beyond

1.1 A philosophical view: the status of Earth's civilisation

The status of Earth's civilisation has reached a pivotal moment[2]. The population, now exceeding seven billion inhabitants, continues to grow. Humans are an interdependent species and know that collaboration rather than confrontation is the key to securing civilisation while continuing to maintain progress with peace and freedom: only a growing economy, in a context of a new industrial development, can assure the basic conditions for a continued ethical, cultural and civil growth. The recent crisis of China, after many years of impetuous growth, and of the Brasilian economy, confirm that the resources of our mother planet are not enough, to allow the peaceful development of all the Earthlings.

Therefore, should the world remain closed, our civilization will face a very high risk of implosion, due to the growing social, resource and environmental problems, that can only keep on growing, in the closed environment of our now small world[3]. Such risk is now stated not only by the astronautic humanist philosophers, but also by independent thinkers, like Stephen Hawking, who recently declared that Earth will not sustain more than one billion people, withing this century[4]. If civilization will not begin expanding into space, within 2050, we will see an holocaust of unprecedented size: six billion people will die, due to conflicts, environmental disasters, healt systems devolution and endemic illnesses. As an alternative to the dire and deteriorating state of the world it is now evident that expansion of civilisation into space is the true moral imperative of our time[5]. By focusing our energies and creativity on the challenge of opening and developing the space frontier instead of destroying civilisation there can be true hope for peace and prosperity for all[6]. To save the civilization, and not to loose the huge intellectual patrimony accumulated during two centuries of industrial revolution[7], it is urgent to retake the path of economic and cultural growth: the only strategy to get this goal, creating millions new qualified jobs, is an exo-development strategy, the only way to revert the global crisis. Developing civilian astronautics, starting from space tourism and the geo-lunar space region industrialization[8], is essential to relaunch the industrial development, so not to loose the social progress determined by the industrial technological revolution of the last two centuries[9]. Starting the exodevelopment, humans can help to solve the environmental global problems, such as pollution and antropogenerated climate changes[10]. In the industrial countries human dignity and ethics knew substantial progress, due to technological achievements, mass education and mass employment. Such progress decreased the social fear, gave free time to the people, allowing for the first time a mass aim to the maximum Maslov's levels needs[11]: technology demonstrated to be the main support of morals. The exo-development will relaunch the technological progress, and the economic and cultural growth[12] at an unprecedented pace[13], a true renaissance in space[14].

1.2 Bootstrapping a serious space industrialization program, within 2030

It is essential that the space frontier was open before humans pass the threshold of 9 billion inhabitants on one only planet, or the resources to finance the space programs could dramatically drop down, due to the worsening of the several combined crises. The expansion into space and the space settlement will be a long lasting process, and the global problems will not be solved in few years, but the opening of a new development horizon will trigger a very meaningful change, swicthing on again the hope, the awareness to be working on big projects, for a great objective. It is essential that this event will take place during the next ten years.

Particularly interesting, from this point of view, is the recent statements by the new Director General of ESA, Prof. Johann-Dietrich Woerner, about building a village on the Moon[15]. Dr. Woerner explicitly pronounced in favor of the development of industrial activities in space: the village to be built on the Moon, would be strongly propaedeutic to such goal, as well as the proposed infrastructures in lunar orbit, enabling entrepreneurs to visit the Moon soil, and start working on the Moon[16]. We believe that such a program, if developed, will determine a true change of paradigm: from mere *space exploration* to *space industrialization*, exactly what our exhaust societies need!

As a short-term agenda, within 2030, a large world wide collaboration and fair competition should develop, in order to settle the so-called Greater Earth (the Earth's magnetosphere), with general commitments at all levels, public and private investments, as well as in money and in personal effort, to develop the following areas, at least:

a) sub-orbital tourism, vehicles and infrastructures (spaceports)

b) fully reusable, low cost, orbital vehicles

c) space tourism[17], orbital hotels, accomodations, workshops, yards

d) industrialization of the geo-lunar space region, including Lagrange Points

e) recovering of the Earth Orbit space debris[18], and their reuse for building space infrastructure

f) tourist, mining[19], industrial and research infrastructures on the Moon

g) mining, industrial and research settlements on Near Earth Asteroids[20]

h) space based solar power plants

i) a big rotating space station (O'Neill concept[21]), with artificial gravity, in a Lagrange Libration Point, using lunar and asteroids raw materials

j) friendly policies toward civilian astronautics, industry and commerce, with tax discounts and grants to astronautic enterprises

k) international space investment funds, to allow savers and investors to invest their money in the opening of the Space Frontier, financing the many small and medium enterprises aimed to entry the civilian astronautic market

l) human exploration of Mars and the Asteroids Belt.

1.3 Exploring and settling the Solar Systen, within 2050 and beyond

Being a concrete agenda as the one drafted above well in place and rooted, it will make sense sending manned missions to more distant destinations, and possibly settling first outposts. The twenty years between 2030 and 2050 could count several thousand people living in space, working in space, thinking in space, in a full 3D environment, anymore conditioned by the heavy terrestrial gravitational well. In a well balanced expansion process, the colonies will spend the main part of their time in big rotating cities, reproducing the 1 G gravity of Earth, so they will not suffer too many physiological changes, and will be able to return on Earth, when they like so, without being disabled. Normal space workers will descent to the Moon surface, or to the asteroids, to do their working shifts. Explorers will undertake long lasting missions, and return to Earth or to their O'Neill cities. In such a new social reality, while the Greater Earth infrastructure will consolidate, new exploration and settlement missions will be conceived, with the support of a global economy finally recovered and growing up at an unprecedented rate. The program will include, at least:

a) a permanent research settlement on Mars, with the goal of studying the environment, and understand the conditions for a terraforming project -- i.e. a big "anthropogenerated climate-change" on Mars!

b) extended missions to the Asteroids Belt, with the goal of capturing asteroids rich of raw materials, minerals and ice, and moving them to space regions where they can be used in several ways: mining and rotating habitats, with accomodations digged inside

c) extended exploration of the Juppiter Moons, assessing the possibility to settle and to exploit their raw materials

d) improve our knowledge on comets and the Oort Cloud, with the goal of capturing ice comets, in order to increase water on Mars and other bodies in the Solar System

2 How 3D Printing can contribute to the human expansion and settlement in space

Having sketched the above progressive space colonization scenario, we are going to introduce and briefly discuss a number of possible conceptual applications of the 3D Printing techniques in such a context, and report the current status of the art, at D-Shape.

The 3D Printing technique is being used since several years on Earth, in collaboration with well internationally reknowned architects and scientists, to build habitation modules, bridges, artificial koral structures in the sea, for claiming desert areas, by supporting the growth of vegetable life and trees, and a growing number of solutions, often characterized by a regime of costs lower than traditional approaches, since the 3D printing technique mainly uses sand -- a quite common and abundant resource[22].

The 3D Printing technique, properly modified, was also tested in vacuum, in the frame of an ESA contract, developed in 2009 - 2010. We can therefore proudly talk, nowadays, about ***3D Space Printing***, appliable in a wide number of manned space situations and missions.

Talking about living and working in space -- and not just exploring --, two are the main issues to be resolved as soon as possible:

- sheltering from the hard radioactive radiations from the Sun[23], and
- protecting human phisiology from the effects of low or zero gravity.

As we will see, 3D Space Printing will contribute to the solution of both these relevant issues, as already discussed in the paper published by the author and partners by Acta Astronautica in 2012[25]

2.1 D-Shape[24] state of the art, March 2016

3D-Printing technologies, developed during the last twenty years and largely used nowadays by the architecture community, are highly relevant for any program of space settlement on celestial bodies such as the Earth's Moon and Mars. The capability to agglomerate inert materials (sands) using a special liquid binder is especially attractive for in-situ resources utilization related to the building of habitats. Namely, in airless environments (such as the Moon), an habitat made of tick 3D printed walls can be as much protective, against space hard radiations and micrometeorites, as an underground cavern, while its construction is less energy-intensive and requires a lighter equipment, provided that water is available. Moreover, the characteristcs of the underground rocks of the Moon are far less known than those of its sandy surface.

In 2009 ESA awarded a General Study Programme contract to an industrial consortium formed by Alta SpA (now SITAEL SpA), Monolite UK Ltd., Foster+Partners and Scuola Superiore Sant'Anna, to assess the 3D printing concept as a potential way to build habitats on the Moon using lunar regolith. The consortium merged knowledge in space technology development, 3-D printing at building scale, complex architectural design, and robotics. In particular, Monolite UK Ltd. holds the rights for the patented D_SHAPE 3D-printing technology, which is -among several different rapid prototyping systems- the one closer to enable full scale construction of buildings.

The physical and chemical characteristics of lunar regolith and terrestrial regolith simulants were assessed, with respect to the working principles of D_SHAPE, and a novel lunar regolith simulant was selected, using the ashes of the Bolsena volcano in Italy, which almost exactly reproduces the characteristics of the well-known JSC-1A simulant produced in the US. Tests in air and under vacuum demonstrated the reticulation process using the regolith simulant and a newly formulated chemical binder. The prevention of the ink evaporation or freezing in vacuum was proofed, by adopting a proper injection method. A preliminary design of a lunar habitat was made at

Foster+Partners, and a section of the outpost wall was manufactured at full scale using the D_SHAPE printer and the regolith simulant. Tests of mechanical properties were also made on pieces of the reticulated “concrete”. Within the outputs of the study, guidelines have been developed for future spatialization and automation of the printer and for design and 3D printing of the outpost.

The consortium is now approaching the executive design of a 3DPrinter-Robot prototype, and the run of a full simulated construction of the Lunar Habitat, inside a proper indoor test analogue to be developed.

2.2 Printing solid walls using in situ resources, sheltering from hard space radiations and micrometeorites

The 3D Printing technique allows to build, by a process quicker than any traditional building one, solid walls thick in the order of tens of centimeters, thus 100% protective against the Sun radiations, and micrometeorites as well. Competitor solutions so far proposed are to use water, or inflatable mattresses, thick enough. The water solutions require to move huge quantities of water, that could be largely available, from the Moon, Mars, asteroids and comets, but present a main problem: how to stem the water wall, protecting it from being dispersed in space by holes caused by micrometeorites. The inflatable mattress solution, as well, requires deep research and a huge experimentation process of suitable properly designed materials. The walls printing can be used both on the surface of exo-planets and in space, in orbit stations, yards and workshops.

2.3 Simulating exo-planetary conditions on ground

Before using 3D printing techniques on the Moon, Mars and other celestial bodies, we need to test technologies, methodologies, systems, tools and equipements (both human operated and robotic) on ground, simulating the conditions of the target location. Monolite UK is the only enterprise owner of DNA Regolith Simulant, based on the vulcanic sand of the lake of Bolsena (Italy).

We are ready to setup an indoor testbed analogue, using an industrial building of suitable size (e.g. 30 x 50 meters). The basic requirements of the testbed match the ESA requirements for the Moon 2020-2030 scenario, at least:

- a proper layer of regolith simulant, 1 meter thick
- rocks and crater structures, in a scenario designed by the architect Norman Foster
- proper illumination, similar to the Sun on the Lunar Polar region
- man made objects
- possibility to embedd ice in the soil (for water searching simulations)

Such a testbed (sketched in Figure 2) will be available for simulating both robotic and manned missions and, our main purpose, to properly test a 3D printer robotic rover.

With proper reorganization, the same environment can be set up for simulating missions to Mars, and possibly other exo-planets.

An outdoor test environment could be organized as well, on the Etna vulcan (Sicilia), where suitable terrain and geomorphic configurations exist, should the simulation environment match particular requirements, such as rovers testing on long distances and nearly “unpredictable” terrain configuration conditions.

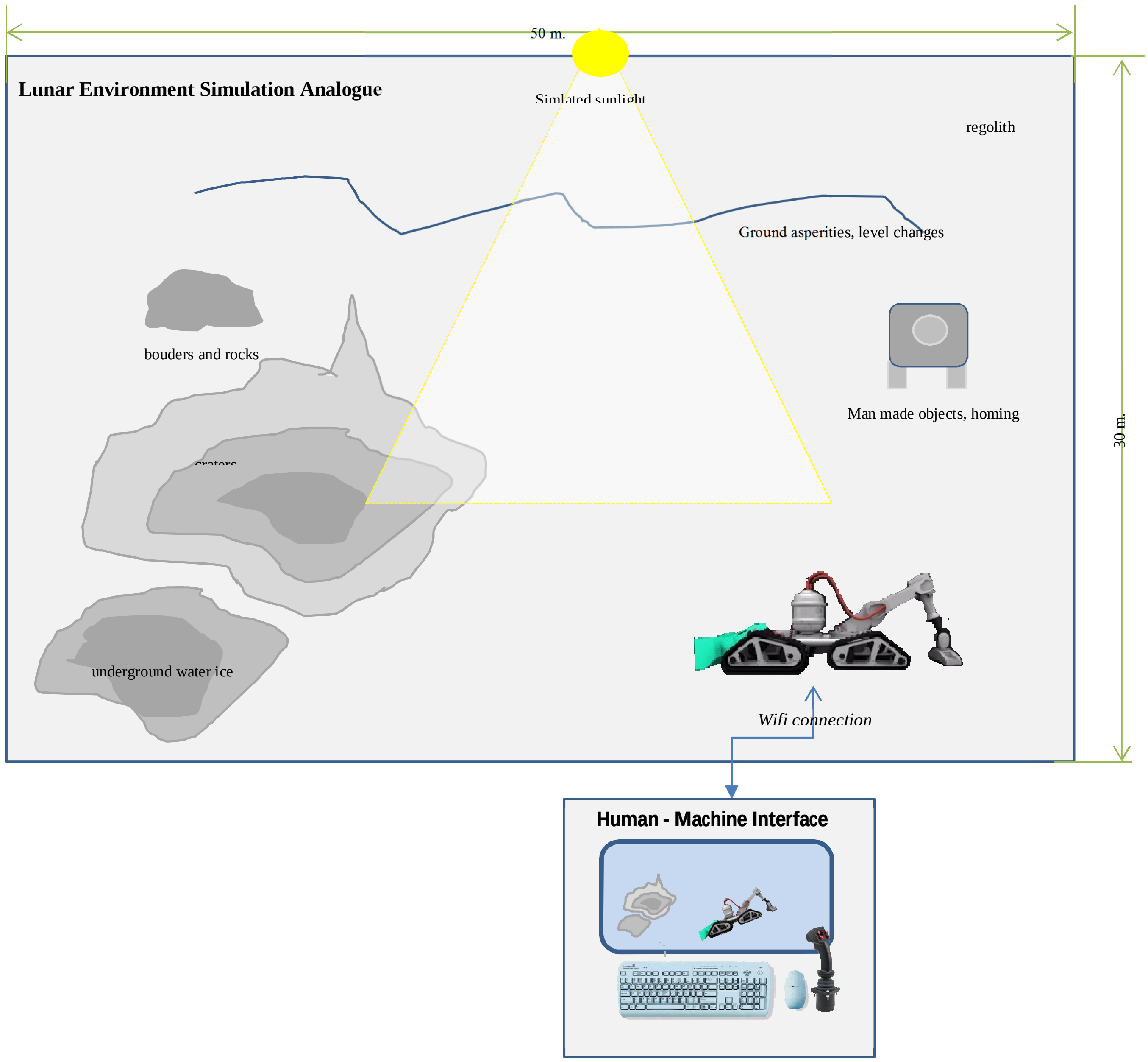

Figure 1 Lunar Scenario Indoor Testbed

2.4 Lunar habitats

The case of the lunar habitat was already investigated[25], and a proper method proposed, based upon an automated rover, that incorporates a 3D Printer using lunar regolith and proper glues. This technique was already experimented in vacuum, on ground.

The following pictures (nowadays very popular on the web social networks) are abstracted from the work made by Architect Norman Foster, in the frame of an ESA contract developed in 2010.

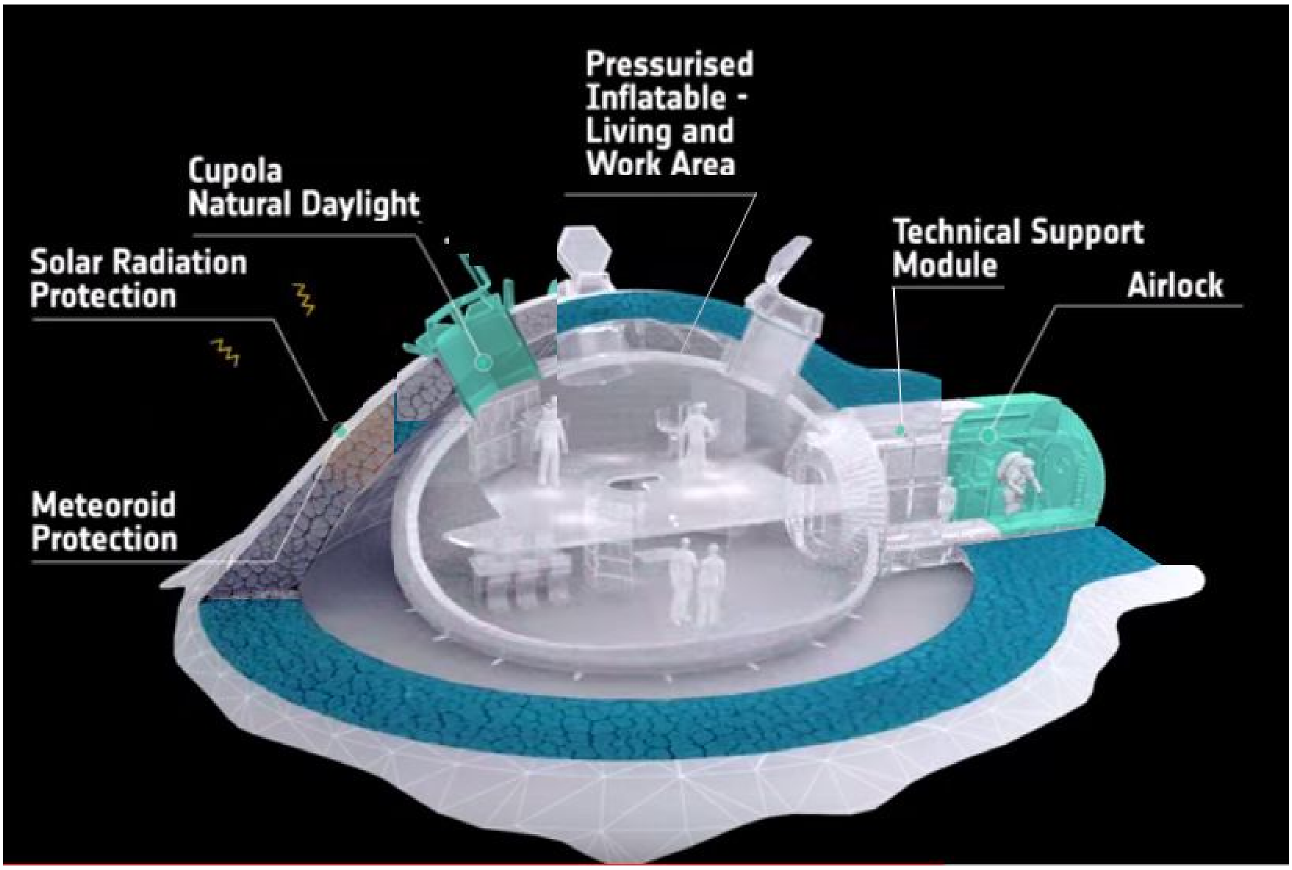

Figure 2 The pressurized 3D printed lunar habitation module

Figure 3 A Moon base, composed by several 3D printed modules

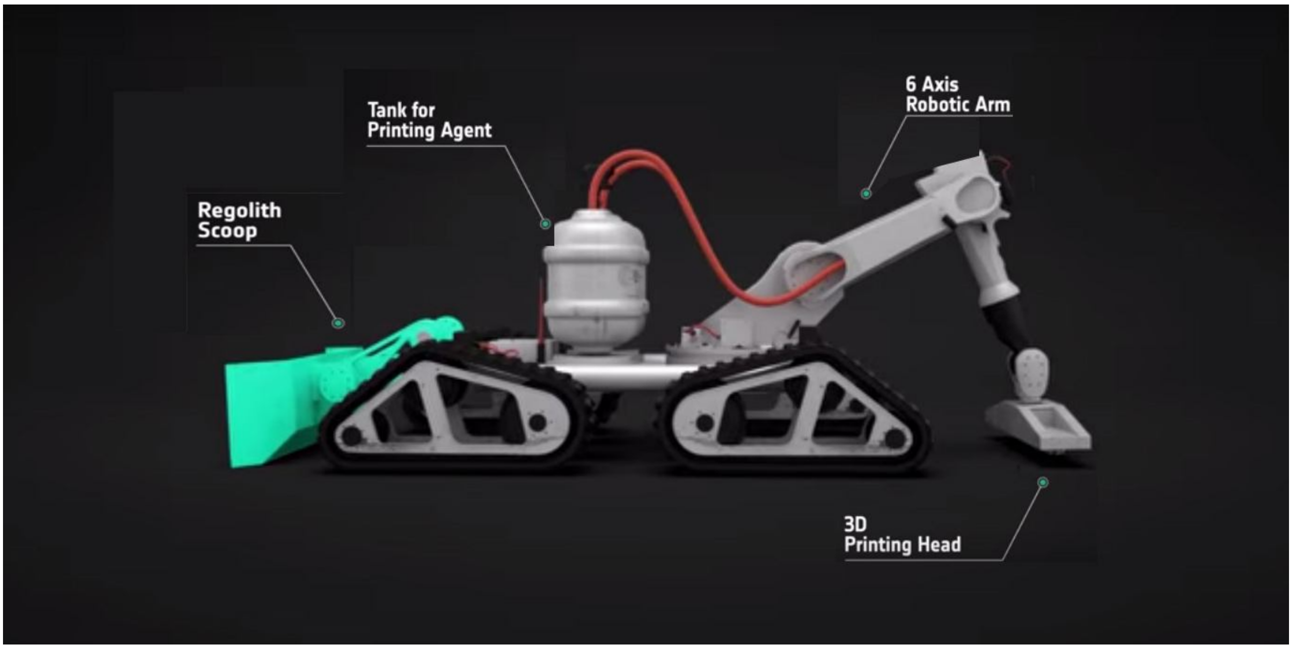

Figure 4 The lunar 3d printer robotic rover

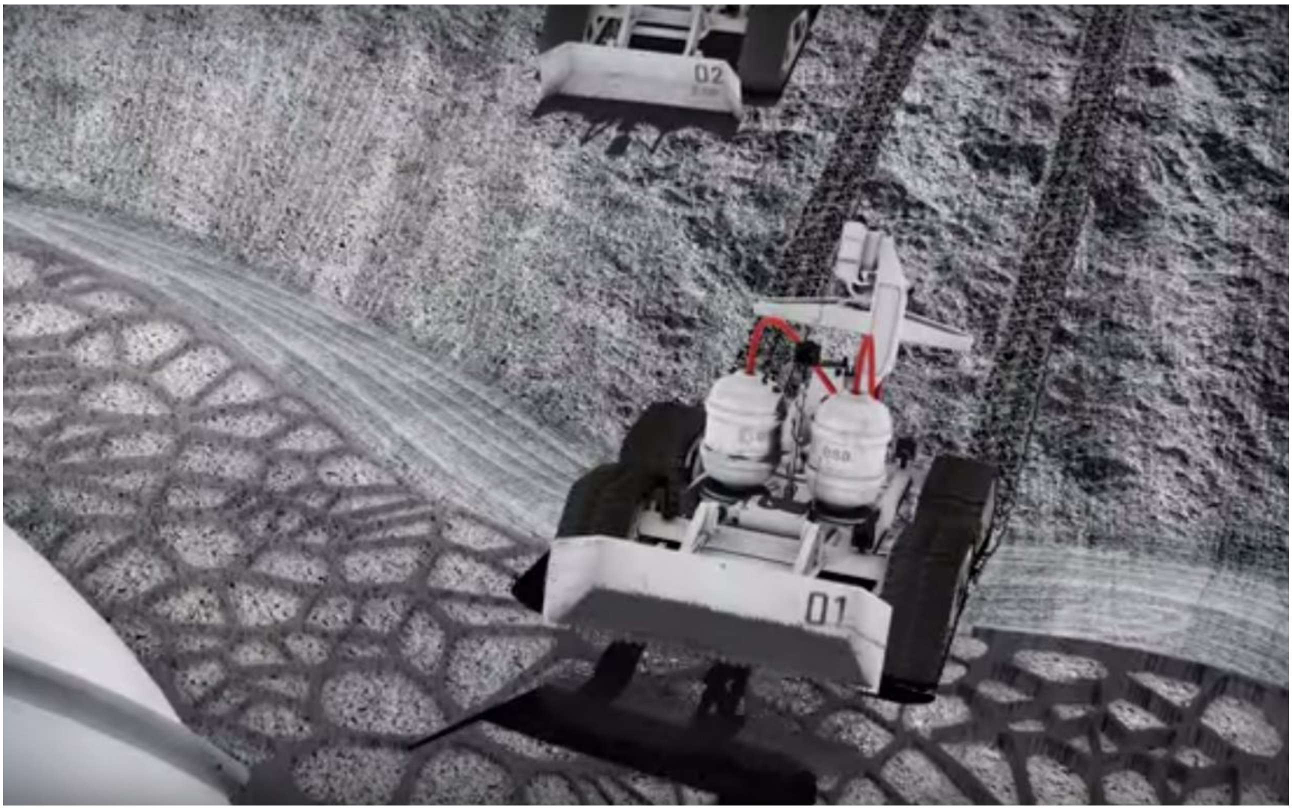

Figure 5 The lunar 3d printer robotic rover while depositing a layer of regolith

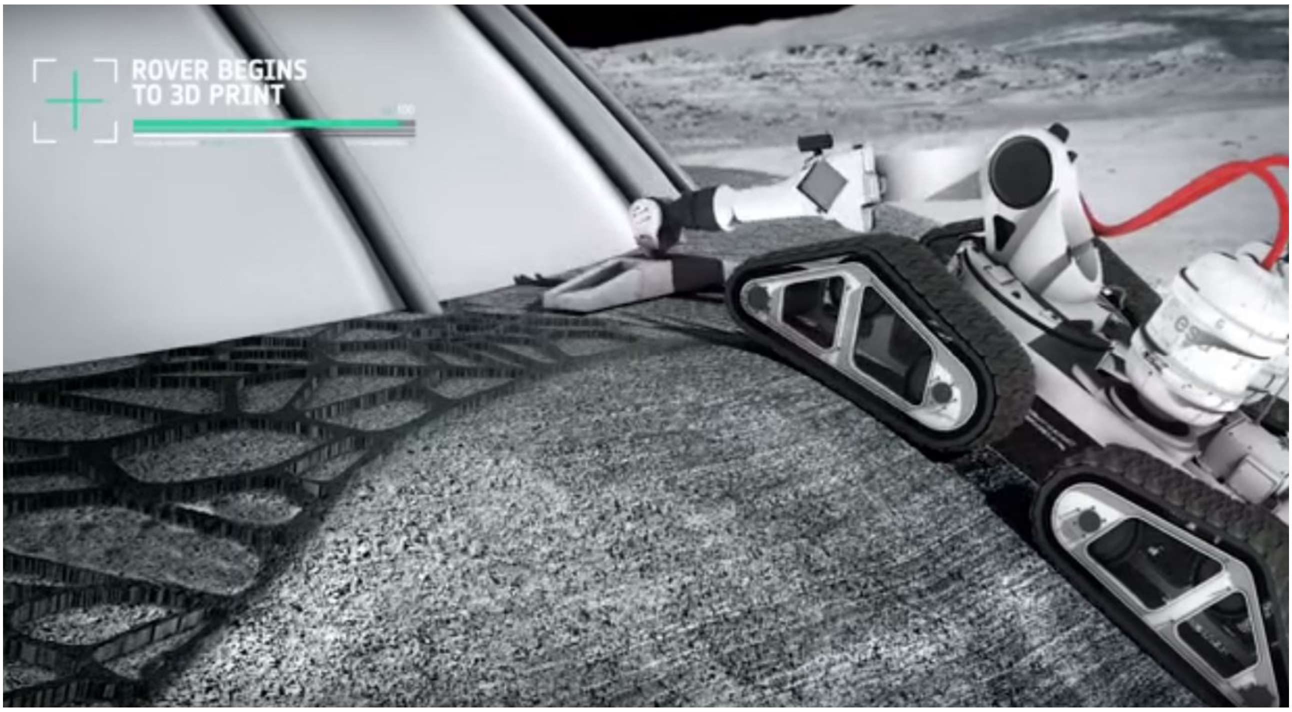

Figure 6 The lunar 3d printer robotic rover while cementing a layer of the wall

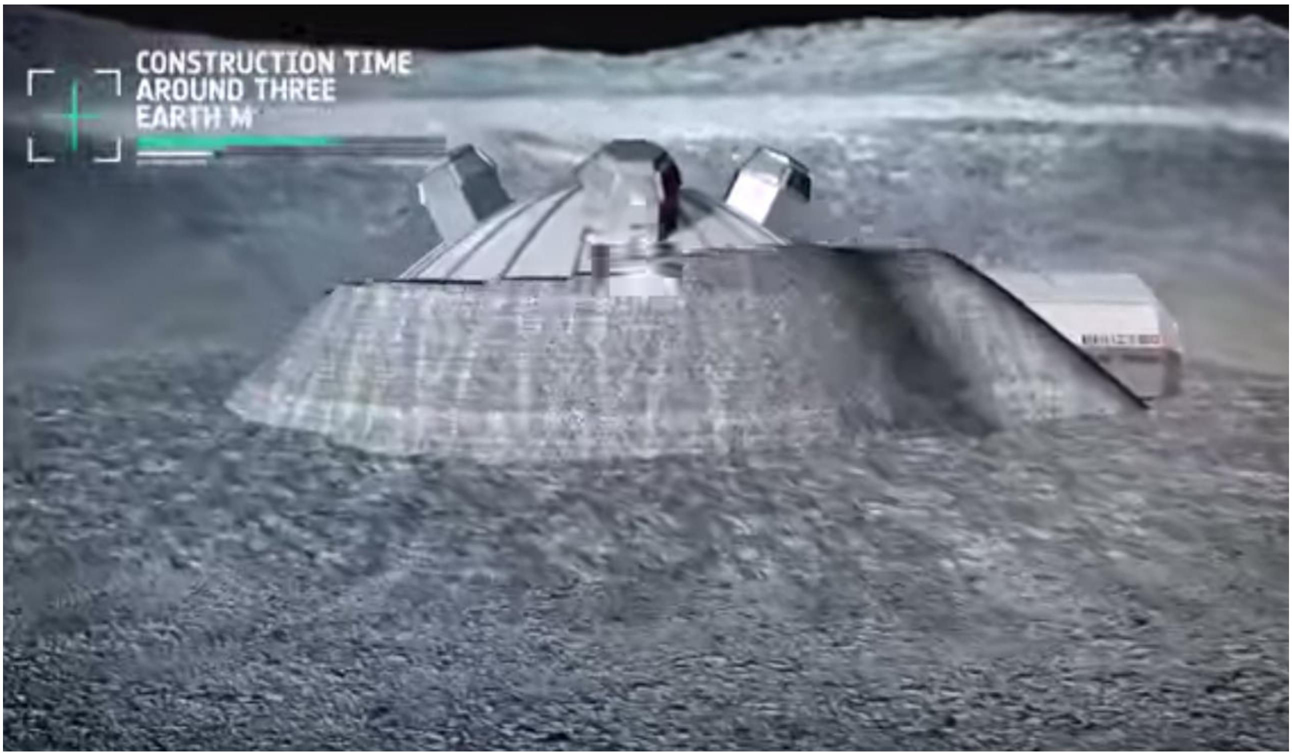

Figure 7 The lunar 3d printer robotic rover, 60% work done

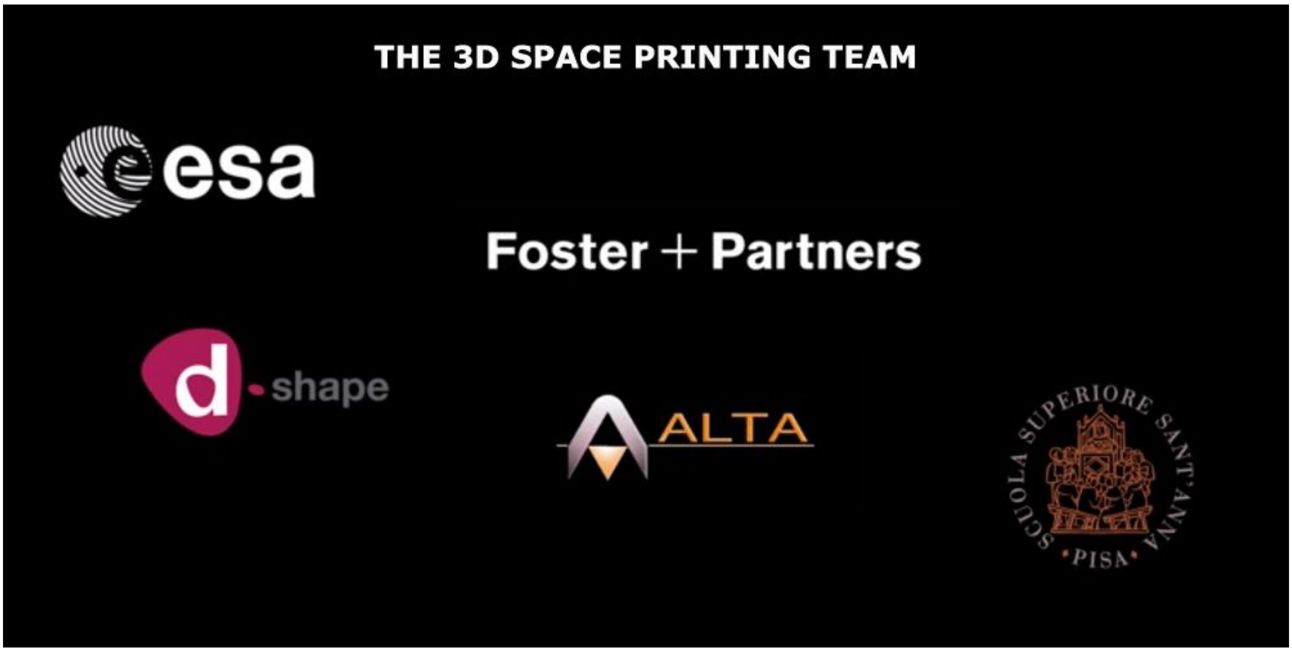

Figure 8 The 3D Space Printing Team

2.5 Mars habitats

Being sand a very abundant resource on Mars as well, we can envisage to develop a similar technique for building habitats on the Martian soil.

In areas where temperature never exceeds the icing temperature, igloo techniques can be used, to build habitats, by melting the permafrost, mixing it with regolith and 3d printing it in properly shaped building blocks. Also see the recent competition, held in the USA, NASA's Centennial Challenges, 3-D Printed Habitat Challenge. The winner of the competition developed a concept of an ice pyramid.[26]

2.6 Orbiting infrastrutures construction

Using properly designed inflatable and chemically rigidizable frames, 3D Space Printing can be used in space, in yards located in Earth or Moon orbits, or at a Lagrange Point of the Earth-Moon system. Infrastructures located at the L4 and L5 positions would have the advantage of being stable, without any need for stationkeeping, and could be used as a waypoint for travel to and from cislunar space.

As sketched in Figure 9, a tubular inflatable structure is firstly deployed and chemically rigidized. Such structure shall provide a cylindric interpsace, inside which the 3D injector will deposit the regolith and the glue (or a properly designed foam, endowed with suitable adhesiveness). The circular open side will be properly closed, according to the specific requirements (hatch, porthole, ...).

It is easy to imagine even very big rotating infrastructures, composed by several tubular modules assembled together, to form toroidal structures. Other formats can be envisaged as well: sea urchin, starfish, etc... All of these formats will allow rotation, and artificial gravity at periphery, conserving zero g, for reserch, sport and recreative activities[27].

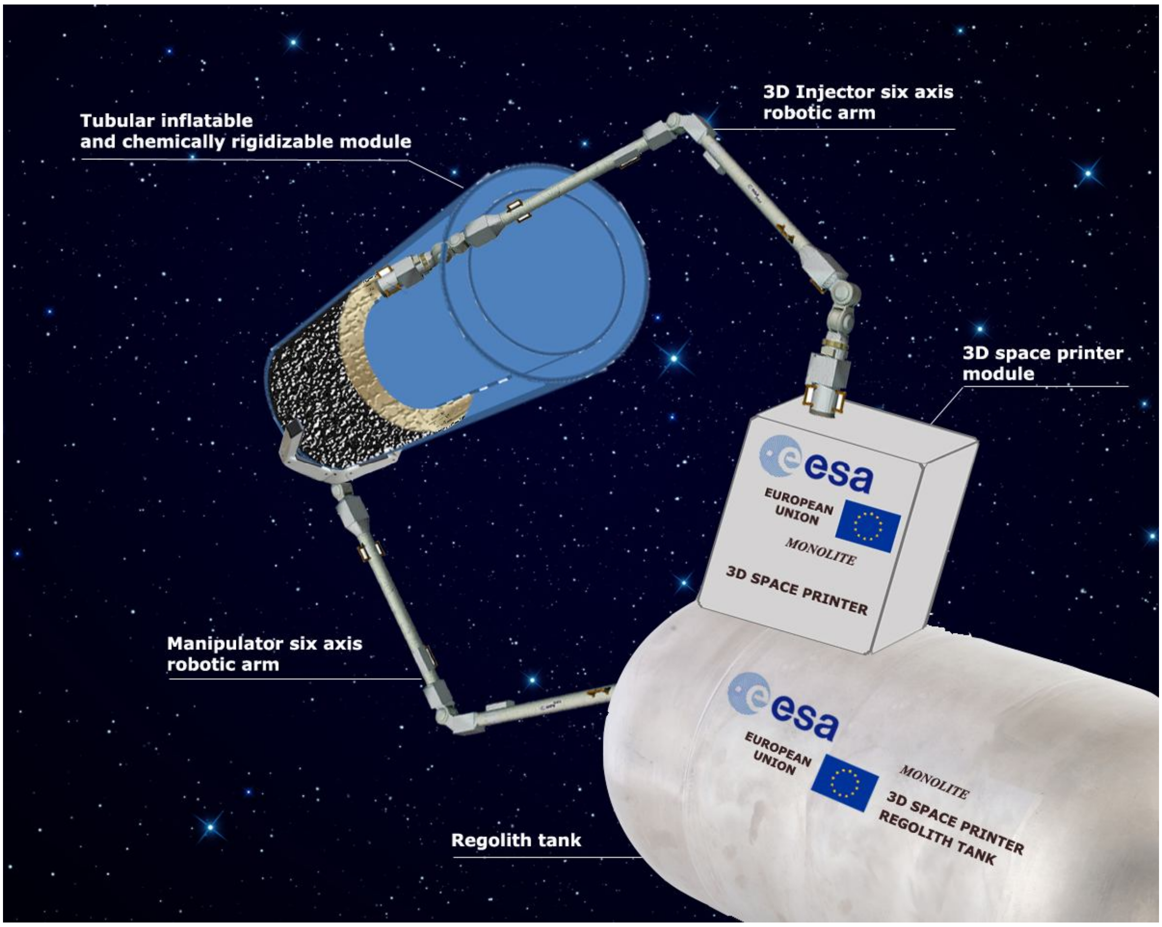

Figure 9 3d printing at zero G, vacuum conditions - conceptual view

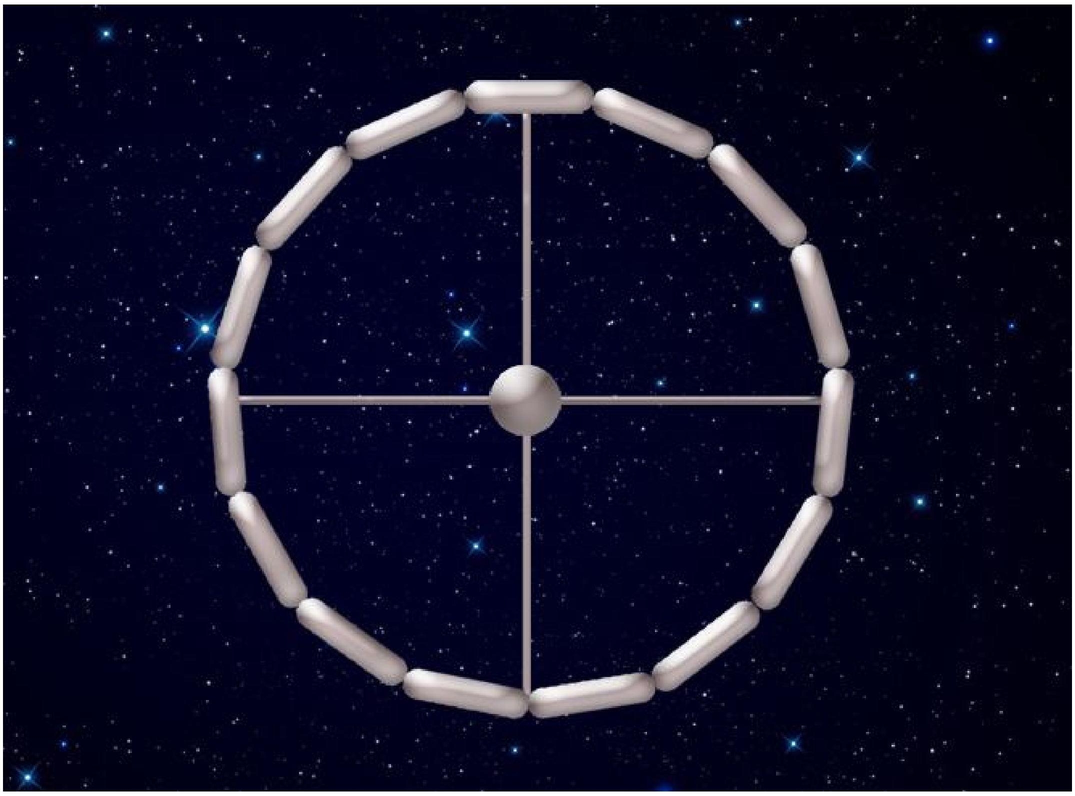

Figure 10 A thoroidal space hotel, made by 3D printed modules - conceptual view

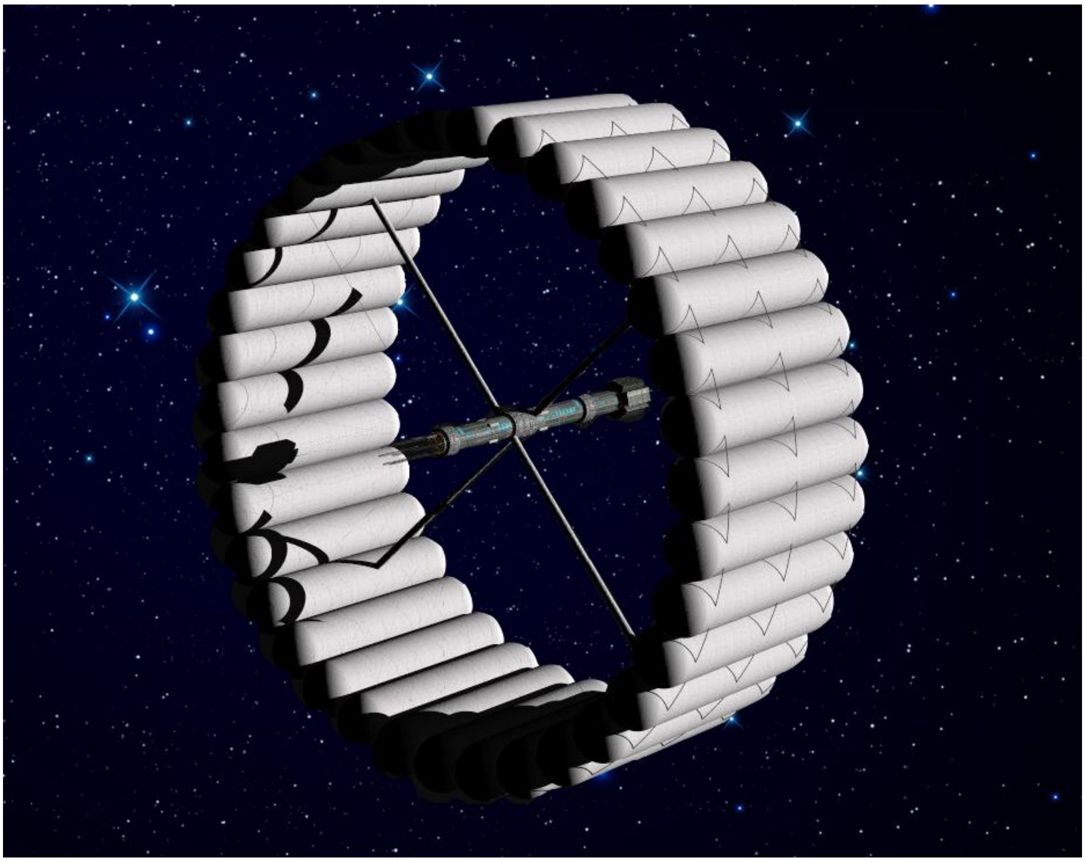

Figure 11 A thoroidal space hotel, made by 3D printed modules - conceptual view

2.7 Asteroid shelters

The same concept used for zero G environments can be applied to situations endowed with very low gravity, such as asteroids and small moons.

Possibly, the 3D printer module could be integrated by a machine properly designed to smash mineral materials, getting a powder to be used for 3d printing.

Another possible use of 3D printing, to cover and build well shaped and sheltered accomodations inside caverns hollowed inside an asteroid.

2.8 Building ground infrastructures and facilities in extreme Earth' environments

3D Printing techniques can be used on Earth, to build up facilities in extreme environments, such as desertic areas, very cold environments, remote islands.

Facilities in extreme Earth environments could be useful at least for the following goals:

a) to simulate extraterrestrial planets and natural satellites environments, such as the Moon and Mars, in order to experience missions conditions similar to the target space environments

b) quick building of habitation modules and facilities for ground stations and launch bases that need to be located at particular latitude coordinates

Using 3D techniques would allow:

a) a very quick performing of the building task

b) cheap cost, using in situ resources, such a sand or similar inert materials

c) a strong shelter against extreme weather and climate conditions

d) a robust construction, against strong winds and hurricanes

3 Beyond 2050

3.1 Mars terraforming

The biggest challenge that our civilization will likely face during the current Century, will be the colonization and settlement of Mars.

Many scientists believe that in past ages Mars had surface water and an atmosphere very much richer that the current one. It is also a very common understanding, that Mankind coul restore a living environment on the red planet, giving birth to a process called *terraforming*.

Such a project will be a giant effort, lasting several centuries. Key concepts include:

a) forcing the liquefaction of the Martian water, encouraging a greenhouse effect, that will raise CO2 and causing the melt of the underground ice

b) maybe catching some big comets, in order to increase the amount of water on the Mars surface

c) create artificial aquifers, in order to create humid and fertile ground areas

d) build structures that can support the growth of vegetation suitable to generate oxygen in the atmosphere

Besides the building of habitation, research and industrial modules, using a method similar to the one used on the Moon, proper methods can be investigated, in order to stimulate the growth of (initially) closed climatic environments, propaedeutic to growing up vegetable and animal life on the surface of Mars.

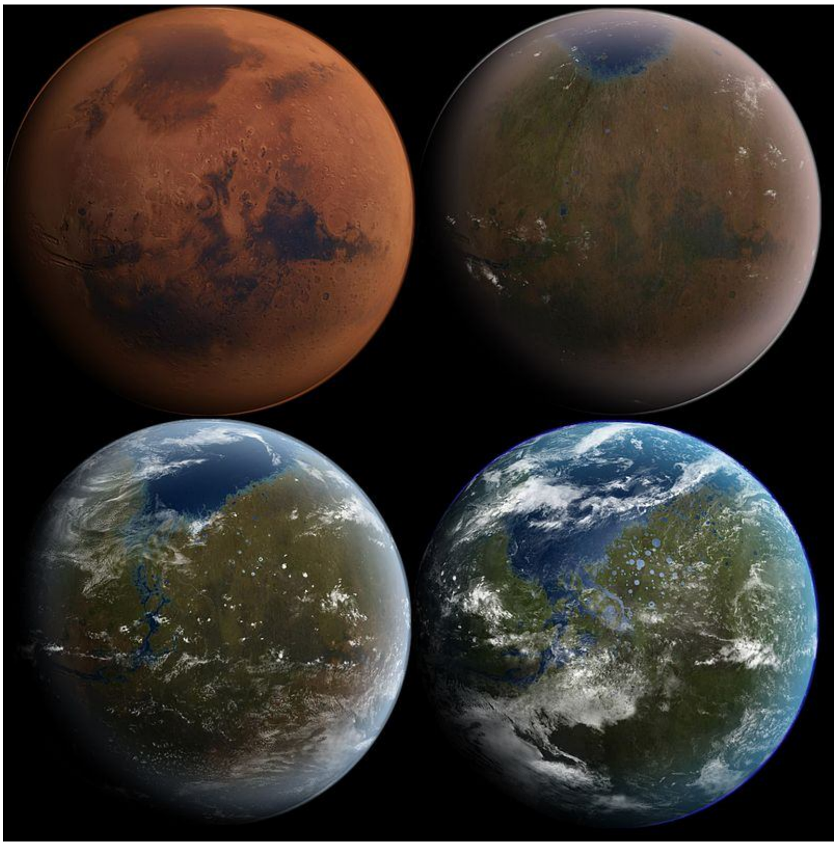

Figure 12 The Mars Terraforming process - an artistic view

E.g., in order to support possible very large domes, big towers could be built up (50 meters high and more) by means of 3D printing tecnhiques, using the martian sand in combination with proper glue. Inside the towers, habitations, offices, restaurants, shops and workshops could find place as well.

4 Research lines

D-SHAPE, in collaboration with its partners, is developing research activities in the field of 3D Printing technologies for exo-building.

4.1 Goals

The main goals of the research are summarized hereafter:

1) to provide a safe shelter against hard radiations and micromeorites impacts, to protect human life and health
2) to maximize the use of exo-resources (in situ)
3) to minimize the weight and volume of the materials to be carried from Earth

4.2 Investigation Guidelines

The following technologies will be investigated:

1) 3D printing, using poliuretans and regolith simulants
2) 3D printing, using laser syntherization
3) 3D printing, using permafrost combined with regolith simulants
4) 3D printing, combined with inflatable and chemically rigidizable structures as containers for building blocks and temporary pressurized workshops

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