**HexHab - 3D Printed Mars Habitat Construction and Outfitting Sequence Timeline.**

Samuel Ximenes[1], Dallas Bienhoff[2], Serdar Baycan[3], Prashant Rao[1], Subramanian Sankaran[1], Suzana Bianco[4], Zachary Taylor[4], Allison Shaffer[5] [1]Exploration Architecture Corp. 110 E. Houston St, 7th Floor, 78205, sximenes@explorationarchitecture.com, [2]Cislunar Space Development Company, Annandale, VA [3]Tectura Architects, Melbourne, Australia [4]WEX Foundation, San Antonio, TX [5]Texas A&M University, College Station, TX

**Introduction:** Additive construction technology opens a new freedom of architype for form and structure in space architecture design to take advantage of new esthetic potentials 3D printing offers for producing atypical shapes. The hexagon is a common and prevalent geometry of nature. Our HexHab design takes its cue from nature and relies on the simplicity and versatility of this geometric shape, grounded in functionality, for autonomously constructing in-situ shelters for human habitation on distant worlds. The HexHab design concept provides a sturdy, extreme environment, in-situ constructed, protective platform that serves as a core shell enabling multiple secondary structure outfitting options for habitability, together with research and science functions.

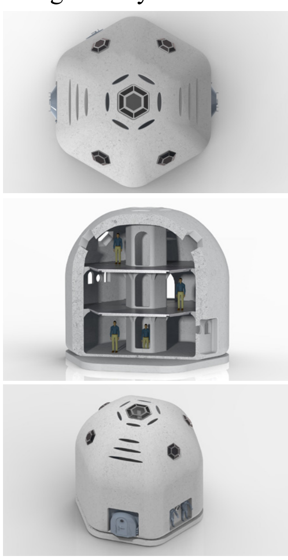


**Figure 1: HexHab**

**Insitu Material Processes:** HexHab's print material is produced from Mars' atmosphere, regolith and water. Carbon dioxide is extracted from the atmosphere and broken down into carbon and oxygen using solid oxide electrolysis and the Boudouard Reaction. Water, from icy regolith or underground reservoirs, is electrolyzed to produce oxygen and hydrogen. Carbon and hydrogen are combined to produce polyethylene while oxygen is liquefied and stored for later use. Mars regolith is excavated and dried and then sent through a hammer mill to create micron-sized particles. The talc-like regolith is mixed with polyethylene to create our printer feedstock with a regolith to polyethylene mixture ratio between 7:3 and 9:1. The regolith/polyethylene blend is sent to the printer head, heated and extruded to create the habitat primary structure. Compressed atmosphere is used to pneumatically move material from one process step to the next.

**Autonomous Robotic Elements:** Our build process is graphically laid out around a site plan that provides additional habitat protection by building the lower deck below grade level and backfilling after construction. Depicted in Figure 2 are robotic elements used for excavation, feedstock mixing, processing, and piping to the printer, and the 3D printer configuration.

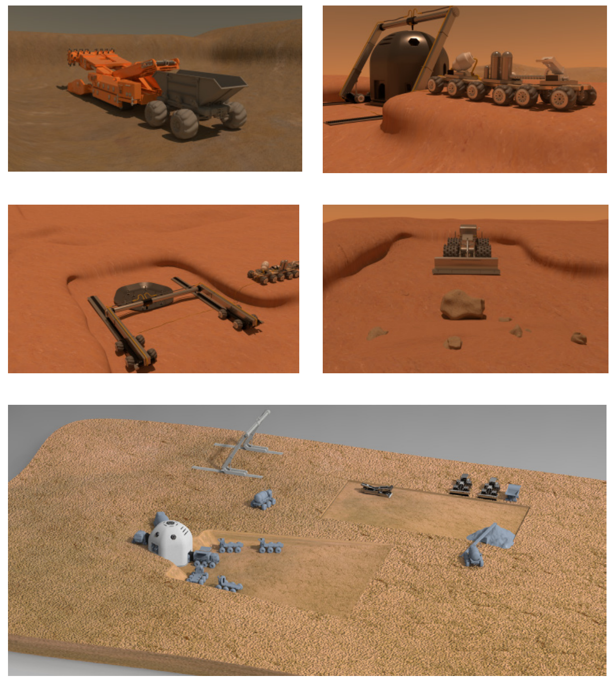


**Figure 2: HexHab Construction Elements**

**Construction Timeline:** The volume of regolith to be excavated for habitat printing is 20 meters square by 2.5 meters deep with an access ramp that fans out to 40 meters wide at the surface elevation over a 40 meter length for approximately 3000 cubic meters. With two scrapers removing 3 cubic meters per hour each, it will take 500 hours to excavate the habitat site. This is 20.3 sols at continuous operation or 30 sols operating 67.7% of the time, (a Kilowatt reactor for power is assumed).

Backfilling the excavated area after printing the habitat requires filling in a volume that is 375 cubic meters. At 2 cubic meter per hour, this will take 11.2 sols operating 67.7% of the time. Reduced rate relative to excavating is allowed for packing and tamping.

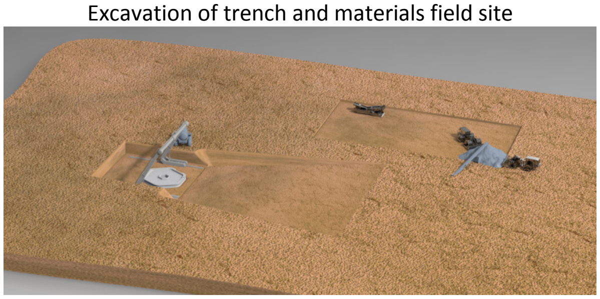
The HexHab design was developed in response to NASA's 3D Printed Habitat competition for the virtual construction level competition phase. Habitat printing time is based on the same printing rate required of the construction level competition contestants to print a 1/3 scale version of a habitat in 30 hours [1]. We assume a rate of 600 kg/hr. The mass flow rates equate to 203,218 cc/hr. The Hexhab wall cross section has a honeycomb design with two 10 cm solid inner and outer bands with a 70% hollow/30% solid middle band to decrease thermal conductivity. This reduces printed material volume from a solid wall of 164.42 m3 to a honeycomb wall of 87.7 m3. We estimate the print time to be 17.5 to 32.9 sols operating around the clock as actual wall material density increases from 53% to 100% as it reaches the top of the dome. At 50% printer up time, it will take 35 to 65.7 sols to print one habitat.

*Outfitting of Secondary Structures.* The HexHab concept provides a basic form factor as a core shell to accommodate a variety of options, such as outfitting options for secondary structures, multiple ingress/egress access points, and connection locations for rovers or addition of other modules. The habitat shell's extra wide openings allow large item entry prior to hatch installation and HexHab pressurization. Transport of large bulk outfitting items is robotic and crew assisted, upon arrival of the construction outfitting crew. All large bulk items listed have been designed and assessed for form fit through the Hexhab large openings prior to pressurization.

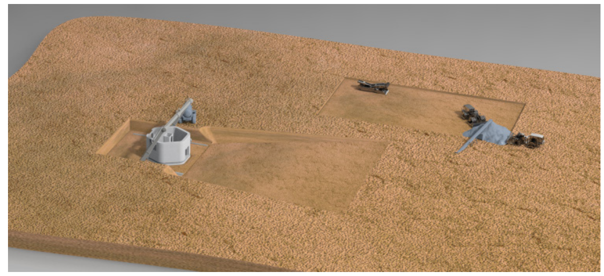
We allow 30 sols to move all interior large secondary structures and outfitting items into the pressure vessel. Windows, cupolas and suit ports are installed while internal items are moved inside through the large airlock openings. Airlock openings are installed last. We install and seal two airlocks, two suitports, one elevator, the floor system, four hexagonal cupolas, six ellipsoidal windows and the apex window. Another 30 sols is allowed to install interior secondary structure and outfitting items after pressurization using human and robotic capabilities.

Total estimated time from excavation start to outfitting complete is 20.3 sols + 17.5 sols + 11.2 sols +30 sols + 30 sols = 109 sols (112 days) minimum to 157.2 sols (161.2 days). Site excavation, printing and outfitting are shown in the following images.

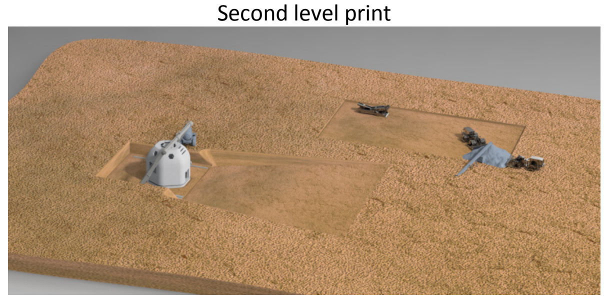
Excavation of trench and materials field site



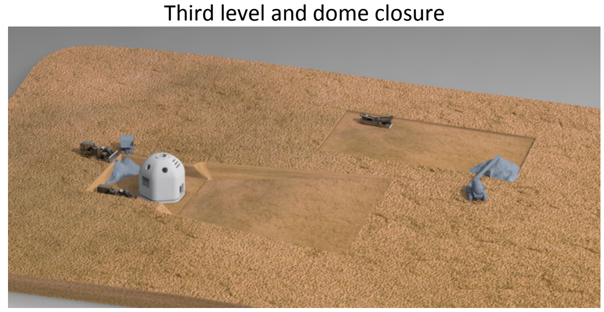
Printer arrives and first floor taking shape



Second level print

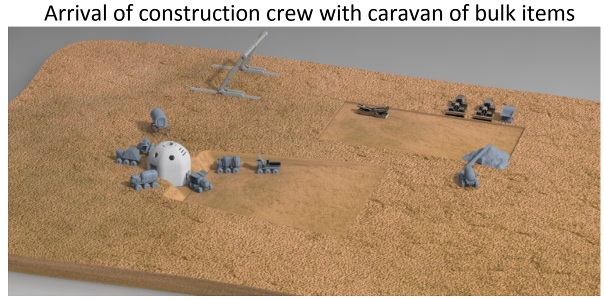


Third level and dome closure



Backfill of excavated site up to second level surface

Arrival of construction crew with caravan of bulk items



Bulk item insertion prior to pressurization

A video presentation of the animated 4D construction sequence timeline was created.

**References:** [1] NASA and Bradley University, "On-site Habitat Competition Rules", Version 1.0, Nov 6, 2017, NASA Centennial Challege 3D Printed Habitat Competition.