# Engineering and Innovation Research Studentship 2023/2024

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| **Project title:** | **Melting, Processing, and Solidification of Lunar Regolith** |
| **Discipline** | Materials Engineering; Construction; Space |
| **Key words:** | Geology; Mineralogy; Moon; X-Ray Diffraction; Raman; Nanoindentation |
| **Supervisory team:** | Dr James Bowen, Dr Sungwoo Lim, Dr Zahra Golrokhi |
| **URL for lead supervisor's OU profile** | https://www.open.ac.uk/people/jb36559 |

## Project Highlights:

- Habitat construction on the Moon;
- High-temperature processing of geological materials;
- Analytical characterisation of physical and chemical properties.

## Overview:

Over the last decade, Space Architecture – the theory and practice of designing and building an environment for humans in outer space – has become an emerging issue in the context of future space exploration. Habitat construction in resource-poor environments is viewed as a fundamental challenge for enabling long-term space settlement and exploration on other planetary bodies. The challenges associated with construction processes in extra-terrestrial environments must be investigated and overcome here on Earth to mitigate the risks involved.

Developing processes suitable for manufacturing airtight structural elements will undoubtedly include the use of high temperatures, typically over 1200 °C. Construction processes and materials for Space Architecture, particularly on the Moon, are likely to use the resources already existing there, i.e. the native regolith. Many different local regolith compositions exist, consisting of minerals including olivine, pyroxene, plagioclase, and ilmenite, each of which exhibit a spectrum of compositions and physical properties.

This project will investigate the structure and composition of lunar regolith simulants during their melting and solidification. The rate of cooling will influence the shape and size of any crystallised phases which form during solidification. This information, when transposed to manufacturing processes such as casting, can be used to generate specific microstructures within manufactured components.

The project will explore macro-scale physical properties of materials created from solidified regolith simulants, both experimentally and via Multiphysics simulations, which will assist in the design of processes for *in situ* construction in hostile environments. These data will inform a theoretical exploration of the architectural structures which are achievable using these materials on the lunar surface. Particular emphasis will be given to load transmission from an above-surface structure to the structure's foundation with an optimal architectural design.

This research will play an essential role with regard to the durability and structural integrity of new human habitats to be executed over the lunar surface environment, to constitute a future development of improved methodologies and guidelines for lunar surface construction processes.

Figure 1. Concept image of a settlement on the Moon.

## Methodology:

By late 2023 when this studentship starts, the School of Engineering and Innovation will have commissioned a high-speed, high-temperature X-Ray Diffraction facility, which will be the primary instrument associated with this project. Analytical techniques including nanoindentation, Raman microscopy, and electron microprobe analysis will also be used extensively throughout the project. Simulation of macro-scale physical properties of the molten and solidified regolith will be conducted using COMSOL Multiphysics software.

## References & Further Reading:

The project team consists of Dr James Bowen, Dr Sungwoo Lim, Dr Zahra Golrokhi, Dr Andrew Morse, and Prof Mahesh Anand. The following list includes some of the critical literature associated with this project.


1. Lim, S.; Reeve, S.; Lekuona, E.; Garbayo, A.; Le Toux, T.; Morse, A.; Bowen, J.; Anand, M.; Challenges in the microwave heating of lunar regolith – analysis through the design of a Microwave Heating Demonstrator (MHD) payload. *Adv. Space Res.*, **2022**, *69*, 751-760.

2. Lim, S.; Bowen, J.; Degli-Alessandrini, G.; Anand, M.; Cowley, A.; Prabhu, V.L.; Investigating the microwave heating behaviour of lunar soil simulant JSC-1A at different input powers. *Sci. Rep.*, **2021**, *11*, 2133.

3. Spedding, C.; Lim, S.; Nuttall, W.J.; ISRU technology deployment at a lunar outpost in 2040: a Delphi survey, *Acta Astronautica*, **2021**, *181*, 316-324.

4. Anand, M.; Crawford, I.A.; Balat-Pichelin, M.; Abanades, S.; van Westrenen, W.; Péraudeau, G.; Jaumann, R.; Seboldt, W.; A brief review of chemical and mineralogical resources on the Moon and likely initial in situ resource utilization (ISRU) applications. *Planetary Space Sci.*, **2012**, *74 (1)*, 42-48.


## Further details:

We are looking for highly motivated individuals with a strong background in materials, mineralogy, chemistry, or engineering. Strong enthusiasm for space exploration with interest in the experimental realisation of novel materials characterization for the benefit of lunar construction would be a plus.

Applicants should have a first-class or upper second-class MSc degree (or equivalent) in a relevant discipline, including Engineering, Construction, Materials or Planetary Sciences. Any previous experience with X-ray diffraction measurements would be an advantage.

Applications should include:

- A 1,000-word cover letter outlining why the project is of interest to you and how your skills match those required
- An academic CV containing contact details of three academic references
- An Open University application form, downloadable from: http://www.open.ac.uk/postgraduate/research-degrees/how-to-apply/mphil-and-phd-application-process
- IELTS test scores where English is an additional language

Enquiries should be addressed to the Lead Supervisor, Dr James Bowen james.bowen@open.ac.uk

Applications should be sent to **STEM-EI-PhD@open.ac.uk by 15.02.2023**