Space Architecture for exploration and settlement on other planetary bodies – *In-Situ* Resource Utilisa-tion (ISRU) based structures on the Moon

Conference or Workshop Item

How to cite:

Lim, Sungwoo and Anand, Mahesh (2014). Space Architecture for exploration and settlement on other planetary bodies – In-Situ Resource Utilisa-tion (ISRU) based structures on the Moon. In: European Lunar Symposium 2014, 15-16 May 2014, London, UK.

Space Architecture for exploration and settlement on other planetary bodies – *In-Situ* Resource Utilisation (ISRU) based structures on the Moon. S. Lim[1] and M. Anand[2,3], [1]Department of Engineering and Innovation, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK, [2]Department of Physical Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK. [3]Department of Earth Sciences, The Natural History Museum, Cromwell Road, London, SW7 5BD, UK

Introduction: Space Architecture is the theory and practice of designing and building an extraterrestrial environment for human habitation [1]. It combines engineering and aesthetics, requiring knowledge of space environments, space systems engineering, and the psychology of isolated and confined environments [2]. The Space Architecture field was incidentally established when, shortly after 1968 when humans left Earth's orbit for the first time, architect Maynard Dalton and industrial designer Raymond Lowy designed the interior of NASA's first space station, Skylab [3]. Other professionals then began to develop the theory and principles of Space Architecture, and it was finally officially established through a peer-reviewed Symposium at the World Space Congress (Houston) in 2002.

Building a human habitat in hostile environments on other planets requires locally sourced and manufactured construction materials, known as *In-Situ* Resource Utilisation (ISRU), and a fully automated construction assembly. Because ISRU is one of the most important concepts in the potential realisation of a deep-space exploration and space architecture, a significant amount of ISRU-related research has been carried out over the past 4 decades [4]. NASA has classified three types of extraterrestrial habitations as (i) Class I: pre-integrated hard-shell modules, e.g. the International Space Station; (ii) Class II: prefabricated and surface assembled modules, e.g. inflatable structures; and (iii) Class III: ISRU derived structures integrated with the Class I and II modules [3]. As more and more complex lunar missions are planned by various space agencies, the topic of ISRU will gain prominence, and be of fundamental importance for the viability of such ambitious undertakings. Thus, those involved in the Space Architecture field believe ISRU is particularly important for deep-space exploration; for example, ISRU on the Moon would produce propellant, shielding materials, water and oxygen which can reduce the amount of mass launched from the Earth to other planets such as Mars, thereby saving billions of dollars of the space budget. They thus contemplate robotised manufacturing technologies as key technologies in the construction of Class III human habitations and infrastructure, including radiation shields, surface paving, bridges, dust-shield walls and spacecraft landing fields, etc.

Background Technology. Additive manufacturing (AM) is defined by the American Society for Testing and Materials as "the process of joining materials to make objects from 3D model data, usually layer upon layer" [5]. Over the last 30 years, improvements in AM materials and processes have resulted in successful commercial realisation. AM is now an integral part of modern product development [6] and the technology has been commercialised to the extent where machines are now affordable for home use. The linear cost/production relationship for small-batch production is unique in the manufacturing sector providing a strong business case for mass-customisation or personalisation of components. For example, a comparison between AM and injection moulding demonstrates that AM can be cost-effective for smaller batches (up to 10,000x) [7].

In construction, the first attempt at using cementitious materials in an AM approach was suggested by Pegna [8]. Because of the slow adoption on new construction technologies and the relatively short history of AM in construction – less than two decades – only two large-scale AM processes focus on the built environment in the academic literature: Contour Crafting [9] and 3D Concrete Printing [10], and one in industry: D-Shape (Monolite) [11]. A range of construction forms has been identified where geometrical freedom has great potential for introducing mass-customisation in the construction industry, replacing the need to restrict component variability to the limits of how many moulds can be economically produced. These include major urban developments in the Middle East (e.g. Masdar city housing in Abu Dhabi) which would require an enormous number of detailed temporary formwork installations using conventional construction processes, to achieve the complex geometry envisaged for the building façade to control shading, solar gain and ventilation [10].

R&D on space Architecture: In industry, Beglow Aerospace signed a contract with NASA in January 2013 to explore options for a lunar base and public-private orbital outposts near the International Space Station. However, Beglow's habitation will be an inflatable module, Class II under NASA's classification. ESA and Foster+Partners (F+P) collaborated with D-Shape in 2010 to investigate the capability of the process to be used for Space Architecture (Top image in Fig. 1), and the team tested a closed-cell structure (Bottom image in Fig. 1) which both retains loose regolith and ensures shielding from cosmic rays and solar flares [12, 13]. However, such efforts to develop construction processes for Class III structures are still in their infancy and require further development to become a practical application.

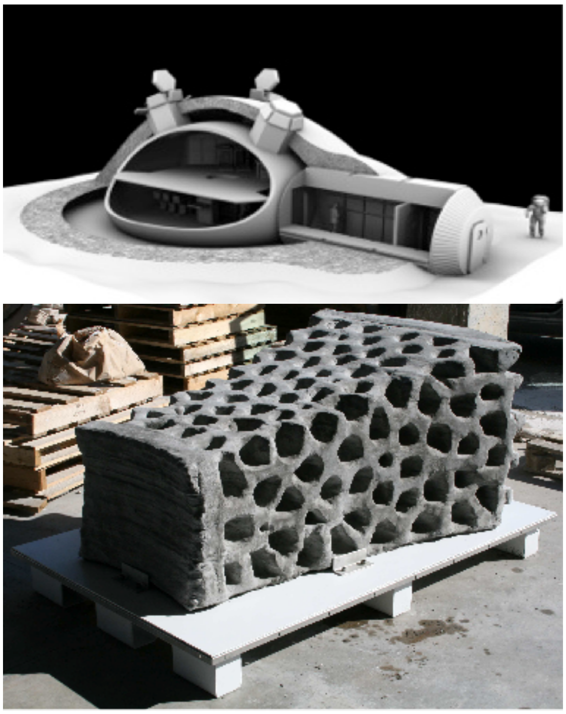

Figure 1: *Top - Outpost design that shows a core and extendable modules covered by a lunar regolith shield (F+P)* [12]; *Bottom - Printed block using a Lunar simulant (D-Shape)* [13]. The exact size of the block is unknown, however, the footprint of the block is estimated to be less than 1,000 by 2,000mm compared with the European pallete (800 by 1,200mm) beside of the block.

In academia, there is only one institution – Sasakawa International Centre for Space Architecture at the University of Houston – which focuses primarily on planning and designing Space Architecture. Moreover, despite a number of publications discussing the designs and deployment strategies of Lunar and Martian outposts [14, 15], few publications focus on the construction processes and technologies required to realise such designs.

Discussion: Over the last decade, Space Architecture has become an emerging issue for future space exploration, and is increasingly seen as a fundamental requirement for supporting long-term space exploration and settlement on other planets. However, despite this surge in interest and needs, awareness and understanding of Space Architecture are lacking, in both the academic and industrial built environment field; consequently, Space Architecture studies are still an under-researched and under-practiced discipline in the built environment field. Thus, developing a new research is both timely and critical given the current upsurge of interest in Space Architecture, and the potential application of Space Architecture across multiple sectors including the Built Environment, Materials and Planetary Sciences because of the nature of its interdisciplinary research.

Lunar Aplication: The ESA test [13] shows the potential freezing of the binder and the related operation with a wet-mix based printing process under the extreme temperature changes of a lunar environment. In this case, a sintering-based printing process using microwave or laser power, which does not require any binder, could be a more appropriate technique. Nevertheless, there will be some challenges to material fabrication which need to be addressed, e.g., (i) vacuum tribology – friction, lubricant and wear – during the mechanical operations of fabrication, including material delivery, due to the presence of highly abrasive and electrostatic lunar dust and an almost non-existent atmosphere; and (ii) less self-compacted materials during deposition due to weak gravity. In addition, potential of a collaborative construction using smaller modular printing robots needs to be investigated, as a single printing system would require a longer construction period.

At the Open University, we are embarking on a multi-disciplinary research project to integrate our existing expertise in 3D Concrete Printing [10] and knowledge of ISRU potential on the Moon [16] to perform a series of experiments using lunar simulants to optimize 3D printing process and its potential application to building structures and components on the Moon in the context of future habitation of the Moon.

References:

[1] SAW (2002) *Space Arch. W.* [2] Osburg, J. (2003) *ICES*. [3] Howe, A. S. and Sherwood, B. (2009) *AIAA*. [4] Anand, M. et al. (2012) *Planet. Space Sci.*, 74, 1, 42-48. [5] ASTM (2010) *ASTM*, F2792-10. [6] Hague, R. et al. (2003) *J. Mech. Eng. Sci.*, 217, 1, 25-30. [7] Hopkinson, N. and Dickens, P. (2003) *J. Mech. Eng. Sci.*, 217, 1, 31-39. [8] Pegna, J. (1997) *AIC*, 5, 5, 427-437. [9] Khoshnevis, B. et al. (2006) Int. J. Ind. & Syst. Eng., 1, 3, 301-320. [10] Lim, S. et al. (2012) *AIC*, 21, 1, 262-268. [11] Dini, E. (2009) *Monolite UK Ltd.* [12] ESA (2013)http://www.esa.int/Our_Activities/Technology/Building_a_lunar_base_with_3D_printing. [13] Cesaretti, G. (2012) *ESA*, 3DP-ALT-RP-001. [14] Rousek, T. et al. (2012) *Acta Astronaut.*, 74, 98-111. [15] Doule, O. et al. (2011) *ICES*. [16] Anand, M. et al., (2012) *Planet. Space Sci.* 74, 42-48.