Lunar Base Construction Planning

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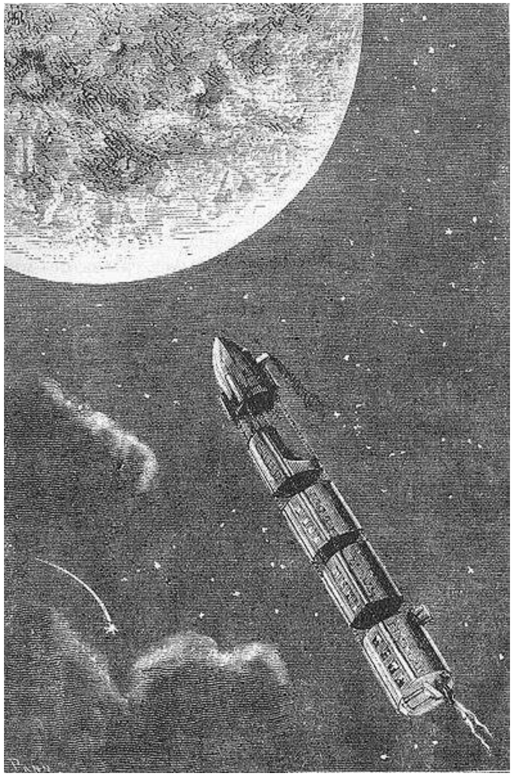
Introduction

LUNAR BASE: from Jules Verne to NASA Artemis

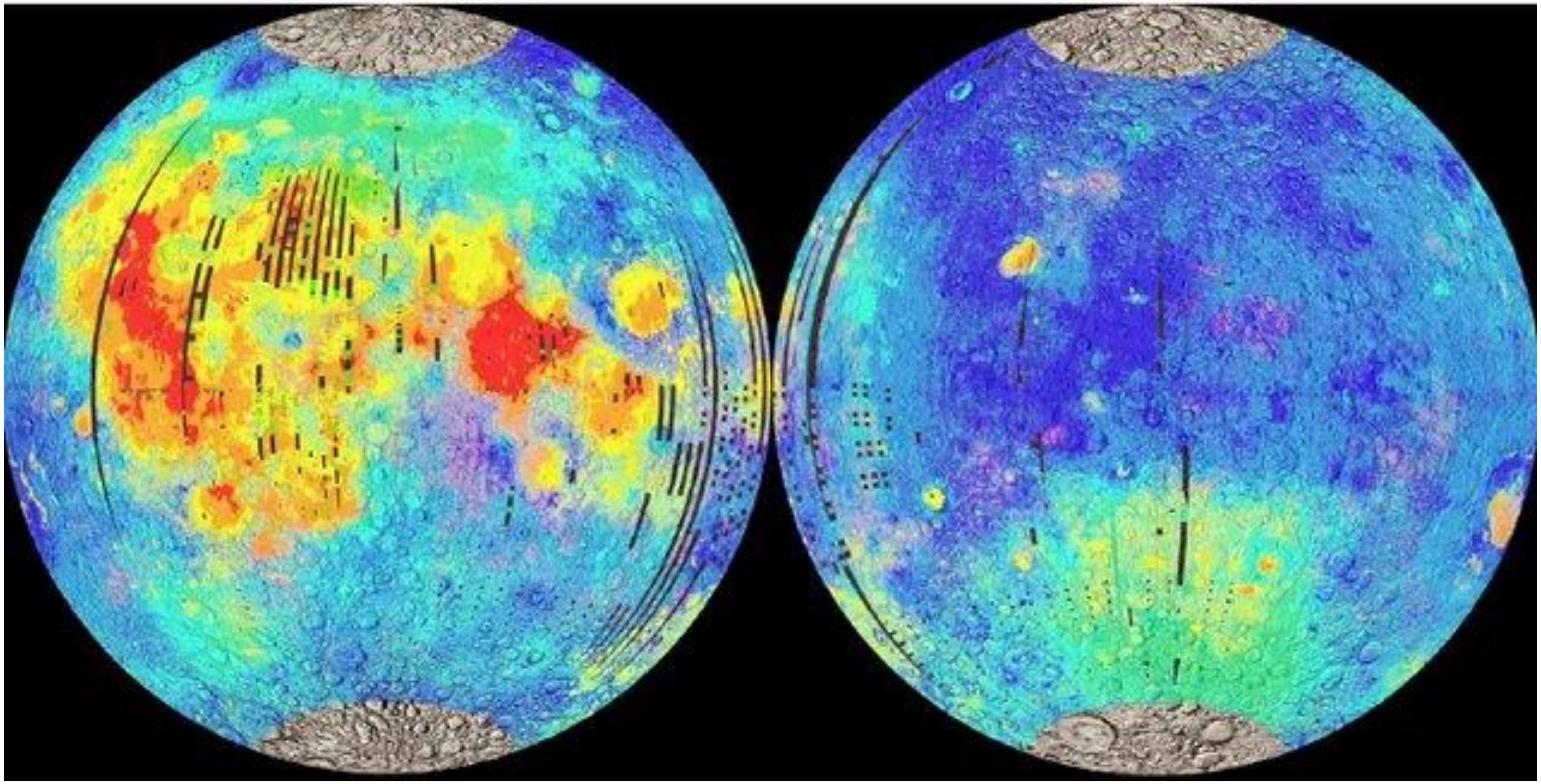


1865: An illustration from Jules Verne's novel 'From the Earth to the Moon,' drawn by Henri de Montaut. Credit: Wikimedia Commons [Public Domain]

2022: NASA Artemis Program (NASA, ICON, SEArch+, BIG)

Resources

In-Situ Resource Utilization



Distribution of regolith compositions on the lunar nearside (left) and the farside (right) based on Clementine multi-spectral imaging data. Blue: anorthositic highlands; yellow: low-Ti basalts; red: high-Ti basalts. The large yellow/greenish area in the southern hemisphere of the farside is the South Pole-Aitken Basin, where the colours mostly reflect the more Fe-rich nature of the lower crust exposed by the basin rather than basaltic material (Spudis et al., 2002; courtesy Dr Paul Spudis/LPI).

Mission Architecture

Table 1. NASA Lunar and Mars Space Mission Architecture Studies (Drake, 2005)

Office of Exploration (OExP) - 1988 Case Studies Human Expedition to Phobos Human Expedition to Mars Lunar Observatory Lunar Outpost to Early Mars Evolution	**First Lunar Outpost - 1993** **Early Lunar Resource Utilization - 1993** **Human Lunar Return - 1996**
Office of Exploration (OExP) - 1989 Case Studies Lunar Evolution Mars Evolution Mars Expedition	**Mars Exploration Missions** Design Reference Mission Version 1.0 - 1994 Design Reference Mission Version 3.0 - 1997 Design Reference Mission Version 4.0 - 1998 Mars Combo Lander (Johnson Space Center (JSC)) - 1999 Dual Landers – 1999
NASA 90-Day Study - 1989 Approach A - Moon as testbed for Mars missions Approach B - Moon as testbed for early Mars missions Approach C - Moon as testbed for Mars Outposts Approach D - Relaxed mission dates Approach E - Lunar outpost followed by Mars missions	**Decadal Planning Team (DPT)/NASA Exploration Team (NExT** Earth's Neighborhood Architecture Asteroid Missions Mars Short and Long Stay **Exploration Blueprint - 2002** **Space Architect - 2003**
America at the Threshold - "The Synthesis Group" - 1991 Mars Exploration Science Emphasis for the Moon and Mars The Moon to Stay and Mars Exploration Space Resource Utilization	**Exploration Systems Mission Directorate (ESMD) 2004–2005**

Infrastructure Functions

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Table 2. Lunar Base Surface Infrastructure Functions

Landing / Launch	Radiation Protection
Lander servicing	Meteorite Shielding
Propellants management	Moonquake mitigation
Power	Science activity stations
Communication	Resource mining / utilization
Habitation	Regolith operations / hauling
Life Support & Consumables	Logistics management
Transportation	Excavation & Construction Services
Extreme Access	Dust management
Thermal management	Maintenance / Repair / De-commission
Extra-Vehicular Activity (EVA)	Waste management
Food Production	Crew Health

Functional Needs

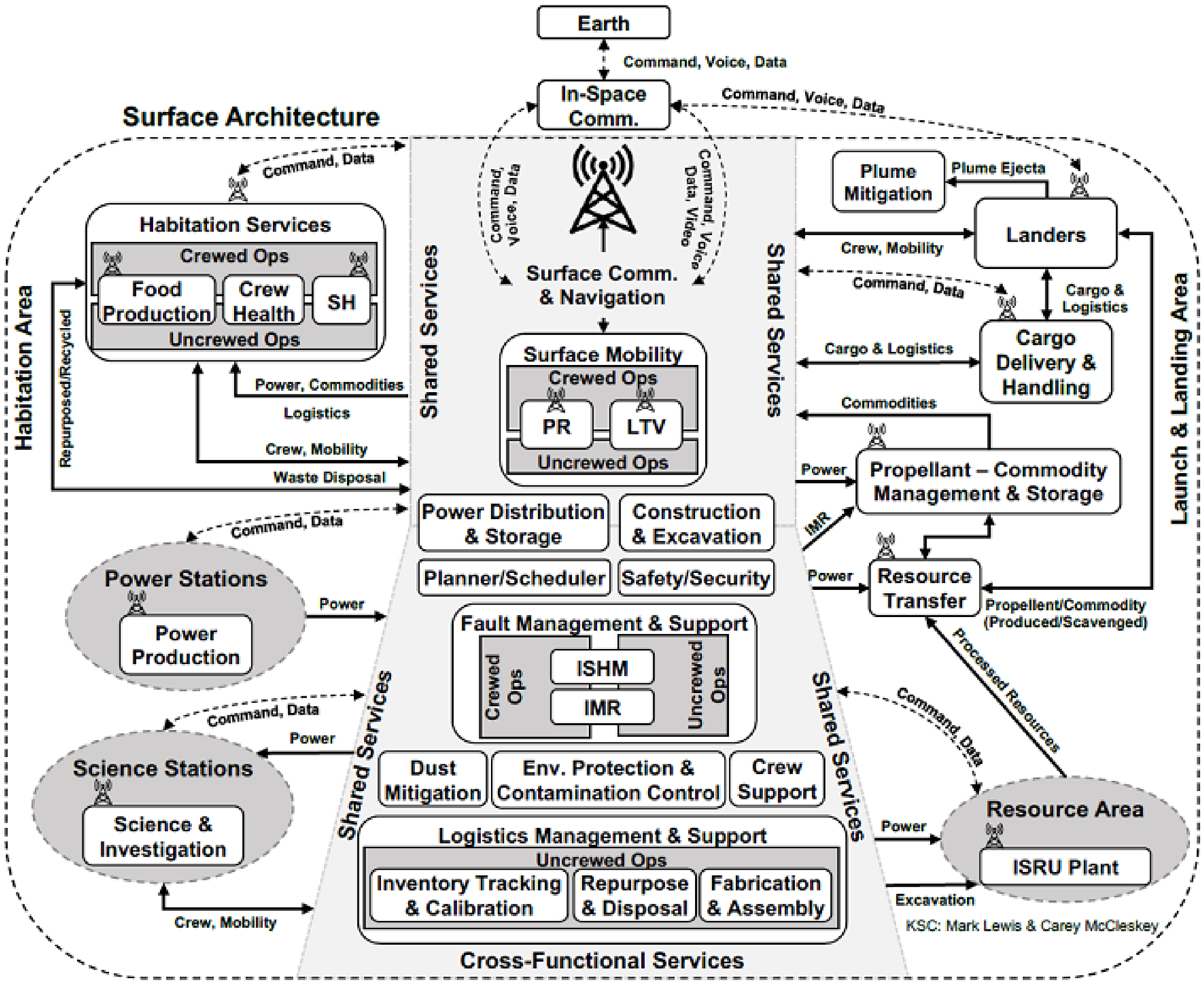
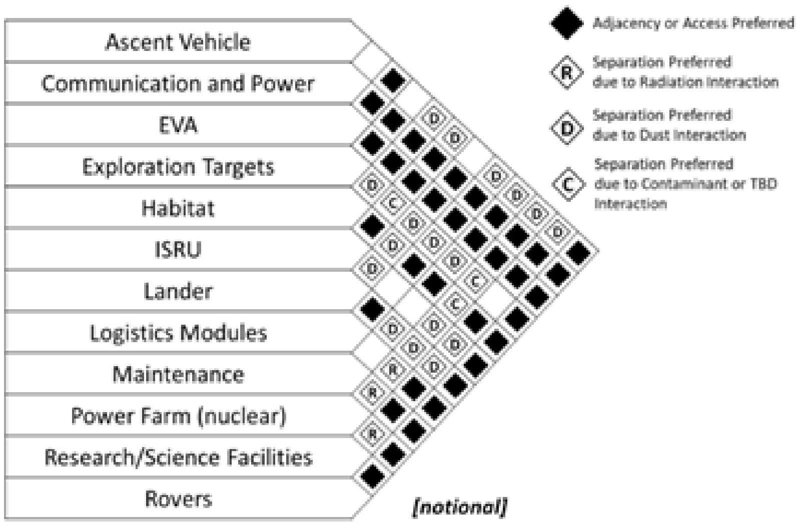


Figure 1. Schematic of Lunar Base Functional Needs
(NASA Kennedy Space Center (KSC), Lewis, M.E. & McCleskey, C.M., 2022)

Site Planning

Interactions

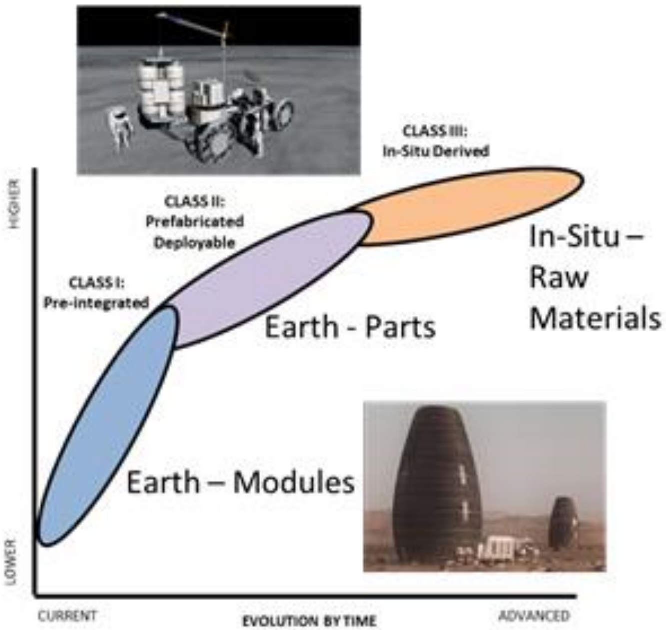


Site and Operational Factors

- **Site location**
- **Terrain and Geomorphology**: soil composition (surface and below), bearing capacity, rocks/boulders, holes/ditches, mounds, dust, etc.
- **Topography and Contours, Altitude, Elevation**: high points, low points, ridges, valleys, slopes, flats; natural barriers
- **Dimensions and Area:** boundaries, thresholds
- **Climate:** space weather, sun angles and path, temperature cycles, wind [Mars], humidity [Mars], dust storms [Mars]
- **Light/Dark (sun/shade) seasonal patterns**
- **Albedo**
- **Radiation:** natural, induced
- **Wind flow [Mars]:** particle movement, cooling
- **Glare and Reflection**
- **Spacecraft Induced Ejecta**

Figure 2. Lunar Base Site Planning Considerations (Lewis, R. et al, 2019)

Classification



Infrastructure Classification	Key Characteristics
CLASS I **Pre-integrated**	• Earth Manufactured • Pre-Integrated & Tested prior to Launch • Space Delivered with Immediate Habitation Capability • Launch Shroud Constrained • Limited to Launch Vehicle Payload Size & Mass Capability
CLASS II **Prefabricated, Surface Deployed & Assembled**	• Earth Manufactured • Requires surface Deployment, Assembly & Outfitting • Partial Integration of Subsystems • Critical Subsystems are Earth Based and Tested prior to Launch • Requires Assembly & Checkout prior to Human Occupancy • Larger Volumes Capable • Not Restricted to Launch Vehicle Shroud Size • Restricted to Launch Mass. Deliver on multiple vehicles • Can include ISRU-derived parts
CLASS III **In-Situ Derived and Constructed**	• Manufactured In-Situ, Derived from local Resources (Lunar or Mars) • In-Space Constructed • Requires Robotic Manufacturing Capability & Infrastructure • Requires Robotic and Human Labor During Construction • Requires Integration of Subsystems • Critical Subsystems are Earth Based and Tested prior to Launch • Larger Volumes Capable • Not Restricted to Launch Vehicle Size • Not Restricted to Launch Mass

Figure 3. Infrastructure Construction Classification (Kennedy, 2002)

Master Planning

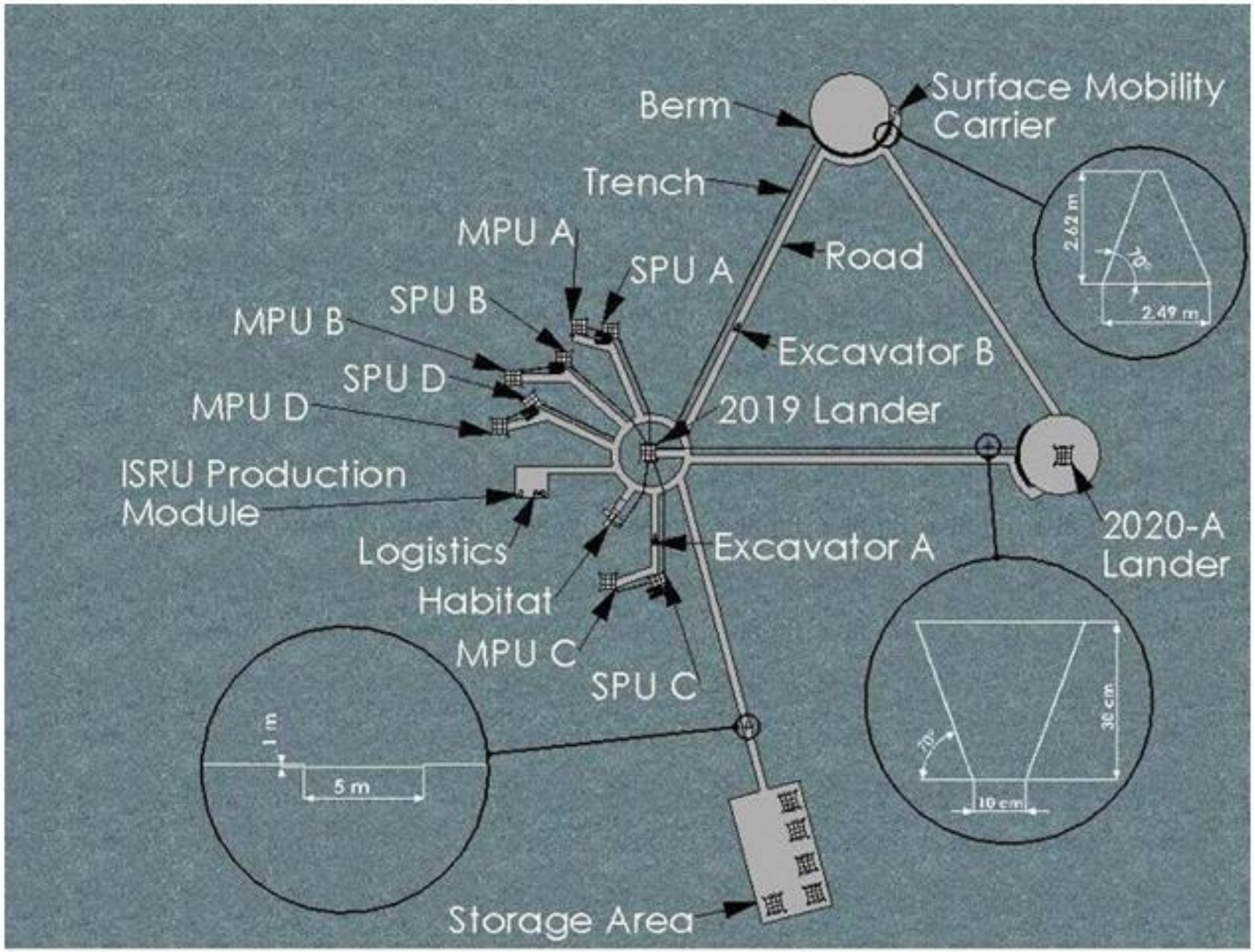


Figure 4. Example of a Notional Lunar Base Site Plan (Mueller et al, 2008)

In-Situ Construction

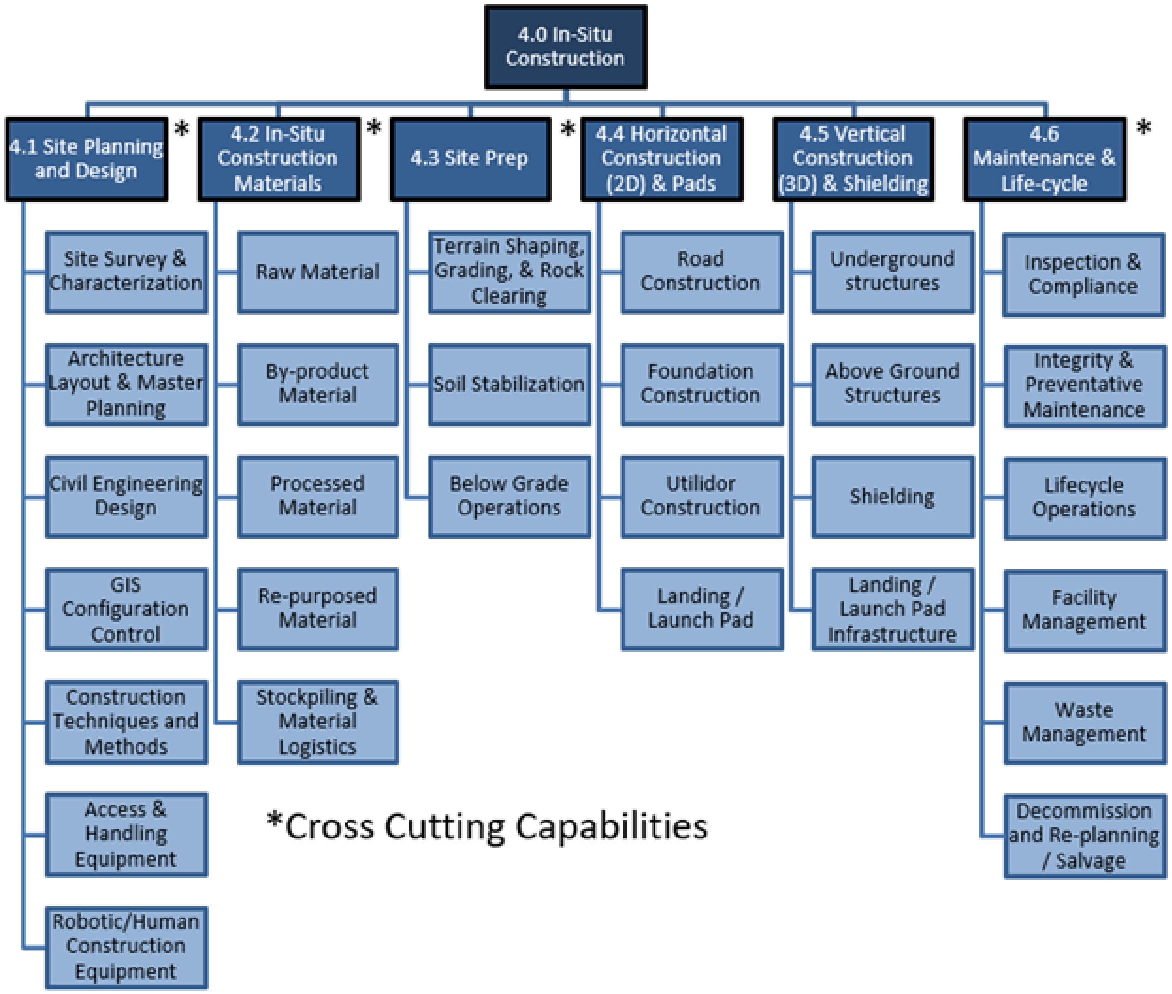


Figure 6. Work Breakdown Structure for Infrastructure Construction Activities

Lunar Construction Equipment

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Table 3. Infrastructure and Associated Construction Equipment

Notional Infrastructure	Robotic Construction Equipment
Landing / Launch Pads	Cut / Fill Excavator, Bulldozer, Regolith Transporter (truck), Grader, Compactor, Paver
Blast Shields / Berms	Robotic Assemblers, Bulldozers, Loaders, Compactor, Regolith Transporter
Propellant Farms	Crane, Robotic assemblers, Grader, Flat Bed and Regolith Transporter, Excavator
Roads / Pathways	Cut/Fill Excavator, Grader, Compactor, Paver
Dust Free Zones	Cut/Fill Excavator, Grader, Compactor, Paver
Utility Trenches	Cut/Fill Excavator, Compactor
Utilities (cables, pipes, fiber optic, etc.)	Crane, Robotic Assembler, Reel Deployer
Nuclear Power Plant Shielding	Cut/Fill Excavator, Loader, Compactor, Grader, Regolith transporter
Space Radiation Shielding	Cut/Fill Excavator, Loader, Compactor, Grader, Regolith Transporter
Meteorite Shielding	Cut/Fill Excavator, Loader, Compactor, Grader, Regolith Transporter
Foundations / Seismic Mitigation	Cut/Fill Excavator, Grader, Compactor, Paver, Flat Bed and Regolith Transporter, Crane, Robotic Assembler
Dust Free Zones / Plazas / Storage Areas	Cut/Fill Excavator, Grader, Compactor, Paver
Communication / Power Towers	Grader, Compactor, Vertical Constructor
Un-Pressurized Hangars	Grader, Compactor, Vertical Constructor
Pressurized Habitats	Grader, Compactor, Vertical Constructor
Consumables Logistics Tanks	Crane, Robotic assemblers, Compactor, Grader
Resource Mines / ISRU Zone	Cut/Fill Excavator, Hauler
Thermal Wadis	Cut/Fill Excavator, Grader, Compactor, Paver
Waste Disposal / Recycling Facility	Cut/Fill Excavator, Loader, Compactor

Summary

- NASA Space Mission Architecture Studies
- Functional Analysis of a Lunar Base
- Infrastructure Classification
- Master planning & Site layout
- Program Management (Space compared to Construction industry)
- Artemis Phase 1& Phase 2
- In-Situ Construction WBS
- Construction Equipment Needed
- It is hoped that technology development and lunar base construction implementation can be pursued within a common framework by international teams and consortia