Design considerations and challenges of a lunar habitat based on a topological interlocking assembly

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Establishing a sustained human presence on the lunar surface necessitates long-term shelter for both habitats and mission-critical equipment. Current architectural concepts typically rely on inflatable structures that can be transported to the Moon in a compact configuration and deployed on site. Although inflatable systems represent one of the most efficient lightweighting strategies, a more appropriate criterion is the *total* transported mass rather than the mass of the structural shell alone. This consideration brings to the fore the advantages of in-situ resource utilisation (ISRU).

The principal indigenous material available on the Moon is the fine particulate known as regolith. Numerous studies have demonstrated that regolith can be consolidated by sintering—either through concentrated solar irradiation or by applying an external energy source—into a mechanically coherent solid. Sintered regolith exhibits characteristics broadly comparable to a porous ceramic. Its critical limitation, however, is its pronounced brittleness. Consequently, monolithic components fabricated from sintered regolith are highly vulnerable to catastrophic failure once a crack initiates and propagates. One way to mitigate this problem is to adopt a modular design approach, which not only improves structural robustness but also reduces the size of the manufacturing equipment required—and therefore the amount of machinery that must be transported to the lunar surface.

Within a modular construction paradigm, the challenge shifts to reliably joining the individual blocks. The most common approaches—adhesives and mechanical fasteners—each present significant limitations under lunar conditions. Fasteners can, in principle, be used in the near-vacuum environment of space; however, their application to brittle materials requires particular care, and the fasteners themselves must be transported from Earth. Moreover, mechanical fastening demands a level of assembly precision that increases the complexity of the required fabrication equipment. Adhesive bonding poses even greater difficulties. The curing mechanisms of most terrestrial adhesives rely either on solvent evaporation or on chemical reactions with atmospheric oxygen—processes that cannot occur on the lunar surface. Thus, conventional adhesive systems are unsuitable for lunar construction.

Fortunately, there exists an alternative approach that relies neither on adhesives nor on mechanical fasteners but instead exploits the geometry and mutual arrangement of the individual modules. These features become the defining factors governing the behaviour of the entire structure, known as a *topological interlocking assembly* (TIA). A TIA is characterised by the property that fixing only a subset of its constituent blocks is sufficient to render the whole assembly mechanically stable, with each block securely arrested within it.

The earliest geometry known to exhibit this behaviour dates to the late 17th century. The modern re-invention of this materials-design concept (A. Dyskin et al., 2001) has stimulated the development of numerous types of TIAs through systematic generation algorithms. TIAs based on Platonic solids, osteomorphic blocks, Delaunay lofts, Voronoi noodles, and other families of geometries are among the prominent examples. More recently, a systematic method

for generating large numbers of candidate geometries capable of forming TIAs—based on crystallographic groups and their fundamental domains—was introduced (T. Goertzen et al., 2023).

However, all works known to the authors consider only planar assemblies or assemblies curved in a single direction. While such configurations have practical applications, they are not suitable for enclosing a habitat. In the study presented in this talk, we therefore examine the design considerations and engineering challenges associated with constructing a lunar habitat based on a topological interlocking assembly. Our primary objective is to develop a design that is practically implementable—specifically, one that enables the construction of habitats using equipment that can realistically be transported to the lunar surface. An essential requirement is that the resulting structure can withstand the mechanical and environmental loads it will encounter once assembled. A further objective is to minimise the number of different block geometries, thereby simplifying production and potentially enabling robotic assembly. In particular, the approach based on crystallographic groups offers an important advantage: it enables the design of structures that are inherently expandable and reconfigurable. Once a given structure is no longer required, it can be disassembled, and the individual blocks can be reused in new assemblies that differ in size and, potentially, in overall shape.

A specific habitat design, whose protective shell is assembled from topologically interlockable blocks of a novel geometry, will be proposed.