# Characteristics of an Artemis Lunar Construction Modular Toolkit.

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## Introduction

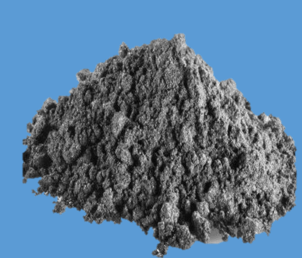
Modularity and complementarity are of high value for lunar construction, especially to the early stages of lunar base development. By leveraging the combined capability of many early construction systems, these attributes enable flexibility to meet a wide range of early construction needs in different locations, scalability, maintainability in a harsh environment, and reusability in different locations for economical re-use of down-mass for lunar development. Ideally, system strengths of each element would augment the capabilities of others.

Understanding that lunar construction of early and sustained infrastructure will rely on a variety of construction elements and techniques, we will examine the possible modular and complementary elements of a lunar "toolkit". This is meant to serve as a roadmap to eventually include larger elements of increased complexity, and provides a method for evaluation of different technologies and their deployment. This work will consider the complementarity of three elements: The NASA Ames ARMADAS construction system [1] ; The NASA KSC IPEx excavator [2]; The University of Arizona/JPL/MDA LUNAR-BRIC construction system [3].

## Module Categorization

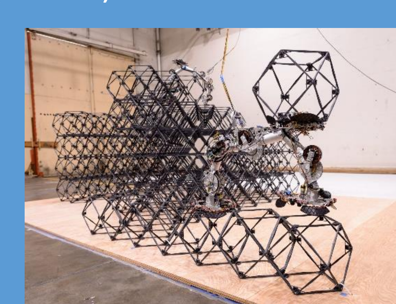
The sub-elements considered are broadly categorized as:

*Construction Units* being the Toolkit modules that are consumable structural elements. They include the ARMADAS truss voxel (at right) and LUNAR-BRIC Regolith Containment Units (center)



IPEx Regolith Load

BRICs Regolith Containment Units

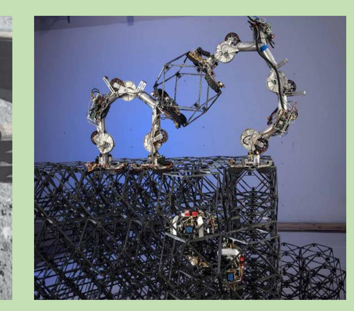


ARMADAS cuboctahedron truss

*Construction Enablers* are the modules that are employed to move / place Construction Units or regolith.

NASA KSC IPEx excavator

LUNAR-BRIC Mobility Platform



NASA Ames ARMADAS Arm

## Modular Properties

Estimates of the properties of both the Construction Units and Construction Enablers provide a means for assessment.

| Construction Units | IPEx Regolith | RCUs | Cubetahedron Truss[1] |
|---|---|---|---|
| Mass per unit (S) | N/A | 1 kg | ~0.350 kg |
| Mass per unit (C/E) | 30 kg | 35 kg | ~0.350 kg |
| Volume per unit (S) | N/A | 40 x 30 x 2 cm | < 22.2 x 22.2 x 1.3 cm* |
| Volume per unit (C) | 25 L | 40 x 30 x 20 cm | 30.5 x 30.5 x 30.5 cm |
| Positioning Accuracy | +/- 10 cm, 1° | +/- 1 cm, 2° in roll | +/- 1.3cm initial req., <mm after installation |

(C) Construction (E) Excavation (S) Stowed
* Stowed vol. for injection molded only. Lower stowed vol. with strut/node const.

| Construction Enablers | IPEx Excavator [2] | BRICS Mobility Platform / RA[3] | ARMADAS Inchworm [1] |
|---|---|---|---|
| Landed Mass | 30 kg | 1500 kg | ~10-15 kg est. |
| Landed Volume | 76 x 63 x 69 cm | 3.3 x 3.1 x 9 m | ~30 x 30 x 30 cm |
| Energy/op (P) | 12 kJ | 171 kJ / 2.8 kJ | <0.5 kJ (ROM) |
| Energy/km (T) | 343 kJ / km | 3000 kJ / km | N/A |
| Placement time | 1 min per load | <13 min per RCU | <5min per CT |
| Traverse Speed | 0.3 m/s | 1.4 m/s | ~0.5 m/s avg |

(P) Placement (T) Traverse distance (CT) Cuboctahedron Truss

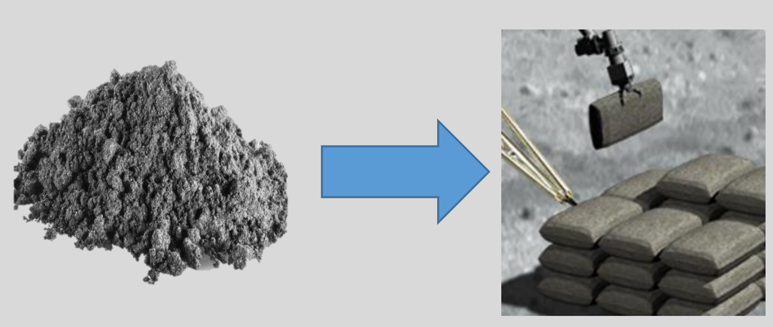
## Complementarity of Modules

Defining module-to-module interactions

**Method**: The Modular Properties are examined for commonality, and modules with similar properties can be grouped together. From this a determination can be made on their suitability for inter-modularity, and the number and types of interfaces that are required between elements. Common interfaces and elements that meet the needs of multiple systems are identified, and universal or "standard" interfaces/elements become evident. This also begins to determine key requirements that would be required for each element and their associated interface(s).
Three examples are provided below.

## Complementarity Modules #1

*Regolith → RCUs*
Complexity: Low

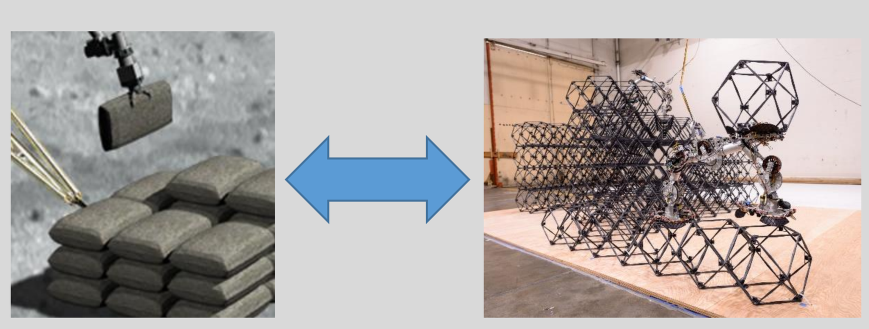


**Assessment**: The Regolith Containment Units will require regolith excavated by the IPEx rover.

**Required Elements:** A Mechanism will be required to transfer the regolith. This consists of an interface to the IPEx platform while it is discharging regolith and the LUNAR-BRIC bagging sub-system (not shown) which produces RCUs

## Complementarity Modules #2

*Mixed Construction*
Complexity: Medium

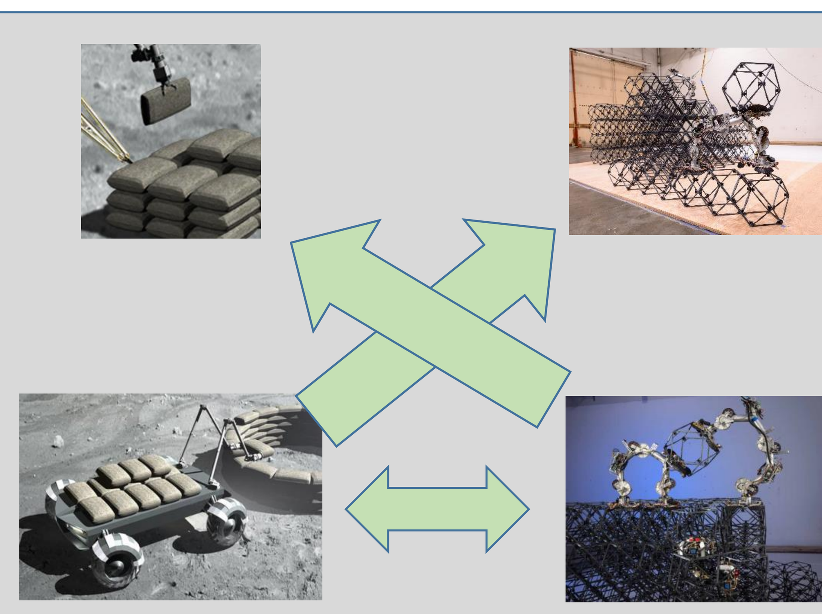


**Assessment**: All construction units that build structures should be compatible. This will allow RCU structures (such as an adobe) to be completed with a trussed roof, or the use of a trussed "chimney" for vertical construction access. Truss structural elements can also be used to provide alignment for RCU structures (commonly used in terrestrial earthen construction) to increase performance and decrease robotic placement requirements.

**Required Elements:** A standard interface and complementary spacing of interfaces between construction units, and generous tolerances on the interface between units.

## Complementarity Modules #3

*Mixed Enablers*
Complexity: High



**Assessment**: Examination of the Modular Properties reveals that the placement accuracy of RCUS and Truss elements are similar. A common interface could allow the ARMADAS robotic arm to utilize BRICs grapple features (and vice-versa). Also, the mass of the RCUs envelopes that of the truss units, which could allow for a single, common arm. This type of interface would be universal.

**Required Elements:** A standard interface between construction units and robotic arms. A common robotic arm that covers both construction methodologies; this could be extended to cover the Mixed Construction needs and create both a robotic and intermodular interface.

## Mission Analysis

A digital twin environment with the above parameters would be created to study construction scenarios. Operations can be quickly assessed to minimize their power, downmass usage and build time (for example), while maximizing construction volume. Simple physics models could show the efficacy of radiation or rocket blast shielding.

In this way the efficacy and operational efficiency metrics on the type of interface used for different construction methods could indicate which elements are more critical, and start to formulate construction requirements.

**References**: [1] Gregg, C. et al Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS), LSIC Spring Meeting (2023) [2] Mueller, R. P. et al. Design of an Excavation Robot: Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0. Earth and Space (2016) [3] Dickinson, C. S. et al., Construction of Lunar Surface Structures Using Regolith Filled Sandbags. LSIC Fall meeting (2023).