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Viable construction technology for habitation on Mars: Fused Deposition Modelling

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Abstract

With the current huge investments in the space exploration programs across the globe, colonizing the planet Mars had become a hot topic since past couple of years. There are many aspects affecting the Mars colonization such as political, economical, social, technological, environmental, and legal. In this study we ought to investigate on the possible expected properties of cementitious materials on Martian condition based on the data published by NASA and scientific principles. Technological suggestions had been proposed in order to clarify the possible technologies those that can facilitate the production of durable construction materials on Mars and in general construction on the red planet. Fused Deposition Modelling had been introduced as the most viable construction technique compromising automation as the trending practice in the industry.

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Keywords

Martian soil; Cementitious Materials; Urban Development; Additive Manufactoring

Introduction

As NASA become leading hand for this project most of other countries also giving their best to achieve this goal as one world. However, there can be considerable social and political impact from this program to people who are going to join with the program, and for the people who is living on earth. Considering basic needs of human as recognized by scientist's, are oxygen, water, food and shelter. There are several ways to produce Oxygen through chemical reactions and that give a potential to make enough oxygen. Mars atmosphere is about 100 times thinner that it is in Earth's and there are 95% of CO_2. In order to manage out daily body intake, we need to change our daily behaviours, which directly effects to the social life. Apart from that, housing and other social needs will be getting different to what its looks like on Earth. Training people for these new experiences will be harsh and it requires huge amount of investments. Upon the success of this program more and more government agencies trying to promote the space programs in order to improve people's interest on space and mars colonization. Other than that, there are broad opportunity for new technologies related to new resources found on Mars. The opportunities that arises to further grow the economy has to be considered. There is a vast amount of jobs created due to the Australian space programs including the demand for engineers, technicians as well as lawyers. The stimulation of job growth in this area would contribute above and beyond the costs of funding, strengthening Australia's economy.

In terms of technology and its impact for Mars and its habitation, we will observe how the Australian Space Agency has impacted research and technology related to mars and its habitation. The Australian Space agency is relatively new and has many potential ways of improving the methods of construction and transportation to Mars. Australian Space agency, in conjunction with the Australian government, plans to support NASA on its mission to go to the Moon and later to go to Mars. It is stated that the Australian space agency will research and develop technologies related to robotics, automation and artificial intelligence.

One of these areas will be robotics, and how they may help in traversing the landscapes on mars. Robots are already in use in many area within the construction sector aiming to improve productivity and lowering the risk associated with large projects [1, 2]; however, they are basic and are used to gather data rather than help build habitations on other planets. In order for robots to be effective at building habitats on mars they need to be self-sufficient. Currently robots are just being used in the construction in industry in the form of large 3d printers. If a robot was to be made for the construction of habitats on Mars, they would need to be able to accurately survey the landscape, understand the reactiveness of the soil and construct/ 3d print a habitat specific to Mars and its environment. Robotics in the construction of Mars habitats will be very useful, this is because they can be deployed to Mars to construct a habitat for humans to use.

With the introduction of Robotics into the mission to Mars and Mars habitation, there will be a need for automation. Automation is used to streamline a procedure with minimal human interference. Automation is rarely used in the construction industry due to projects being unique to each other, however it will be very beneficial for the construction of Habitats on Mars. The evaluation of productivity level once the robotics had been employed in construction shows a great benefit by implementing such techniques[1, 2]. Automation can be easily applied to robots following a blueprint specific to Mars. This is because the buildings that are designed to be on Mars will not be too different from each other and will all follow the same construction method. This will allow for many Habitats to be constructed on the surface of Mars, with minimal human interference.

As Ehlmann, et al [3] note, the prospective benefits Martian exploration overrides the costs. It had been investigated and reported that in a long term perspective, even the expense analysis rationalizes the Martian exploration when it is compared to the other governmental expenditures. The Several technological aspects are present for colonization of Mars. Issues such as low gravity, low atmospheric pressure, temperature variation throughout a day, etc. The list even goes down to the most human's basic needs namely food, water, oxygen, shelter, and clothing. Solutions had been scientifically studied to overcome these barriers. To name a few in accordance with Elhmann [3] evaluation the technological advancement mentioned in table 1 can be seen as an approach towards these problems:

Table 1 Facing challenges and solutions in Mars mission

Challenge to a human Mars mission	Technology development	Terrestrial application
The negative effect of microgravity and solar radiations on human	Pharmacological and mechanical prevention techniques	Prevention, detection, and treatment of illnesses ranging from osteoporosis
Limited air, water, and food resources	Closed loop life-support systems	Conservation, waste management and recycling
Limited energy supply	Solar energy, low energy uses, graphene panels [4, 5]	Renewable efficient energy sources; energy

However, for the sake of this study we will investigate the feasibility of human shelter and appropriate construction practices on Mars.

Since it is well known that the transportation of construction materials and equipment is not cost efficient, the use of in-situ resources is the most viable option available. This concept requires technical advancement in many aspects specially 3D crafting techniques which employs a full automation in construction. From the planning point of view, the first step would be sending a construction robot (3D Printer) prior to the habitation of human as the next step. Kading and Straub [6] propose the utilization of basalt 3D printing approach. This proposal is supported by the chemical characterization obtained from the Martian soil sample which will be discussed in the following sections. It had been claimed that basalt due to its suitable mechanical properties such as 73 GPa as the modulus of elasticity and 14 MPa as the tensile strength, is the right choice for the material to be used [7]. The radiation resistance of basalt is another convincing property [8]. One important aspect of Martian shelters which requires enormous attention is the fact that due to the pressure differences in and outside of the shelter the structure must be sealed and strong in tension.

Soil Characterization

Historically the chemical composition of Martian soil was understood by the data received from the remote telescopic observation. These data had revealed a small portion (2-4 wt%) of well-crystalline iron oxide like hematite is present in a matrix of more poorly crystalline ferric oxides and other, spectrally neutral, aluminosilicates. These interpretations indicate the existence of homogeneous and fine-grained weathering product as the main component of soil everywhere on Mars. Most of the remote sensing data had been obtained from the Viking Lander prior to the landing of Mars Pathfinder.

The Mars Pathfinder had exploited the cluster of knowledge on Martian soil by focusing on morphological, geochemical and mineralogical characterization. The mission carried a well-equipped lander with enhanced multispectral imaging capabilities compared to Viking. The highly mobile rover that was able to perform soil mechanics experiments, was also equipped to measure the elemental chemistry of soils and rocks.

Table 2 Mineralogy of the Martian soil [9]

	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	Cl	K_2O	CaO	TiO_2	Fe_2O_3
Pathfinder soil	2.2	7.5	8.3	48.6	5.4	0.6	0.3	6.3	1.1	17.5
Viking soil	-	6.0	7.2	43.4	7.4	0.8	-	5.8	0.6	18.2

Fused Deposition Modelling (FDM) is a 3D printing technique known for its high sealant properties. FDM is performed by the assistance of Computer Numerical Control (CNC) in order to craft the molten material precisely in the desired place in layers. The molten material flow onto existing material and the new and existing materials fuse together as the temperature drops and solidification occurs. The machine used in this method is equipped with a laser shotgun which typically delivers 100 Watts of laser power at a wavelength of 1070 nm [10]. Khoshnevis et al. upon the same study state that once the incremental energy had been increase to a certain degree the melted substance had become more homogenous. The technique had reported a high accuracy as well when it comes to the shape of the final product.

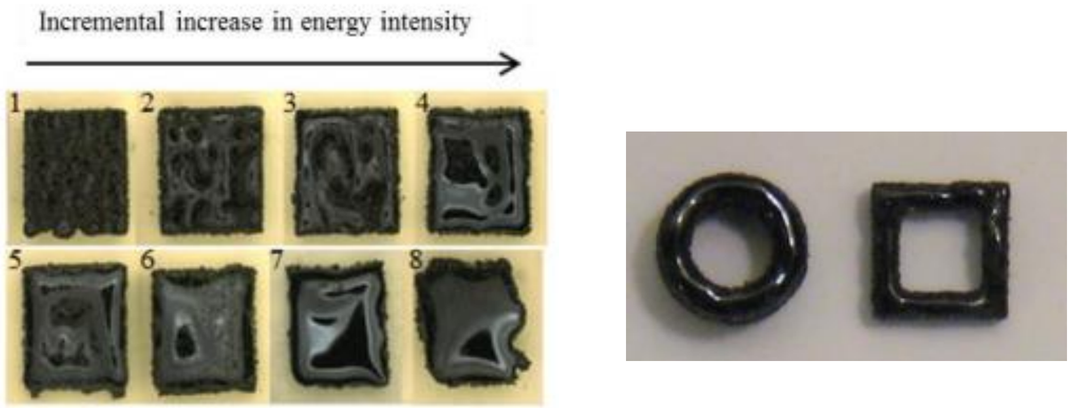

Figure 1 The product of Fused Deposition Modelling on basalt additive manufacturing[10]

Having the chemical composition of Martian soil revealed, the next step is to investigate on the applicability of additive manufacturing techniques [additive manufacturing of physical assets by using ceramic multicomponent extra-terrestrial materials]. A. Goulas had tested the Martian simulant material mainly consists of palagonitic tephra AKA weathered volcanic ashes. It is stated by Goulas that due to the differences exist in the properties of Martian soil in various regions of the Mars the simulant material is not a de-facto standard. The additive manufacturing machine used in that study was Realizer SLM100A Selective Laser Melting (SLM). The following process parameters mentioned in table 3 was reported during the experimental procedure:

Table 3 Process parameters reported in Goulas studies

Parameter	Value
Laser	Near-IR [11] Ytterbium fibre laser
Power (w)	5-50
Wavelength (micro-meter)	1.06-1.09
Diameter of laser spot (micro-meter)	80
Point distance (micro-meter)	30-1000
Hatching space (micro-meter)-(Overlap %)	52-80 (35-0%)
Exposure time (micro second)	100-1000
Thickness of powder layer (micro-meter)	150-300
Velocity (mm/s)	Point distance/exposure time
Environment	Argon atmosphere
Temperature of substrate (Celsius)	200
Substrate material	Mild steel

Despite all of the advancements and the current status quo of knowledge, the practicality of the theories proposed will remain behind the curtains until an equipped construction robot enhanced with additive manufacturing technology lands on Mars in order to perfectly evaluate the performance in the real case. NASA’s plan about creating a liveable environment on Moon prior to starting off the Martian mission is a wise approach towards understanding the structural behavior of housing in extra-terrestrial conditions. Nonetheless, additive manufacturing is the most viable construction technology in terms of productivity, speed, and cost.

In terms of shape, the cylindrical shape had been studied to be the most suitable architectural form (figure 2). A simple trade study of spatial and material efficiency shows that a vertically oriented cylinder is the best form of surface habitat on Mars. Apart from being a highly effective pressure vessel, they provide the greatest ratio of usable area to volume. This means that cylindrical shell when it is compared to a dom, provides more efficient space.

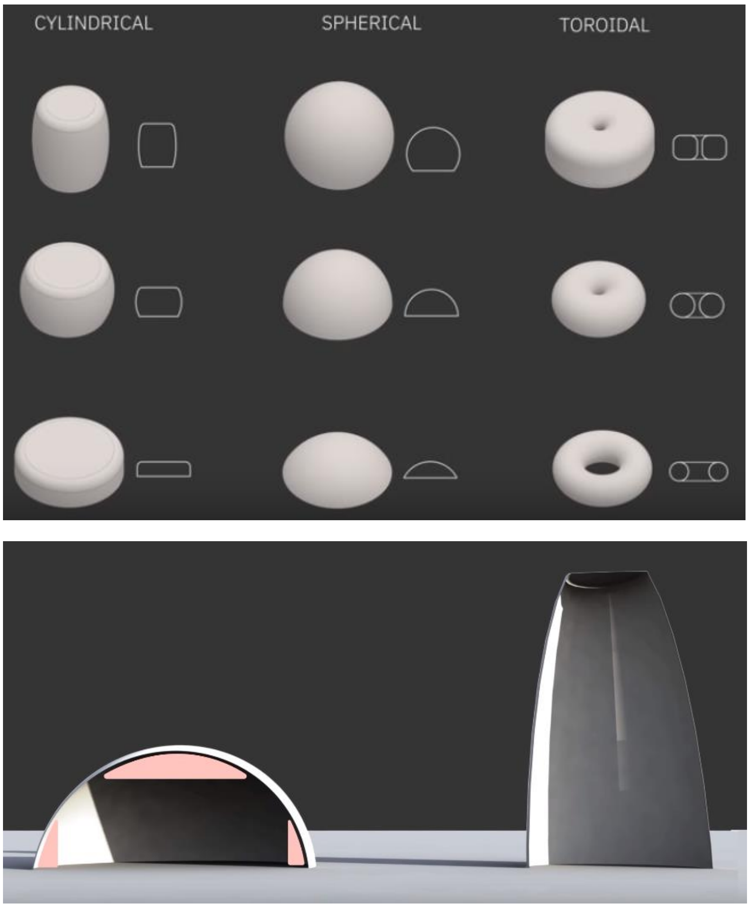

Figure 2 Illustration of the appropriate pressure chambers as the living area for human on Mars

Conclusion

Despite all of the advancements and the current status quo of knowledge, the practicality of the theories proposed will remain behind the curtains until an equipped construction robot enhanced with additive manufacturing technology lands on Mars in order to perfectly evaluate the performance in the real case. NASA's plan about creating a livable environment on Moon prior to starting off the Martian mission is a wise approach towards understanding the structural behavior of housing in extra-terrestrial conditions. Nonetheless, additive manufacturing is the most viable construction technology in terms of productivity, speed, and cost.

Recommendations

The future of studies aligned with the Martian programs rely on the followings:

- A well designed robotic tool compatible with the extra-terrestrial conditions for implementing additive manufacturing techniques.
- The so-called robot must be able to record the performance and be equipped with self-correcting computational programs.
- Self-correcting programs require a well-established set of possible faults that may occur in off-earth construction
- The 3D printing robotic tool needs to be tested on earth in a simulated environment as similar to Mars i.e. the atmospheric pressure and atmospheric composition (CO_2-rich environment)

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