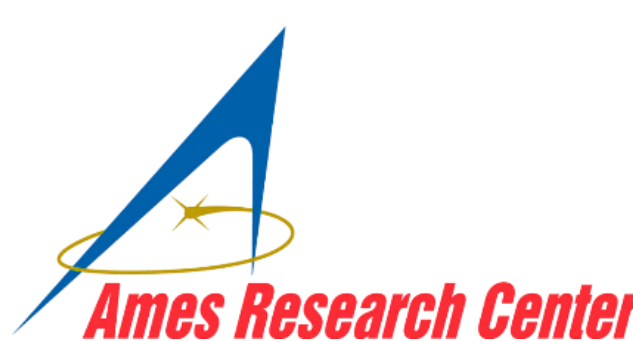


# Characteristics of an Artemis Lunar Construction Modular Toolkit.



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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

## IPEX



IPEX serves as the primary means for any excavation activities, providing lunar regolith for ISRU based construction systems. This could also be used to groom the lunar surface prior to any surface construction.

The main advantage of such a system is to enable the use of regolith in lunar construction – which greatly reduces overall lunar construction downmass. The system can be deployed at a wide variety of locations, and is limited only by terrainable slopes. The main disadvantage of this element is that the IPEX system will need to be scaled up to meet the demands of large scale construction, as the current system has been designed for 10 metric tons.



## 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]	Construction Enablers	IPEX Excavator [2]	BRICS Mobility Platform / RA[3]	ARMADAS Inchworm [1]
Mass per unit (S)	N/A	1 kg	~0.350 kg	Landed Mass	30 kg	1500 kg	~10-15 kg est.
Mass per unit (C/E)	30 kg	35 kg	~0.350 kg	Landed Volume	76 x 63 x 69 cm	3.3 x 3.1 x 9 m	~30 x 30 x 30 cm
Volume per unit (S)	N/A	40 x 30 x 2 cm	< 22.2 x 22.2 x 1.3 cm*	Energy/op (P)	12 kJ	171 kJ / 2.8 kJ	<0.5 kJ (ROM)
Volume per unit (C)	25 L	40 x 30 x 20 cm	30.5 x 30.5 x 30.5 cm	Energy/km (T)	343 kJ / km	3000 kJ / km	N/A
Positioning Accuracy	+/- 10 cm, 1°	+/- 1 cm, 2° in roll	+/- 1.3cm initial req., <mm after installation	Placement time	1 min per load	<13 min per RCU	<5min per CT
(C) Construction	(E) Excavation	(S) Stowed		Traverse Speed	0.3 m/s	1.4 m/s	~0.5 m/s avg
* Stowed vol. for injection molded only. Lower stowed vol. with strut/node const.				(P) Placement	(T) Traverse distance	(CT) Cuboctahedron Truss	

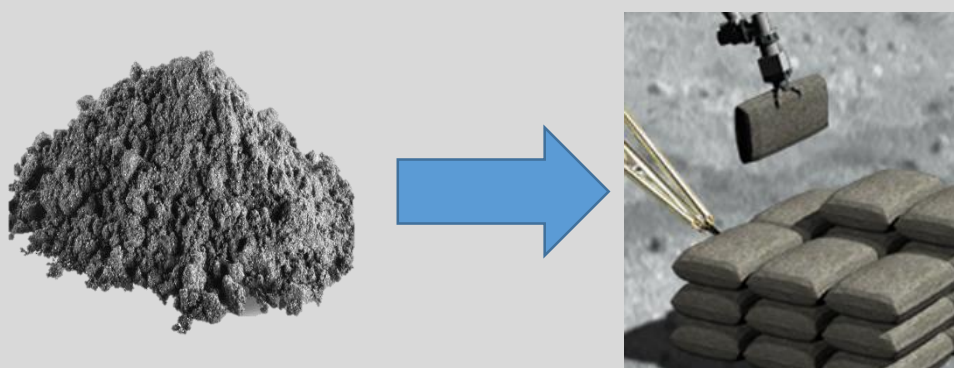
## Complementarity of Modules

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

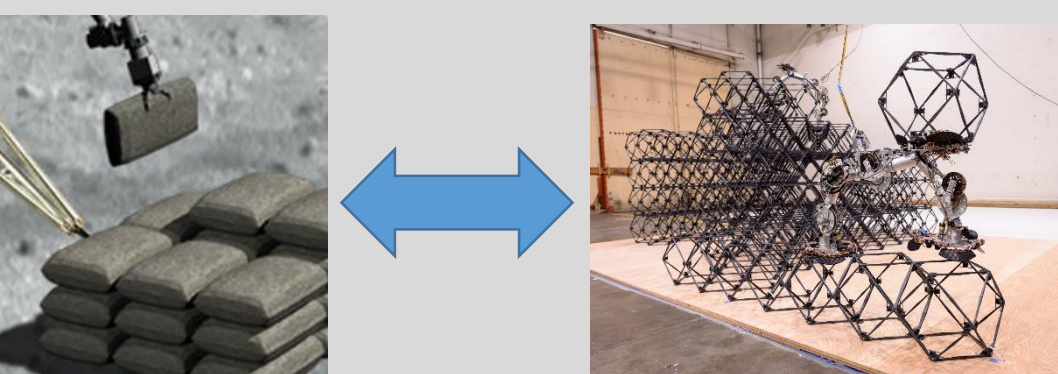
Regolith → RCUs  
Complexity: Low



**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

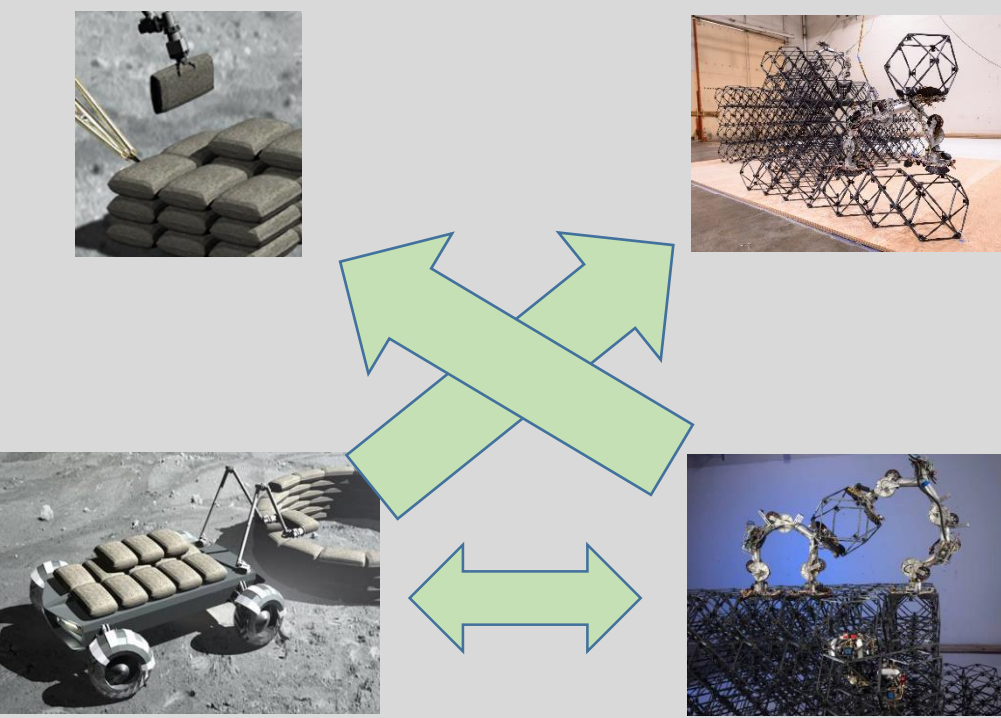
Mixed Construction  
Complexity: Medium



**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.

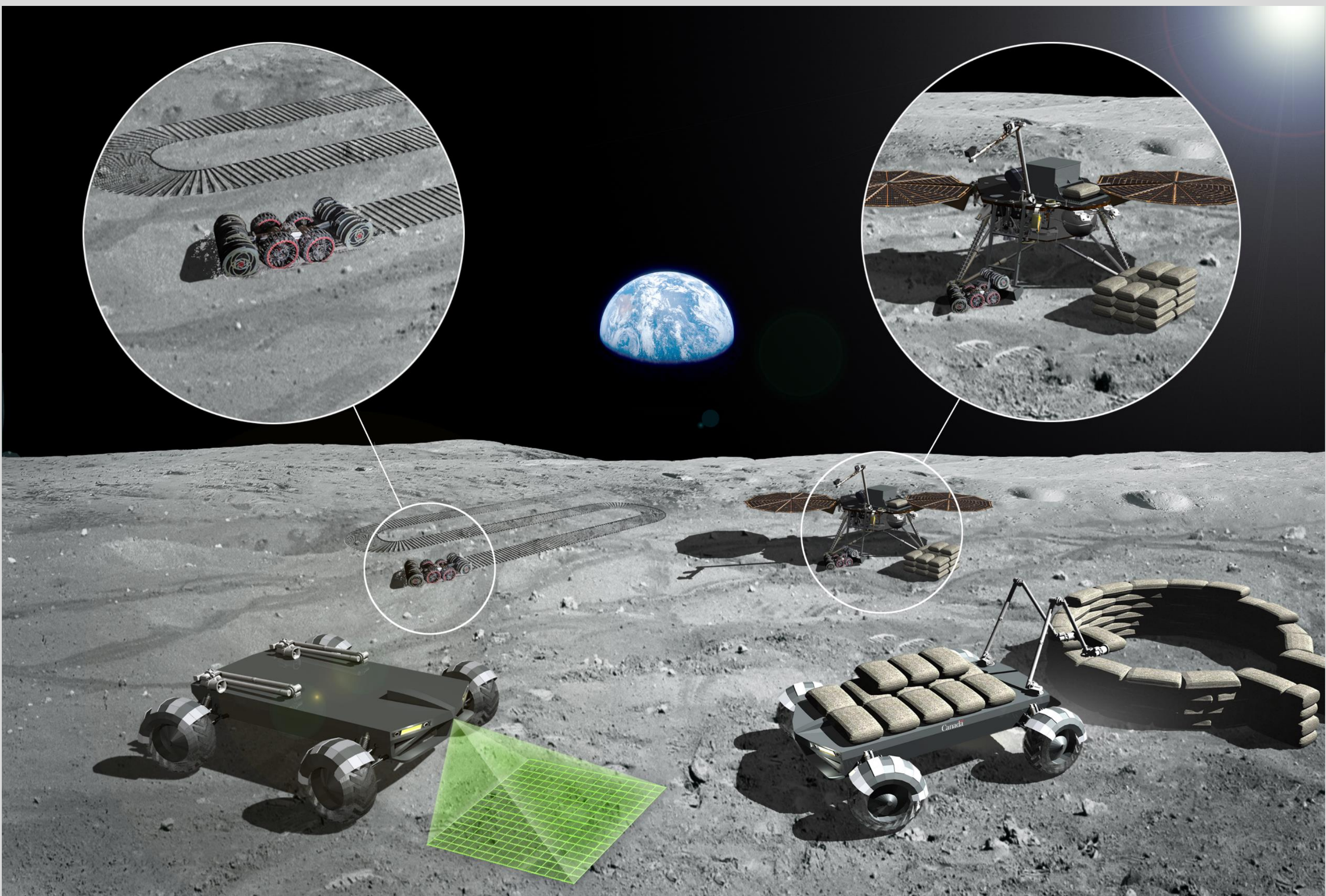
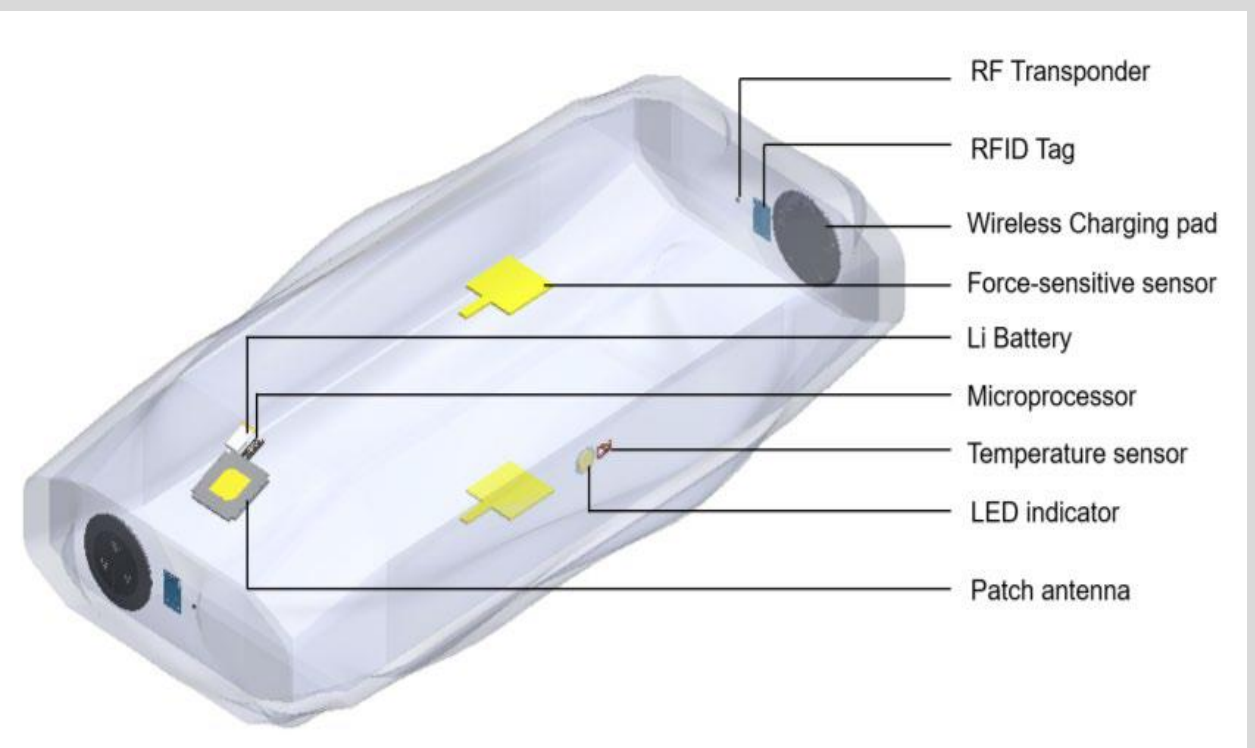
In this way the efficacy and operational efficiency metrics on the type of interface used for different construction methods could indicate which elements are more critical, and start to formulate construction requirements.

**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).

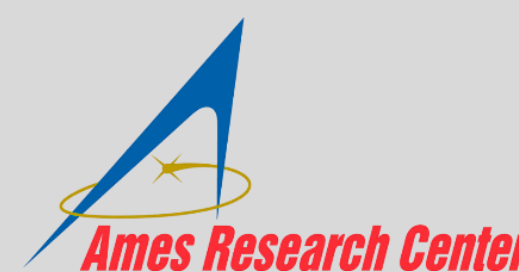
## LUNAR BRIC



The LUNAR BRIC (Lunar Robotically-Based Regolith Incorporated Construction) system aims to provide structures such as blast berms, utility garages, and ultimately human habitats. BRICs has the advantage of providing protection from radiation sources (e.g. gamma rays, x-rays and neutrons) as well as protection from micrometeorites. Use of the local regolith for >90% of construction materials equates to low downmass requirements, and the Regolith Containment Units or RCUs (shown at right) can also be moved and redeployed as required. Lastly, the RCUSs can be employed in either a semi-autonomous or autonomous manner. The main disadvantage of BRICs is the need for bagging materials.



## ARMADAS



The Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS) project is exploring ways to erect a variety of functional structures such as habitat structures or large antennae arrays. Within the lunar toolkit, ARMADAS has the advantage of rapid construction of lightweight structures through autonomous or semi-autonomous means. This could include roofing trusses on an RCU filled structure, or, if covered in lightweight materials, for the construction of blast berms. The ARMADAS structures can also be disassembled for transport and reuse as required. It's main disadvantage is the amount of downmass that would be required to facilitate construction.

