EDITORIAL

Advancements in Designing, Producing, and Operating Off-Earth Infrastructure

Henriette Bier [1, 2, 3], **Angelo Cervone** [1], **and Advenit Makaya** [4]

[1] *Delft University of Technology*
Delft, the Netherlands

[2] *Politecnico di Milano*
Milan, Italy

[3] *Anhalt University of Applied Sciences*
Dessau-Rosslau, Germany

[4] *European Space Agency*
Noordwijk, Netherlands

Sending humans to the Moon and Mars in the near future requires appropriate infrastructure to support and subsequently sustain human activities. This includes infrastructure to shield from environmental conditions, generate energy, and facilitate mobility and communication. Construction of such infrastructure aims to use in-situ resources and reduce the use of supplies from Earth. The establishment and maintenance of the required infrastructure, equipment, and hardware involves the development of adequate manufacturing techniques, which can enable maximal use of the local resources. Those techniques can be based on processing of local materials into construction materials, extraction of useful elements from local materials or in combination with materials brought from Earth. The required manufacturing techniques address the range of needs for sustained human activities, from smaller scale manufactured items to large built structures. The design of such structures is associated with a number of space systems' engineering challenges, ranging from the accurate definition of all resource budgets (mass, volume, power, data) to the design of the interfaces between all subsystems making use of these resources. The interplanetary spacecraft used to transport the required materials (and eventually, crew) from Earth to the final site would probably need to be designed ad-hoc for this specific application, given its peculiar mass and volume constraints, especially in case a reusable concept is adopted. Other engineering aspects involved in the design of the infrastructure systems include the selection of an appropriate power generation approach and the definition of the radiation environment in order to provide sufficient shielding to the habitats. This Spool CpA #4 issue investigates challenges of designing, engineering, constructing, operating, and maintaining off-Earth infrastructure.

These challenges are addressed with contributions from various disciplines ranging from (1) architecture to (2) materials engineering, involving In-Situ Resource Utilisation (ISRU) for manufacturing processes and (3) power generation:

ARCHITECTURE

From reviews of previous designs to new design proposals, authors from academia and industry engage in investigations covering inter alia comfort, sustainability, and autarkic aspects in space architecture.

Häuplik-Meusburger and Griffin review concepts and designs that have been developed in the last 50 years. They all have been dealing with typical lunar challenges, such as lunar dust, microgravity, etc. The authors present them according to the class terminology of habitat design: Pre-integrated modules from Earth (class 1), prefabricated components assembled on-site (class 2), in-situ-resources (class 3), combination of all of the above, with examples included from space industry, space architecture community, as well as academia.

Somewhat similarly, **Konstantatou et al.** reflect on the value, applicability, and posed challenges of what has been designed so far and what could, and should, be designed in the future while taking into consideration the bi-directional relationship between off-Earth and on-Earth architecture and building construction. The paper focuses on past and contemporary structural design approaches – in particular component-based against continuous approaches – and assesses them in terms of sustainability, contribution to the space industry, and applicability to the on- and off-Earth context.

The third contribution with focus on architecture by **Bier et al.** briefly reviews a couple of contemporary off-Earth design proposals to then focus on presenting a novel idea to excavate into the ground in order to create subsurface habitats on Mars. By excavating, not only natural protection from radiation can be achieved, but also thermal insulation because the temperature is more stable underground. The excavated material is used for 3D printing the habitat with the ultimate goal of developing an autarkic system using solar and kite power (Corte Vargas et al., 2021) for building and inhabiting off-earth subsurface autarkic habitats.

In addition to this proposed 3D printing approach using locally sourced regolith, two papers address additive manufacturing (AM) concepts using lunar regolith:

MATERIAL SCIENCE

Laot et al. explore functionally graded materials (FGM) as high-performance composite materials, offering several advantages, including localized tailoring of material properties, improved material boundary compatibility, and enhanced thermomechanical behaviour. The presented research is investigating the feasibility of an in-situ manufactured metallic-regolith FGM. Three AM techniques are assessed with respect to their capability to effectively consolidate regolith on its own and onto metallic substrates.

Furthermore, **Grundstrom et al.** present the use of a lunar regolith simulant as feedstock for a direct ink writing (DIW) AM process involving a bio-organic binder. The feasibility of this approach is demonstrated by manufacturing objects with various three-dimensional geometries. Of particular interest is the proposition to use these compounds as additives produced in-situ through photosynthesis for a future lunar base, utilising carbon dioxide exhaled by astronauts together with the available sunlight.

For such manufacturing processes as well as for habitation, considerable power supply is needed, which is addressed as follows:

POWER GENERATION

Corte Vargas et al. present an energy generation approach that combines complementary resources for an effective renewable energy solution. In this work, a 10 kW microgrid solution is proposed, based on a pumping kite power system and photo-voltaic solar modules to power the construction as well as the subsequent use of the Mars habitat, as presented in the paper from Bier et al.

In addition to these contributions, a dialogue on architecture between experts is reported in the **Interview** section acknowledging that, while all contributions to this issue rely on learning from precedents and advancing development of new technologies, the challenge remains to efficiently transfer technology from on-Earth to off-Earth applications and vice versa.

DOI

https://doi.org/10.7480/spool.2021.2.6056