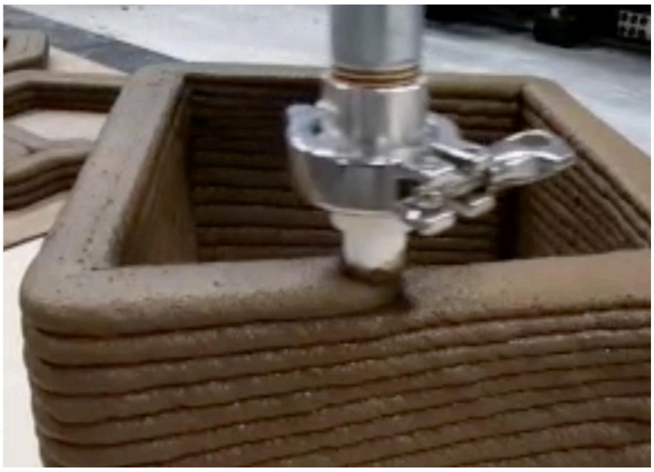
Prototyping Session 4



Purpose:

In-Situ Resource Utilisation (ISRU) of local materials for the production of 3D printed habitats on Mars. Used material is cement-based regolith concrete (CRC) , which is a mix of regolith simulant (Exolith MSG-1), Portland cement, sand, and additives based on the 3 printing concrete recipe of Vertico. For these experiments, a percentage of the sand is replaced with regolith simulant in the mix.

Goal:

Identification of material properties and 3D printing characteristics of CRC:

- Printability of CRC at various percentages (100%-0%) of regolith simulant replacement;
- Stability during printing at various percentages of regolith simulant replacement;
- Viscosity i.e. pumpability of CRC at various percentages of regolith simulant replacement;
- Compressive strength (work in progress);
- Thermal properties of the material (work in progress);

Approach:

1. Mixing CRC with 100% replacement of sand with regolith for the purpose of testing printability
    a. 3-Layer printability test (x3)
    b. 18-layer stability test
2. Mixing CRC with 50% replacement of sand with regolith for the purpose of testing printability
    a. 3-Layer printability test (x3)
    b. 18-layer stability test
3. Mixing CRC with 0%, 25%, 50%, 75% and 100% replacement of sand with regolith for the purpose of testing compressive strength (work in progress)
4. Mixing CRC 100% replacement of sand with regolith for the purpose of testing thermal properties (work in progress)

5. 3D-printing with regular concrete to test componential logic (see previous research steps and is work in progress)

1. Testing printability of CRC with 100% replacement

1.1 Tool paths

In order to test printability, tool paths were made that follow the logic of a Voronoi-based cellular system with density variation. While the 3-layer test is a proof of concept that shows the printability of cells with a varying density from high density (solid) to low density (high porosity), the 18-layer test shows the stability of the material during the printing process. Variable density is achieved through structural optimization: The higher the density the stronger the material. This strategy will allow the structure to be 3D printed with minimal material, but with the required strength.

The tool paths are generated in a continuous manner, allowing the robotic arm to 3D-print the material without starting and stopping. This reduces travel moves during the printing process, therefore, improving the printing efficiency and reducing production time.

1.2 Mixing the materials

The following recipe for the mixture wherein 100% of the sand was replaced with regolith simulant was used:

Regolith	33482 g
Cement	22321 g
Chemicals	446 g
Water according to recipe / water used	8661 g / 11648 g
Material mixing and processing time before printing:	50 min
3D -Printing time:	10 min
Mix/vibrate new batch in loop:	10 min
3D -Printing time:	10 min
Total time:	80 min

In the starting up phase of the printing process, the material needs to be pumped from the material reservoir, through the pump, through the hose, nozzle and back into the material reservoir. This needs to be done in order to remove the air from the system. If there are air pockets trapped in the hose, it will start and stop extruding during the printing process, causing the process to fail.

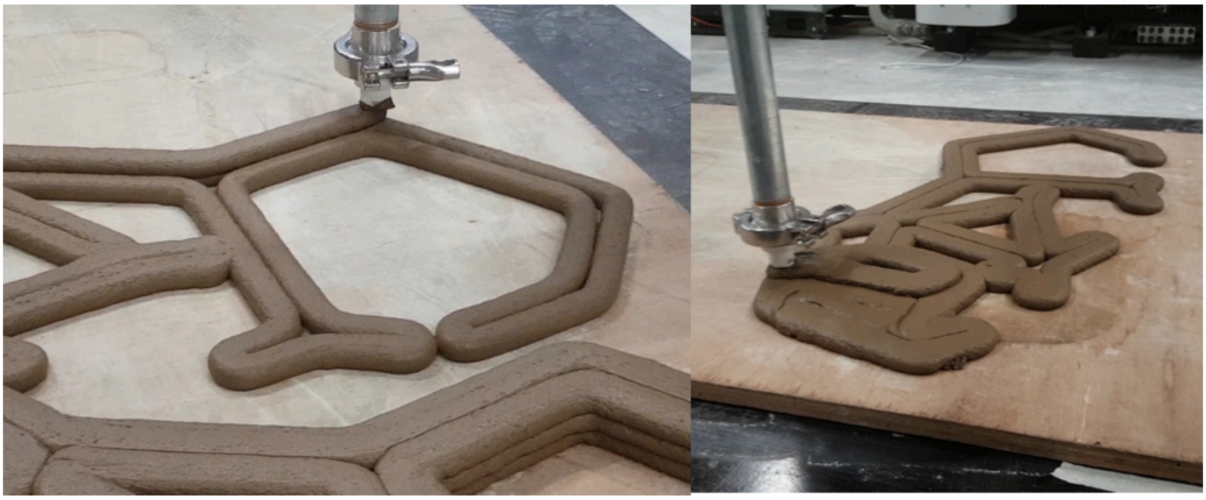
The minimal volume that is needed for this process is the volume of the hose, the volume inside of the pump and a small amount of material in the reservoir. This calculated minimal amount of material allowed implementation of the 3-layer test three times and the 18-layer test once.

When the material was mixed according to the initial recipe, the material was too dry to be pumped through the system (see image/video). Hence, more **water was added** (2987 g) until the material had the right viscosity for the pump.

1.3 Printability

The 100% CRC material proved to print **consistently** while creating **smooth** layers. The mixture in its wet state is quite stable, and has a relatively high viscosity. In order for the material to go through the concrete pump a drill was used to agitate and vibrate the material. This turned the regolith mixture into a lower viscosity mixture that could be pumped through the system.

The **3- and 18-layer tests** were successful, the material looked stable during and after the print.



2. Testing printability with CRC with 50% replacement

2.1 Tool paths

The same tool paths were used as for the 100% simulant replacement.

2.2 Mixing the materials

This mixture has 50% of the sand replaced with Regolith simulant.

Regolith	16741 g
Cement	22321 g
Chemicals	446 g
Water according to recipe / water used	8661 g / 9932 g
Material mixing and processing time before printing:	40 min
3D -Printing time:	10 min
Mix/vibrate new batch in loop:	10 min
3D -Printing time:	10 min
Total time:	70 min

The minimal volume that is needed for this process is the same as for the 100% test. Again **additional water** (1271 g) was needed to achieve the required viscosity.

2.3 Printability

The material prints **not as consistently** as the 100% CRC and creates **uneven** layers. The **3-layer test** was successful, while the **18-layer test** collapsed during printing after the 11th layer. The assumption is that the stability of the material during printing is related to the particle size and shape and since sand particles are smoother they create a less stable mixture than the sharper and smaller regolith particles.

Conclusions:

- The 100% material mix prints really well with clean printing lines
- The material seems to be more stable than Vertico's concrete mix, which has an additional chemical accelerant to improve the stability).