Manufacturing for Planetary Construction using Polymeric Concrete

- Planetary Additive Construction System (PACS) -

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Contents

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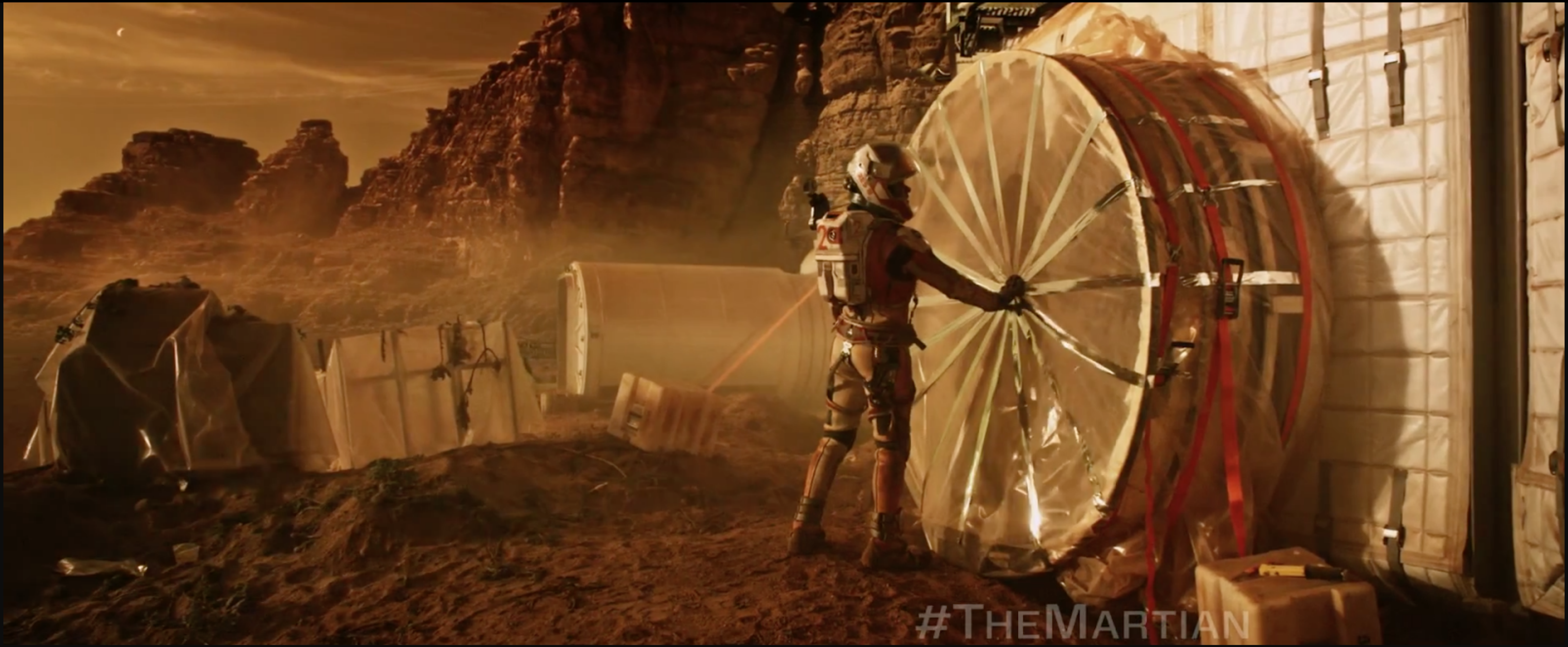
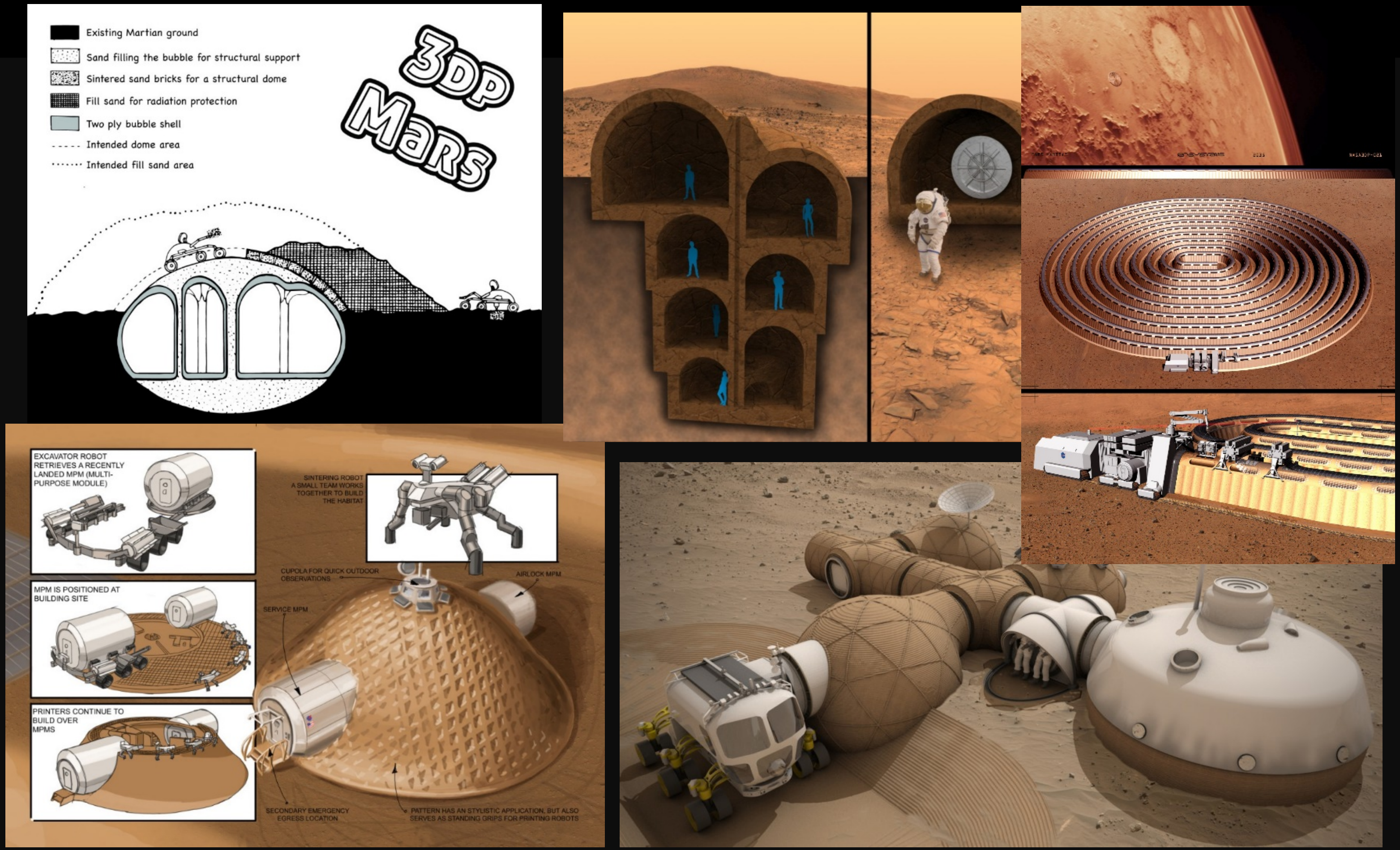
Background



The Martian: Radiation, Pressure, Sandstorm, Harsh Environment

Background

ESA Lunar Base



NASA 3D Printed Habitat Challenge

Modular Habitat + 3D Printed Protection, but **How??**

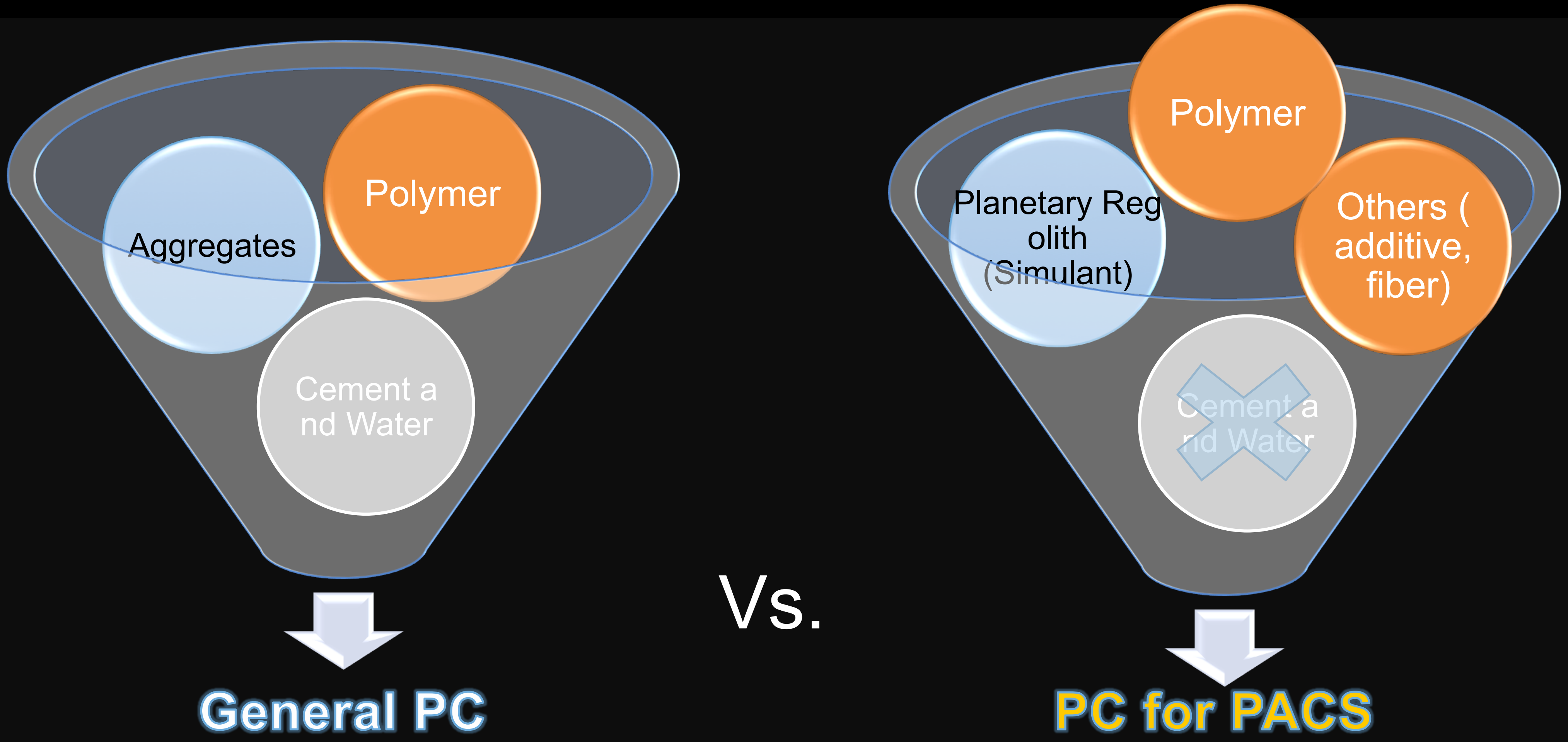
Why Polymer Concrete

- PC is a versatile, durable, composite material produced by mixin g a variety of mineral fillers with a synthetic or natural resin bindi ng agent

- High resistance to chem. and bio. attack
- Lightweight
- Noise and vibration absorption
- Good weathering and UV resistance
- Low water absorption
- High flexural strength
- Good thermal properties and stability
- Smooth finish

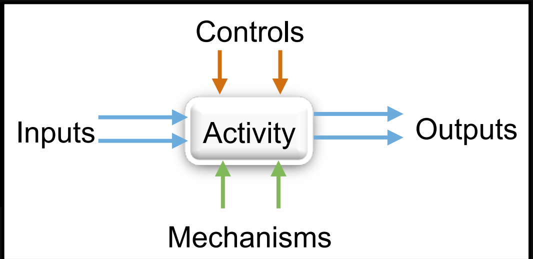
Good Features Proper to Planetary Construction

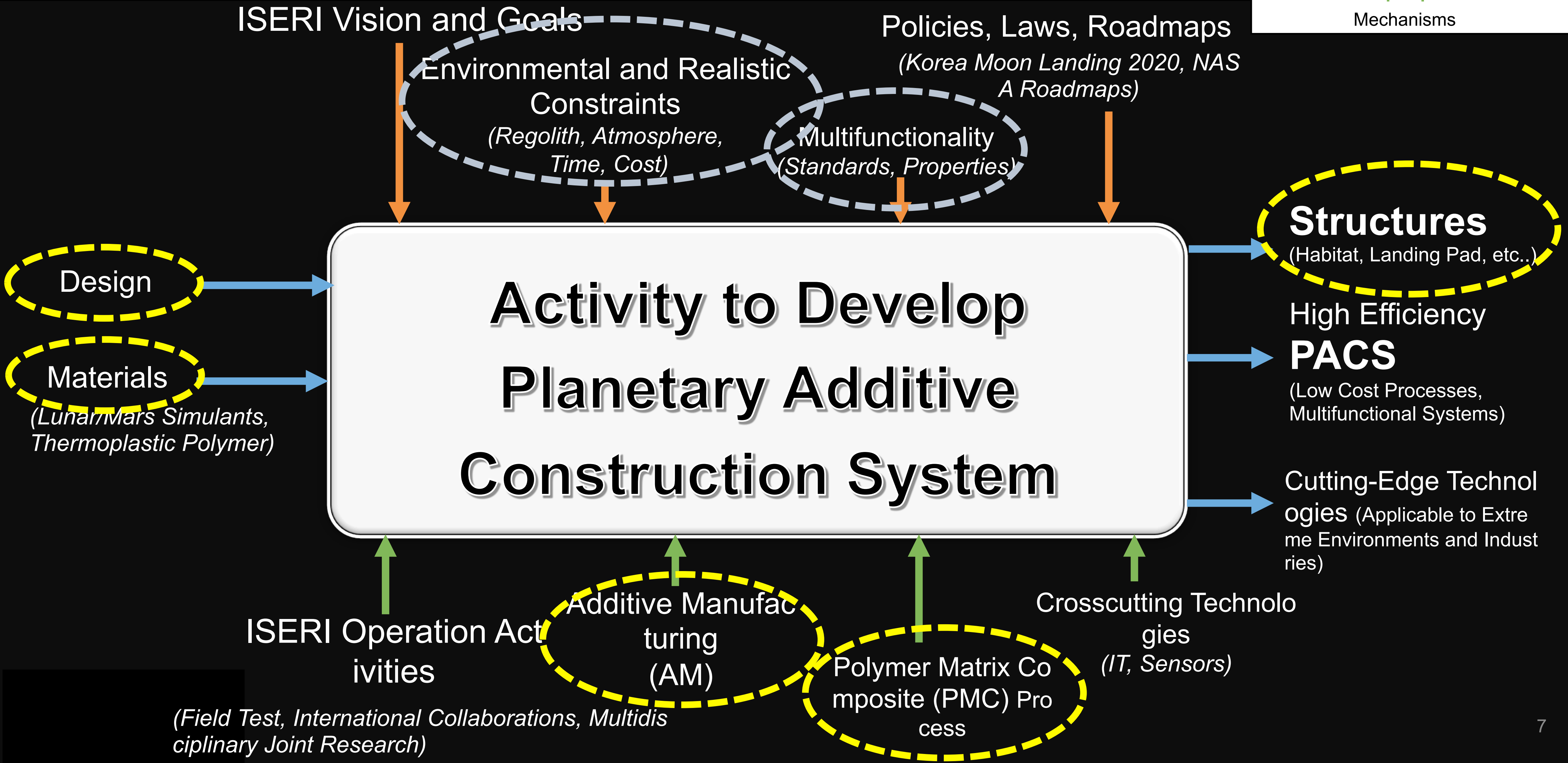
PC for PACS



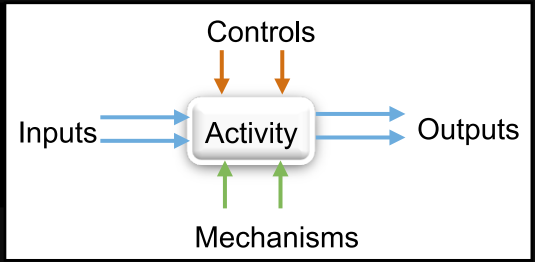
Finding the Best Combination for Planetary Requirements and AM

PACS Development Process

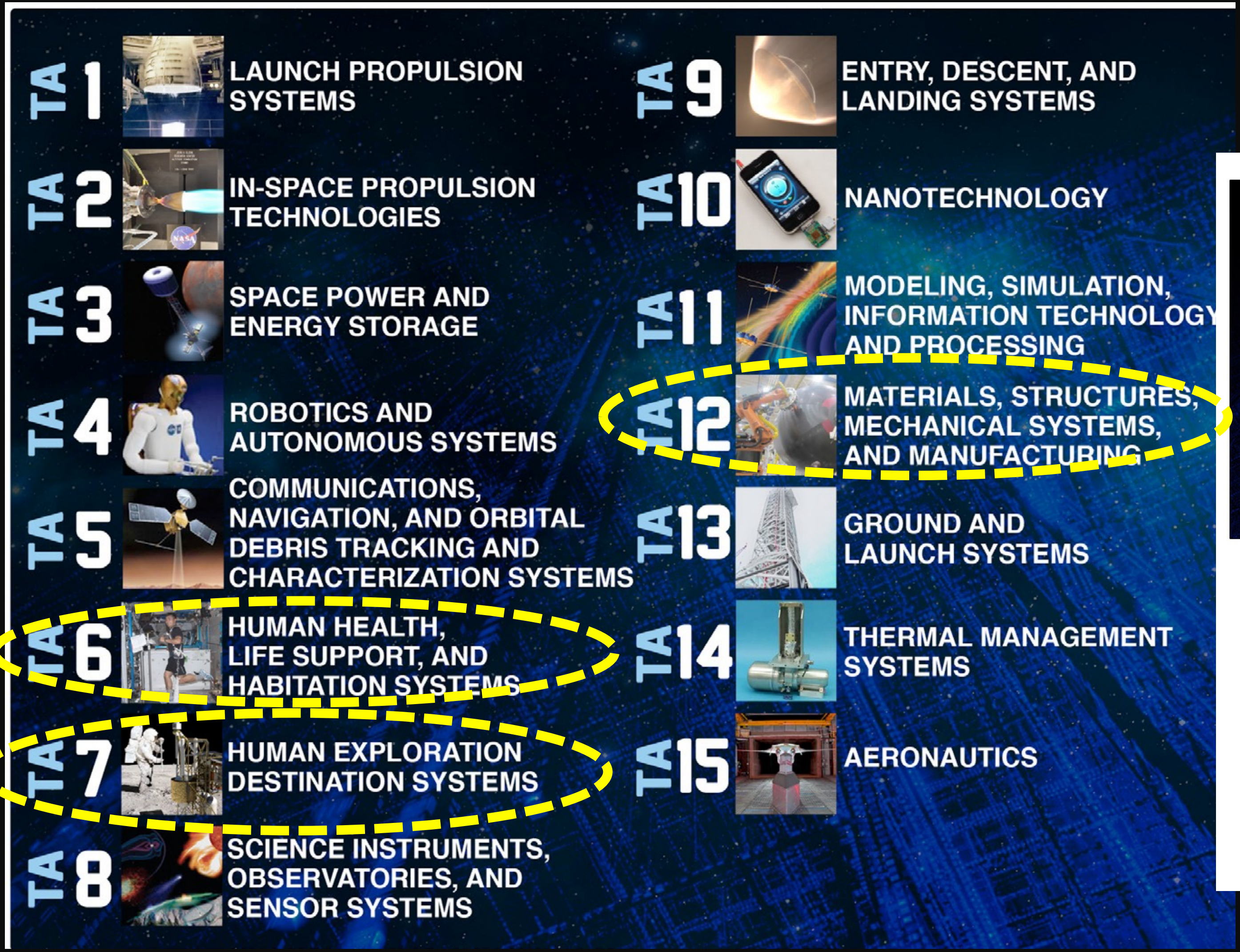


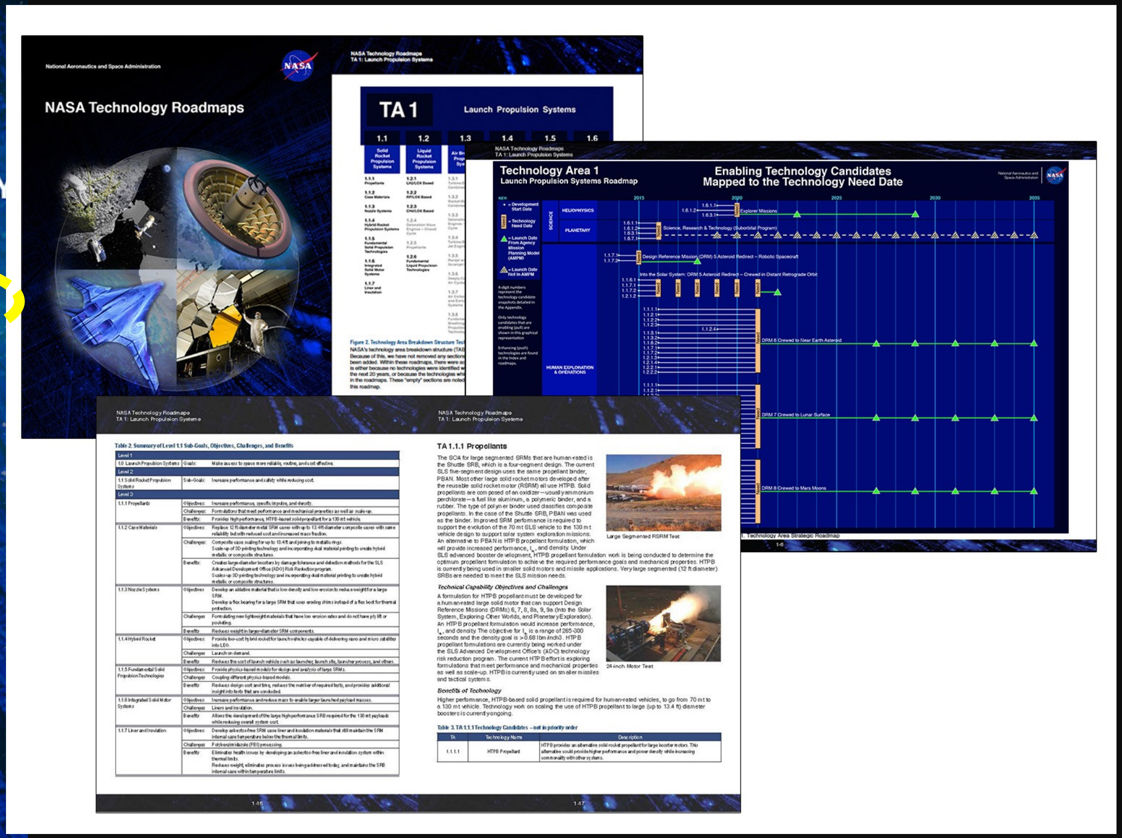


NASA Technology Roadmap

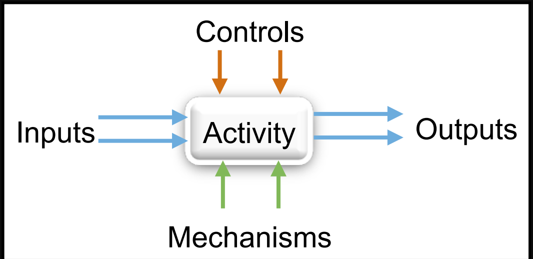


Source: Technology Area Breakdown Structure (TABS), NASA Technology Roadmaps, July 2015



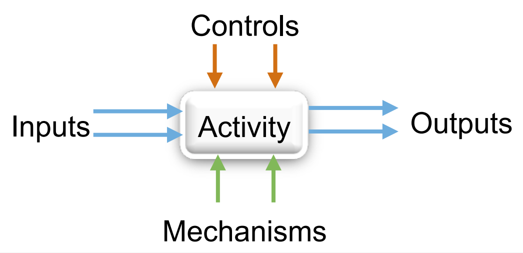


Mapping with NASA TA Candidates



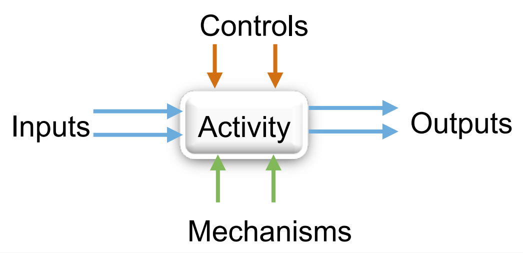
NASA TA Candidates		Design	Material	Construction
6.5.3.3	In-Situ Passive Shielding from Planetary Surface Materials			
7.1.1.1	Penetrometers, Shear Gauges, Compaction, Density Instruments			
7.1.2.9	Pneumatic Excavation and Material Transport			
7.1.2.10	Auger Excavation and Material Transport			
7.1.2.11	Magnetic Excavation and Material Transport			
7.1.2.18	Non-Clogging and/or Self-Cleaning Sieves			
7.1.2.19	Crushers/Grinders for Rock and Metal			
7.1.3.2	Mechanical Regolith Mixing			
7.1.3.3	Vibrational Regolith Mixing			
7.1.3.7	Solar/Thermal Energy Concentrators			
7.1.3.8	Optical Fiber Cables with Thermal Receiver			
7.1.3.9	Heat Storage/Transfer			
7.1.4.1	Regolith Thermal Mass Formation			
7.1.4.4	Radiative Insulation of Regolith Thermal Mass			
7.1.4.5	Sintering Regolith			
7.1.4.6	In-Situ Fabrication Using Electron Beam Freeform Fabrication (EBF^2)			
7.1.4.7	Microwave Sintering for Dust Passivation and/or Soil Stabilization			
7.1.4.8	Solar Concentrator Sintering for Dust Passivation and/or Soil Stabilization			
7.1.4.9	Other Methods of Sintering			
7.1.4.10	Application of Polymers to the Soil for Dust Passivation and/or Soil Stabilization			

Mapping with NASA TA Candidates



NASA TA Candidates		Design	Material	Construction
7.2.1.8	Packaging Foam Additive Printer Feedstock			
7.2.3.9	Additive Manufacturing (3D Printing)			
7.2.3.11	Electron Beam Freeform Fabrication (EBF^2)			
7.2.3.15	In-Situ Manufactured Parts/Components Verification and Certification			
7.3.1.5	Anchoring			
7.6.18	Plume Mitigation			
7.6.1.21	Plume Resistant Concrete			
7.6.2.1	Shaped Charges and Explosives			
7.6.2.2	Ballistic Fabric Barriers			
12.1.1.1	Out of Autoclave Material Systems Resins/Adhesives/Fibers			
12.1.1.2	Low Mass, Multifunctional Materials			
12.1.1.4	Self-Healing/Repair Materials			
12.1.4.1	Cryo-Insulator Material			
12.1.4.2	High/Ultra-High Temperature Material			
12.1.4.3	Coatings			
12.1.4.5	Material for Combined Extreme Environments			
12.4.1.2	Polymer Matrix Composite (PMC) Process			
12.4.1.3	Ceramic Matrix Composite (CMC) Process			
12.4.1.4	In-Space Assembly, Fabrication and Repair (ISFAR) Process			
12.4.2.1	Digital and Model-Based Manufacturing			
12.4.2.2	Model-Based Operations			
12.4.2.3	Additive Manufacturing			

Environmental and Multifunctional Requirements



Environmental Requirements

Temperature | Radiation | Atmosphere | Pressure | …

Temperature Ranges and Variations on the Moon

	Permanently Shadowed Polar Craters		Other Polar Areas		Equatorial Zone		Mid-Latitudes	
Average Temperature	40 K	-233°C	220 K	-53°C	255 K	-18°C	237.5 K	-35.5°C
Thickness of Regolith Cover (m)	Monthly Variation and Range (°C)							
	Variation	Range	Variation	Range	Variation	Range	Variation	Range
0.0	0	-233	+/-10	-63 to -43	+/-140	-158 to 122	+/-50	-85.5 to 14.5
0.5	0	-233	+/-3.9	-56.9 to -49.1	+/-55.8	-73.8 to -37.8	+/-19.6	-55.1 to -15.9
1.0	0	-233	+/-1.2	-54.2 to -51.8	+/-16.6	-34.6 to -1.4	+/-5.8	-41.3 to -29.7
1.5	0	-233	+/-0.5	-53.5 to -52.5	+/-7.5	-25.5 to -10.5	+/-2.7	-38.2 to -32.8
2.5	0	-233	+/-0.2	-53.2 to -52.8	+/-2.8	-20.8 to -15.2	+/-1.0	-36.5 to -34.5

Reference 추가

Material Properties

Polymers | Radiation Shielding | Construction Material

Thermo/Mechano/Chemo/Photo Properties of Polymers

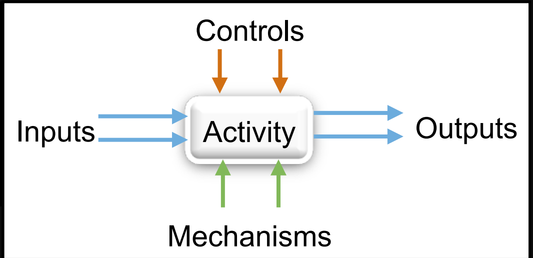
Polymer	P (g/cm³)	Tm (°C)	E (GPa)	σ (MPa)	ε (%)
Nylon-6	1.08-1.23	223	1.9	75	300
Nylon-6,6	1.07-1.24	265	2.0	80	200
Polycarbonate	1.20-1.31	227	2.5	60	125
Polyethylene	0.91-1.00	98-135	0.2-1.0	10-30	600-800
Polyethylene-terephthalate	1.33-1.48	267	3.0	54	275
Polymethyl-methacrylate	1.17-1.23	160	3.2	65	10
Polyoxy-methylene	1.43-1.54	187	2.7	65	40
Polypropylene	0.9-0.95	177	1.4	33	400
Polystyrene	1.05-1.13	240	3.4	50	2.5
Polytetra-fluoroethylene	2.1-2.35	327-332	0.5	25	200
Polyvinyl-chloride	1.39-1.52	273	2.6	50	30

Standards

Polymers | Radiation Shielding | Construction Material

Standard	Feature
ASTM D569	Measuring the flow properties of thermoplastic molding materials
ASTM D621	Deformation of plastics under load
ASTM D638	Tensile properties of plastics
ASTM D695	Compressive properties of rigid plastics
ASTM D746	Brittleness temperature of plastics and elastomers by impact
ASTM D792	Specific gravity and density of plastics by displacement
ASTM D1505	Density of plastics by the density-gradient technique
ASTM D2288	Weight loss of plasticizers on heating
ASTM D2990	Tensile, compressive, and flexural creep and creep rupture of plastics
ASTM D4000	Specifying plastic material

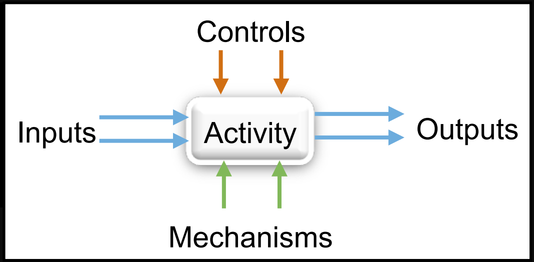
Planetary Regolith Simulant

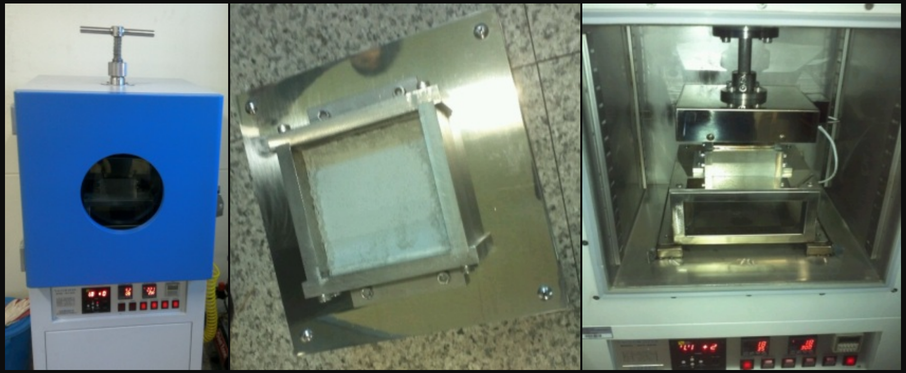


- Lunar Simulant: KOHLS-1(Korea Hanyang Lunar Simulant)
  - Using for rover tests, Lunar concrete manufacturing, etc.

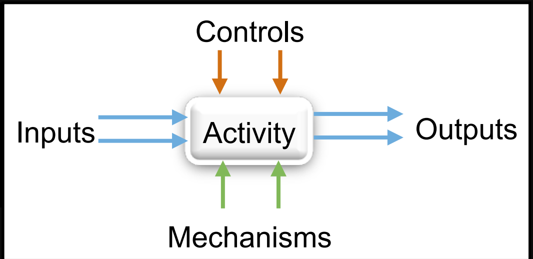
Korea's Geology Map (www.kigam.or.kr)

Polymer Matrix Composite (PMC) Process

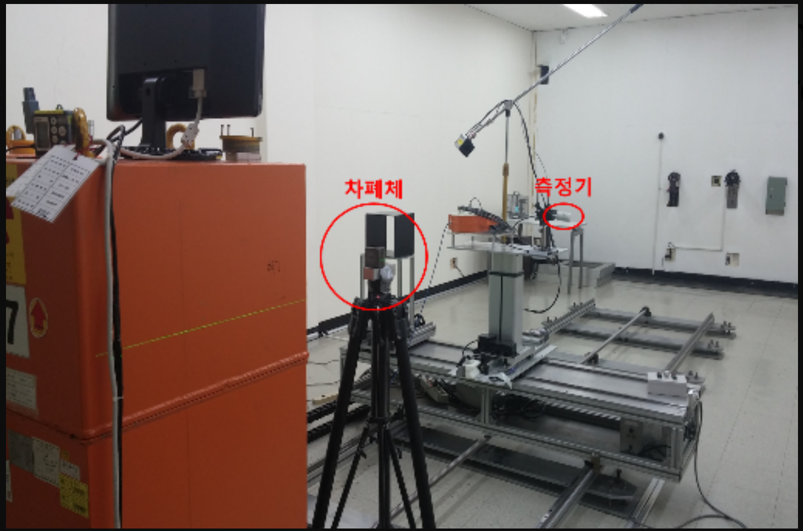




A Study of Radiation Shielding Test on Lunar Concrete



- Experiments



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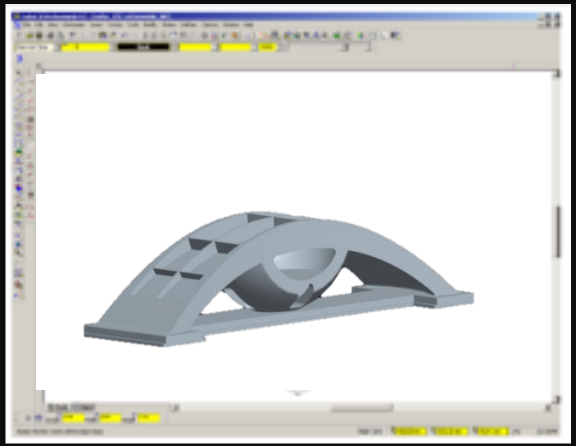
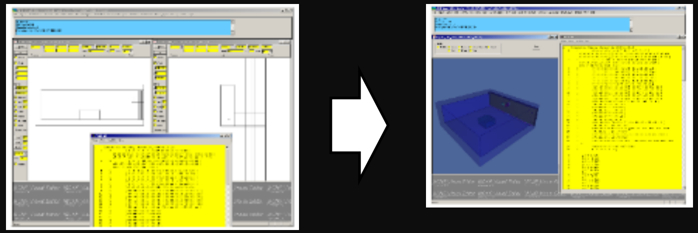
Radiation Shielding Experiment

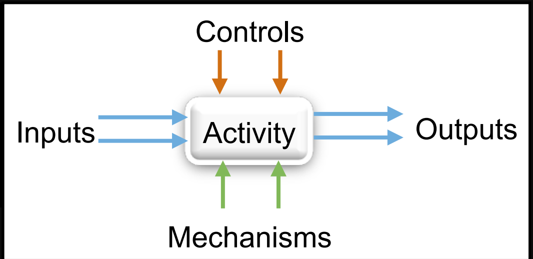
- Simulations(MCNPX)



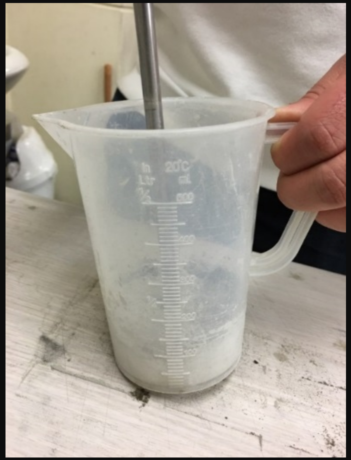


Monte Carlo N-Particle Extended (MCNPX)

PACS



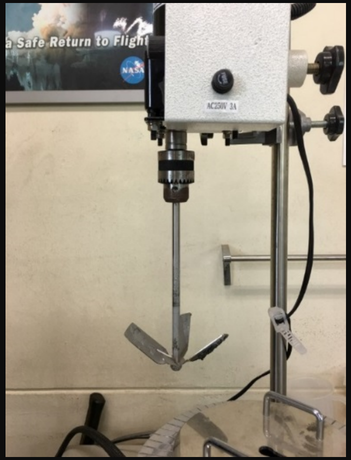
- Parameter, Value (NASA Roadmap TA7) - Bearing capacity: 1,000psi for 20:1 regolith to binder application
  - According to NASA Roadmap & ASTM C109



Mixing

Molding

- Uneven Value
- Wasted Materials, Time
- Failed to meet the parameter



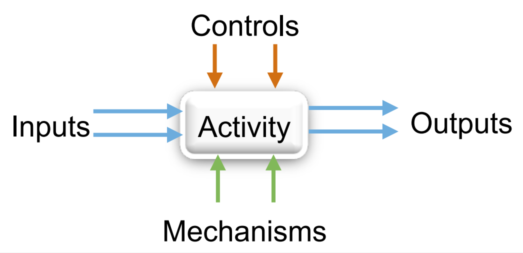
Mixing Machine

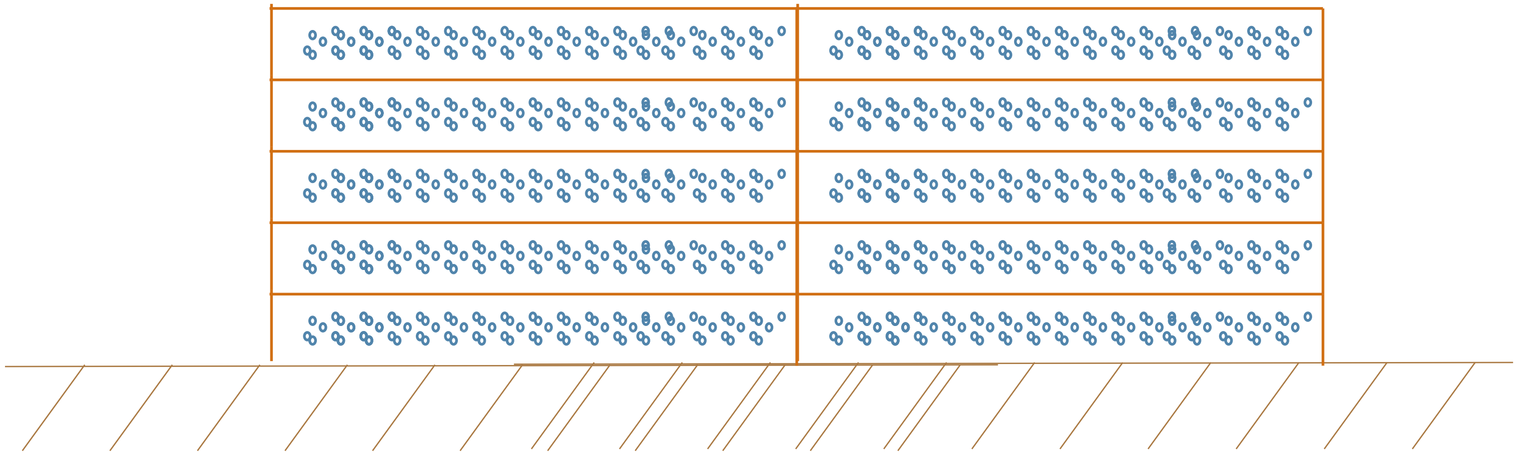
Automatic Compression & Heating Machine

PACS

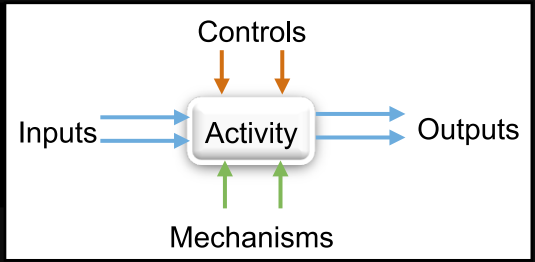
- Time ↙
- Material ↙
- Cost ↙
- Quality ↗
- Automation

PACS Process





Testing and Improving Mechanism of PACS



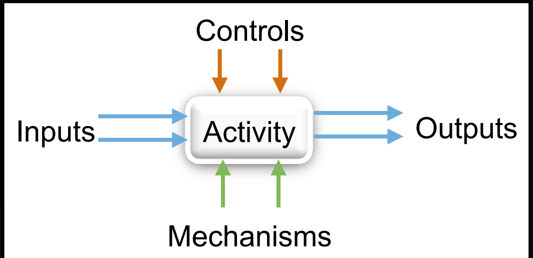
Polymer(10%) Hand Made

Polymer(10%) PACS

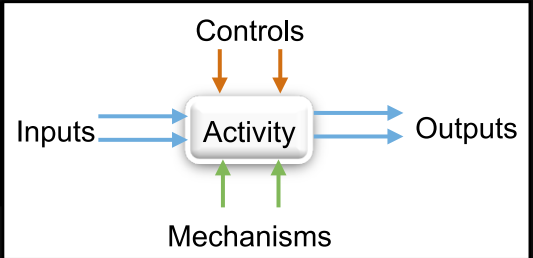
Polymer(30%) Hand Made

Polymer(30%) PACS

Testing and Improving Mechanism of PACS

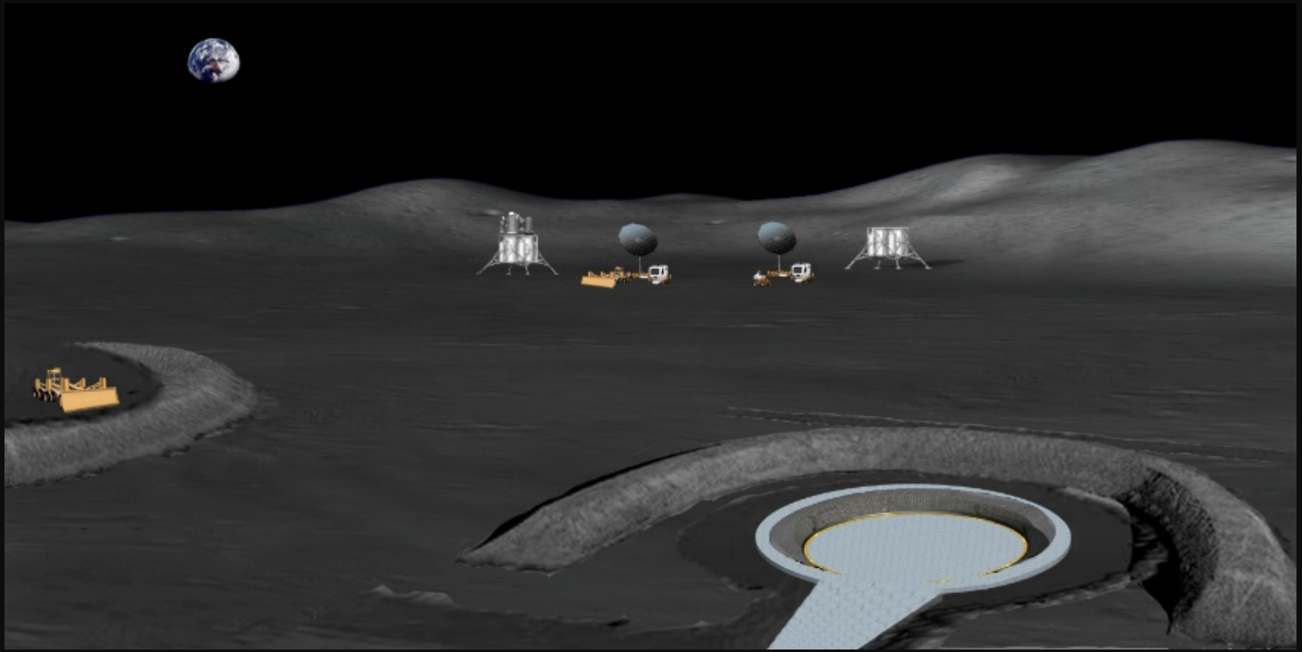


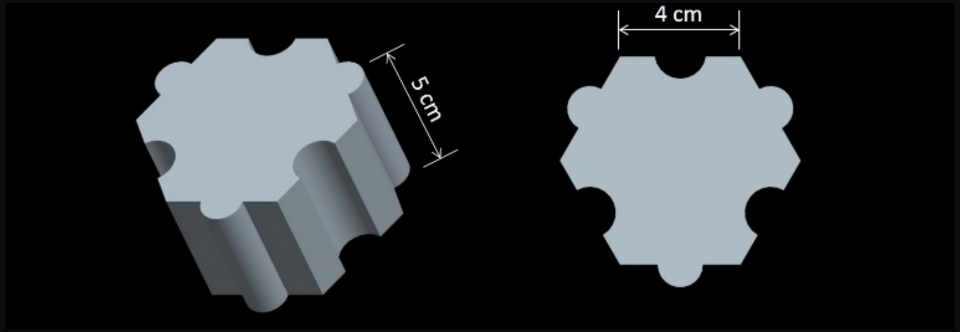
Development of Structure/Facility Design

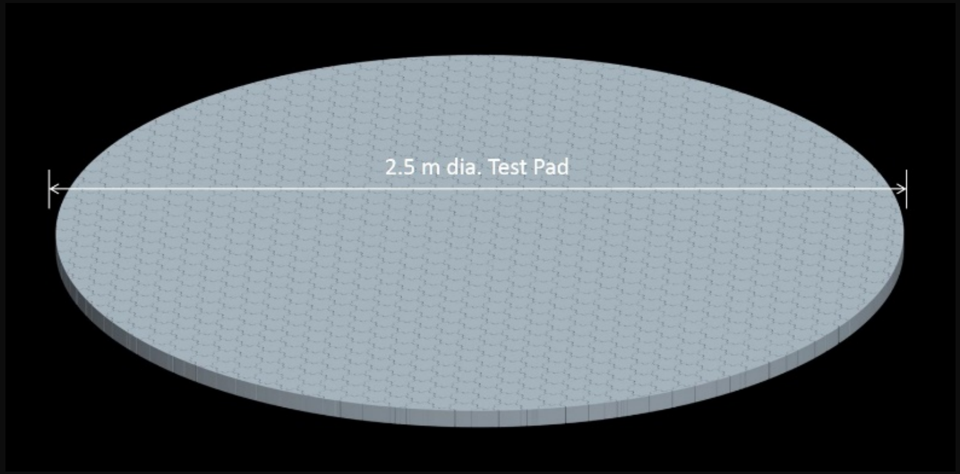


Developing an End to End Process

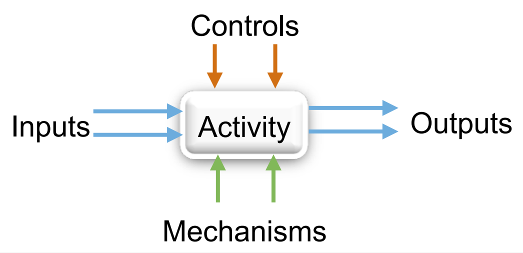
Landing Pad





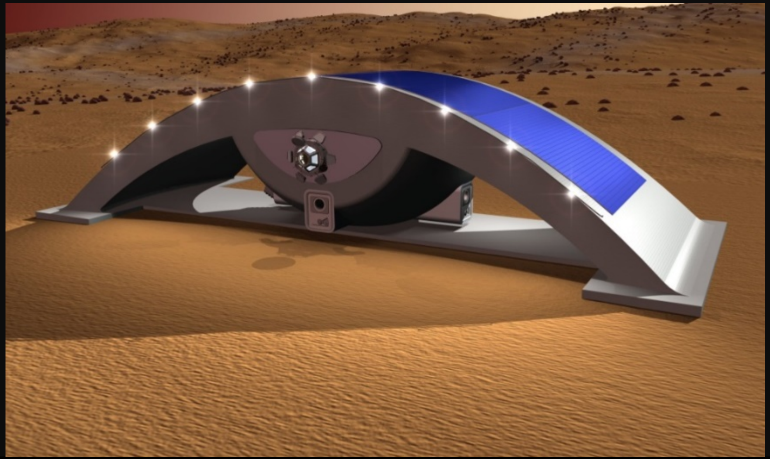


Development of Structure/Facility Design

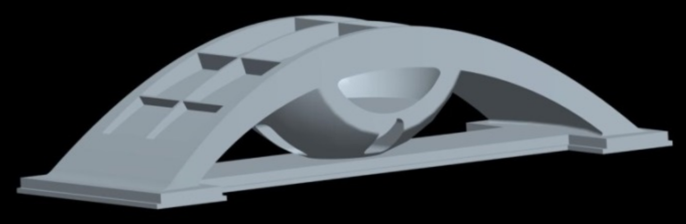


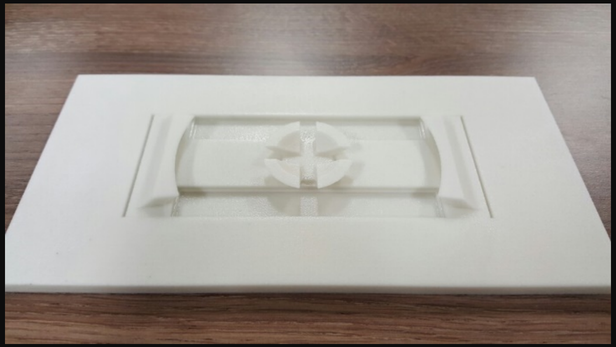
Developing an End to End Process

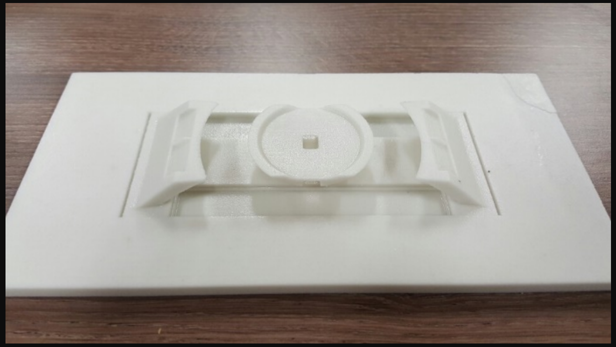
Habitats



ArchHab



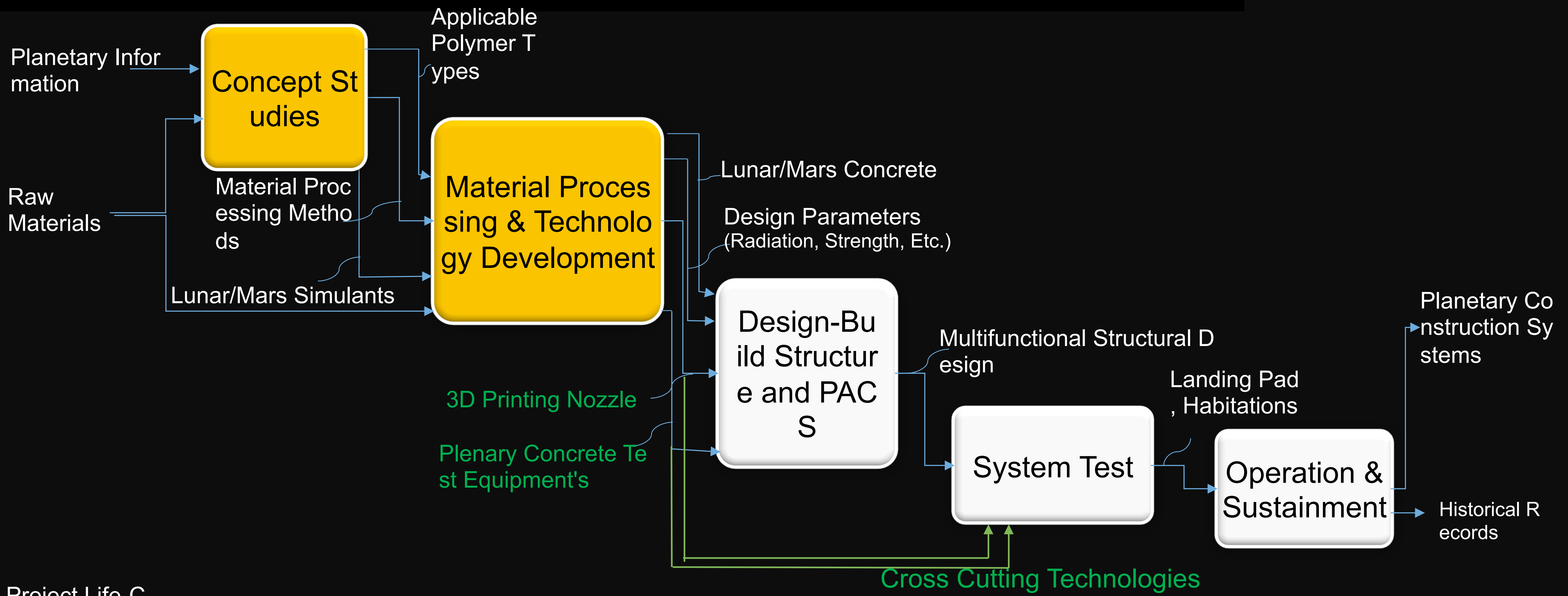




Value/Originality

- Covers end to end process starting from design to construction
- Suitable to granular material which is the main material for earth rammed cons truction and moon and mars construction
- Possible to apply other types of lunar concrete materials such as sintering, co mbustion of mixture of regolith and metal powder, etc.
- Differ from previous additive construction using specific materials such as quic k dry concrete, sintering which is hard to control quality
- f

Future Plan



Project Life-Cycle Phases (NASA)	Pre-Phase A: Concept Studies	Phase A: Concept & Technology Development	Phase B: Preliminary Design & Technology Completion	Phase C: Final Design & Fabrication	Phase D: System Assembly, Integration & Test, Launch	Phase E: Operation & Sustainment	Phase F: Closeout

ISERI: 2011.11 — 2016.06 — 2016.07 — 2017.06

Korea Space Plan: 2020 (Korea Moon Landing) — 2030 (Korea Mars Landing)

Thank you!

Questions?