Planetary Potential Construction Material

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Presentation Objective

- Provide an overview of the available construction materials
- Material Requirements
- Bonus Requirements
- Material Considerations
- Potential Binders
- Environmental Challenges
- On going Materials Research
- Initiate discussions of mutual interest

Main Construction Material Resources

- Regolith
- Atmosphere

NASA's Path to Mars

Material Requirements

- *In situ*
- Withstand micrometeorite impact
- Withstand extraterrestrial temperature variations
- Hold pressure (either by a compressive regolith load, lining, or design)
- Provide radiation shielding

Bonus Requirements

- The less water involved or consumed, the better
- The less power or resources consumed during mining and processing / binder production, the better
- The easier it is to emplace (including layer adhesion), the better
- The less precise the mixture has to be, the better
- The more simplistic the design of the mobility system, the better
- The less insulation, skin, or liner needed, the better
- The less toxic the material is when exposed to oxygen or water, the better
- The less cost for development, the better!

Other Materials Considerations

- Emplacement (extrusion) in a pressurized or ambient environment
- Tension – internal pressurization
- Radiation and micrometeorite protection / shielding
- Aging (thermal, radiation, micrometeorites, settling, etc.)
  - Embrittlement
- *In situ* materials are site-dependent
  - Moon or Mars? Poles or Equatorial Region? Basalt or Sedimentary Rock?
  - Binder selection must reflect and complement available materials

In Situ Materials (Mars)

Mineral	Other Materials
Major minerals	**Present everywhere (“dew”)**
Feldspar ($CaAl_2Si_2$, Na,KSi_3,O_8)	Perchlorates (ClO_4^-)
Pyroxene ($(Ca,Mg,Fe)Si_2O_6$)	**Atmosphere**
Olivine ($(Mg,Fe)_2SiO_4$)	CO_2 (95.32%)
Minor minerals	N_2 (2.7%)
Hematite (Fe_2O_3)	Ar (1.6%)
Magnetite (Fe_3O_4)	O_2 (0.13%)
Clays (Fe-Mg silicates, K-Al silicates)	CO (0.08%)
Sulfates (gypsum-Ca; jarosite-K,Fe; epsomite-Mg)	H_2O (210ppm)
Carbonates (calcite-Ca, dolomite-Mg)	NO (100ppm)
Poles – solid CO_2 (both) and H_2O (northern pole)	

In Situ Materials (Moon)

Minerals	Permanently Shadowed Regions
Highlands (Major Minerals)	LCROSS (ejected material)*
Anorthite ($CaAl_2Si_2O_8$)	Regolith (~85%)
Pyroxene ($(Ca,Mg,Fe)Si_2O_6$)	CO (5.70%)
Olivine ($(Mg,Fe)_2SiO_4$)	H_2O (5.50%)
Mare (Major Minerals)	H_2 (1.39%)
Feldspar ($CaAl_2Si_2$, Na,KSi_3,O_8)	H_2S (0.92%)
Pyroxene ($(Ca,Mg,Fe)Si_2O_6$)	Ca (0.79%)
Olivine ($(Mg,Fe)_2SiO_4$)	Hg (0.48%)
Minor / Trace Minerals	NH_3 (0.33%)
Baddeleyite (Zr oxide)	Mg (0.19%)
Apatite (Ca phosphate)	SO_2 (0.18%)
Zircon (Zr, Si oxide)	C_2H_4 (0.17%)
Spinel (metal oxide)	CO_2 (0.12%)
Ilmenite (Fe, Ti oxide)	CH_3OH (0.09%)
Whitlockite (Ca phosphate)	CH_4 (0.04)
Other phase of note – nanophase iron	OH (0.002%) * Larson et al. (2013)

Potential Binders

- Sorel Cements
- Ionic Liquid
- Geopolymers
- Polymers
- Regolith
  Martian and Lunar
- Sulfurs
- Silicates
- Glass
- Urea
- Sodium Silicates
- OPC
- Igloos

These binders can be produced *in situ* prior to crew arrival.

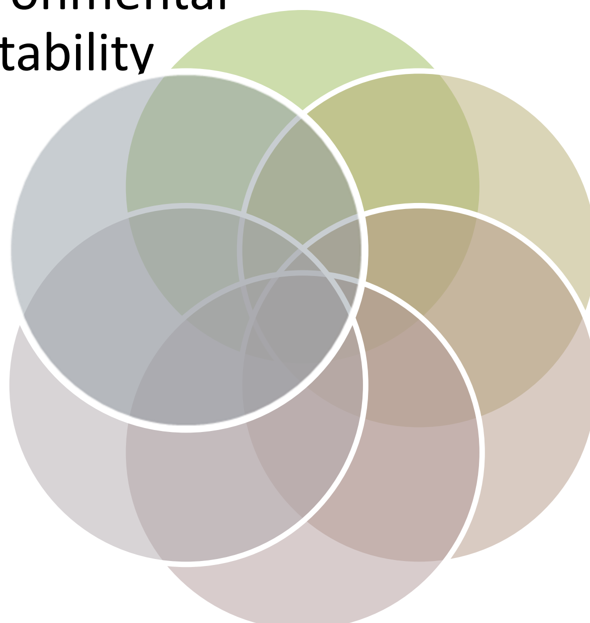
Polymer trash recycling (the topic of the 3D Printed Habitat Challenge) is not the focus of this work.

Environmental Challenges

Parameter	Mars	Moon
Gravity	1/3 that of Earth	1/6 that of Earth
Pressure at surface	3-10 Torr ($4x10^{-3}$ to $1x10^{-2}$ ATM)	$2x10^{-12}$ Torr ($3x10^{-15}$ ATM)
Surface Temperatures	-89 to -31 Celsius (Viking 1)	-178 to 117 Celsius (equator)
Radiation (solar wind particles, galactic cosmic rays)	Some protection offered by atmosphere	Some protection offered by Earth's magnetic field
Surface reactivity	Perchlorates (highly oxidizing)	Reduced material (nanophase iron, elemental sulfur)

Planetary Fact Sheets

Optimization?



- Extrusion Effect
- Mineralogy
- Particle size and distribution
- Water content
- Additives effect
- Technology Transformation
- Cost
- ….etc

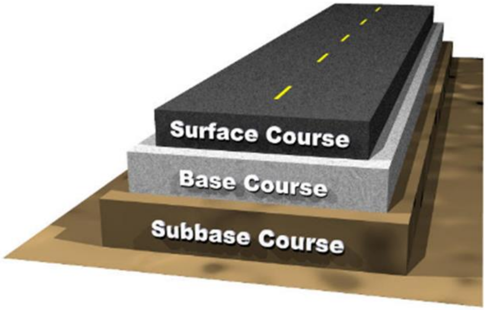
- **Out of these factors and many more, which ones are the most important? Can we find our golden mixture? Can we afford it? Do we have to characterize each one of these composites for all these factors?**

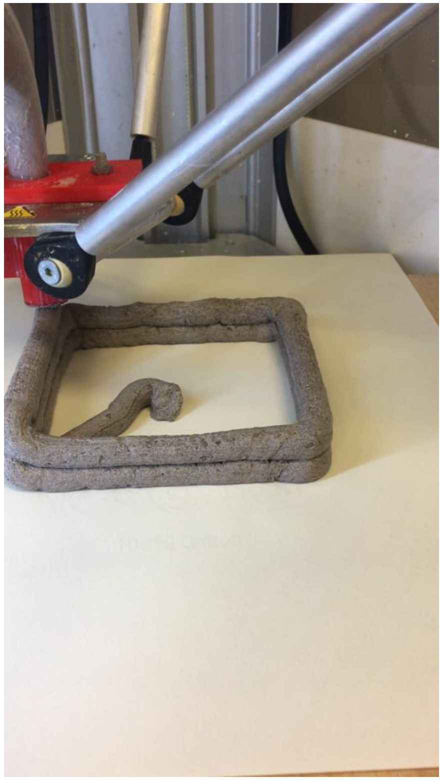
Ongoing Developed Cementitious-Like Materials

- Ordinary Portland Cement (OPC), Stucco Mix (sand, OPC, plaster of Paris/calcined gypsum), Water, Admixtures ± Simulant
- Magnesia Based Binders (MBBs)+ Simulant + Admixtures (primarily set retardant)
- Martian (JSC Mars-1A) and lunar (JSC-1A) simulant
  - Both are basaltic
  - Martian simulant grain size ≤5mm
  - Lunar simulant grain size ≤1mm

AMREC

Additive Construction - the process of joining materials to create 3D structures layer upon layer





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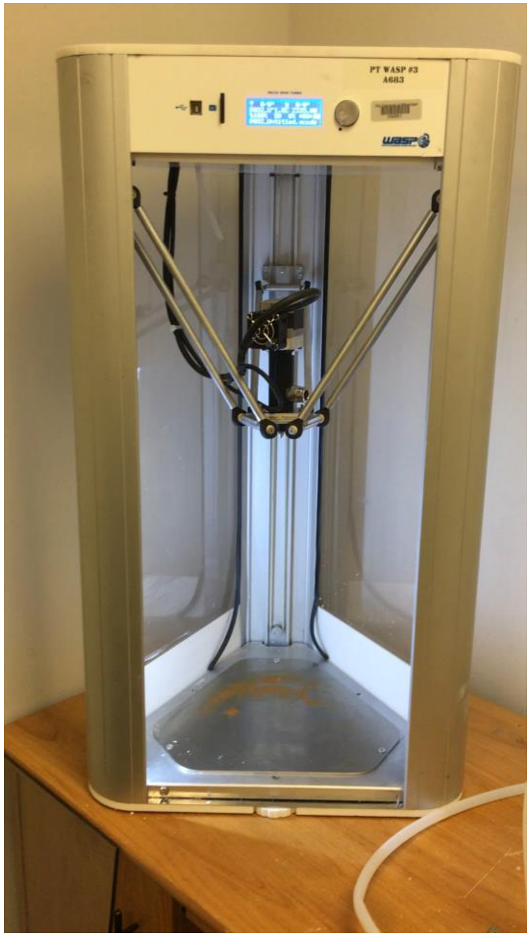
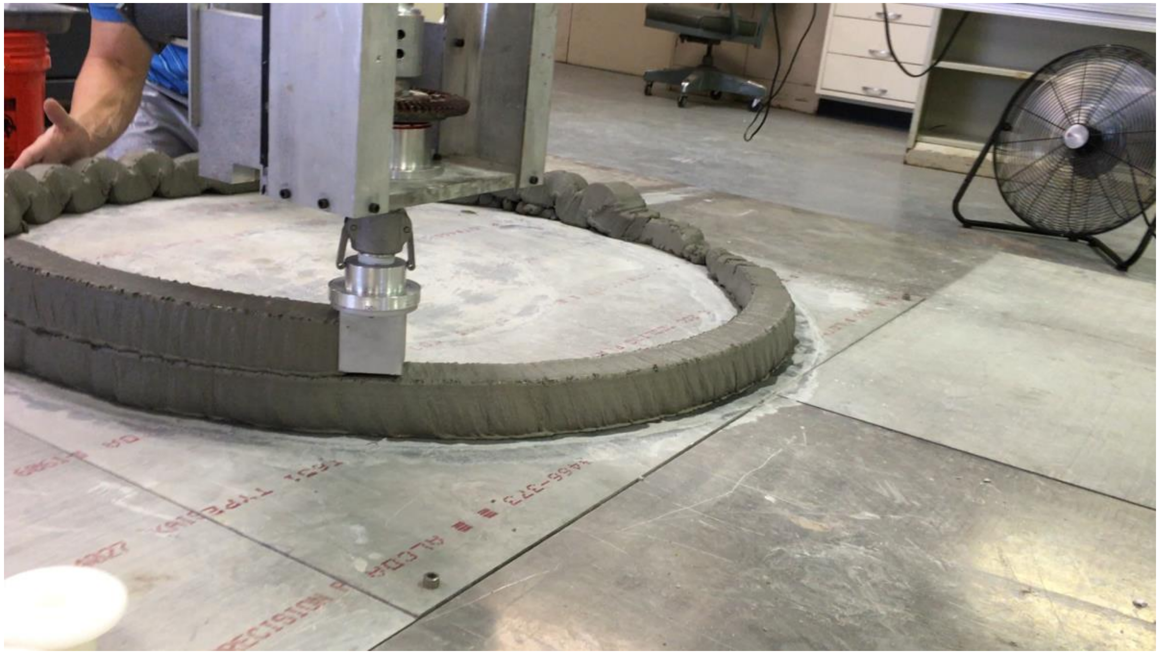


WASP Delta 20x40

ACME 2



Additive Construction and Manufacturing

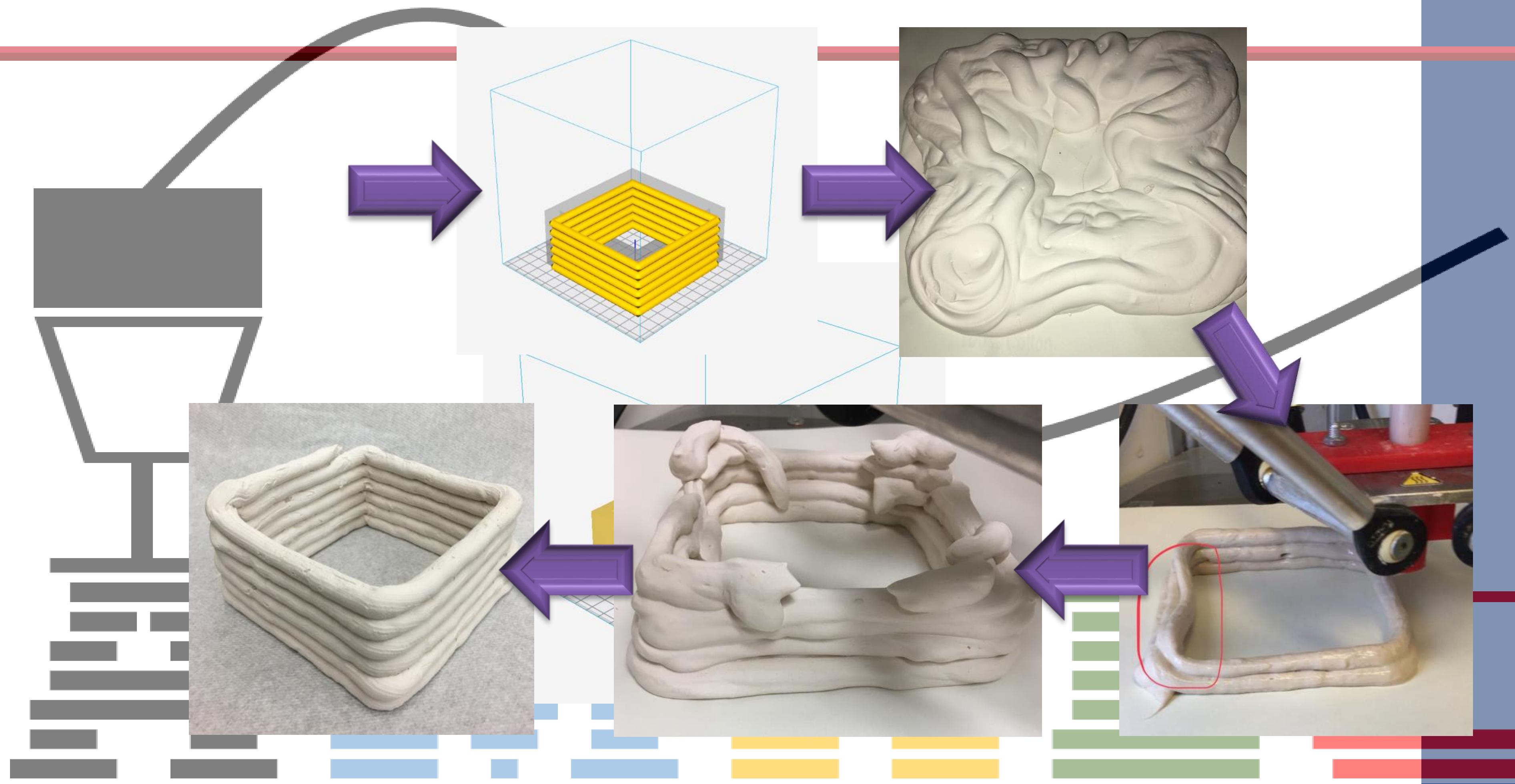
Can it be **PUMPED**?

Can it be **EXTRUDED** ?

Does it have enough **Time** for the printing process?

WILL IT **RESIST LOADS**?

3D Printing MOS



3D Printing MOS

Expected Outcomes

- Full characterization of MBBs
- Development and validation of ANN models to bridge between the MBBs proportions and its properties
- Utilizing MBBs for AC applications

Collaborations with NASA Marshall Space Flight Center

To make infrastructure construction off-Earth more affordable and reduce the amount of up-mass, construction materials must be fabricated in-situ, On going Research:

- **The production of cementitious materials from Martian regolith**
- **Demonstrate the fabrication of cements from known in-situ resources on Mars, while decreasing the energy required in traditional cement formulation and without greenhouse gas emissions**
- **Use ionic liquids and chemistry instead of heat**
- **Expected spin-off to terrestrial cement manufacturing**

(ACME and IL Groups)