

PRINTING OUR FUTURE ON MARS

GREEN CONSTRUCTION FOR THE RED PLANET

By Steve Murray

NASA, the European Space Agency (ESA), and Roscosmos (Russia) are each working toward a permanent human presence on Mars or the Moon. Reaching that goal will require safe, durable dwellings on these worlds as well as cost effective methods for building them.

The lunar landers of the Apollo era only had to serve as habitats for a few days. Future homes for sustained living will be larger and more complex, and will require a much greater volume of raw material to construct. A long-term future in space will almost certainly rely on in-situ resource utilization—making maximum use of locally available raw materials—for sustainable structures. This is where space vision meets space budget; a recent NASA estimate showed that every kilogram that doesn't need to be shipped to Mars could save \$100,000.

Like earlier waves of terrestrial pioneers, astronauts will have to build homes from what's around them.

NASA is betting that 3D printing technology will help build space colonies. The agency is now at the mid-point of a multi-phase 3D Printed Habitat Competition to establish the engineering foundations for practical space habitats using indigenous materials. Along the way, they also hope to learn how to build better housing right here on Earth.

Ice House

LavaHive 2

LavaHive 1

Team Gamma

HARNESSING IMAGINATION

The 3D Printed Habitat Competition launched in 2015 as a part of NASA's Centennial Challenge Program. In the first phase, NASA asked competitors to design a habitat for a notional human colony on Mars using 3D printing methods and materials assumed to be available near the landing site.

Entrants came from a wide range of disciplines, according to "Moni" Roman,

Ice House – Astronaut working in the internal "yard" of the Mars Ice House. Credit: SEArch/Clouds AO

LavaHive 1 – Team LavaHive Habitat on the Martian surface. Credit: Team LavaHive

LavaHive 2 – Working around the Team LavaHive Habitat. Credit: Team LavaHive

Team Gamma – Entry, descent, and landing scheme for Team Gamma Habitat robot system. Credit: Team Gamma

NASA's Centennial Challenges program manager at Marshall Space Flight Center in Alabama. "A Centennial Challenge is a good way to bring in a population that's not always involved in space systems," she said. "Let them poke around to see how we can use [3D printing]."

3D printing or "additive manufacturing" systems build objects by conditioning a source material, usually by heating it, and extruding the material through special printer heads under computer control. Most objects require several applications of the material, which forms the final structure as it cools and solidifies.

The technology has a role in so many industrial processes that it's easy to take its presence for granted. Useful materials, or "inks," for printing applications have expanded from the early days of plastics to include metals, exotic mixtures, and even living cell tissue.

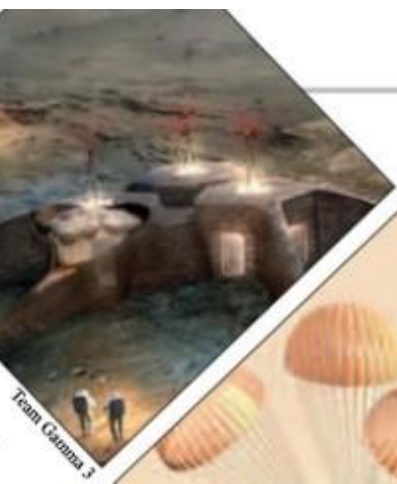
Similarly, the electromechanical systems that deposit these inks have grown from desktop boxes with small work volumes to gantry-supported arms and mobile robots. 3D printing systems are now used to create major structures like housing components, automobile frames, and aircraft interiors.

COMPETITION HEATS UP

The first phase of the competition was held from May to September 2015. "Phase 1 was about the dreaming," said Roman. "We wanted to unleash the public to tell us what a habitat might look like." NASA scored each team design for habitability, functionality, appropriate Mars site selection, and construction practicality using 3D printing.

More than 165 teams submitted entries. Almost all teams relied on landing construction robots in advance of astronaut arrival to prepare the base site and construct the core habitat. Most teams also relied on regolith—the loose sand and rock on the Martian surface—as their building material, which they deposited over a basic (usually inflatable) shell. Beyond that, creativity drove the designs in many different directions.

Cash prizes were awarded to the top three teams. First prize went to the Mars Ice House, designed by an architecture and



Team Gamma 3



Team Gamma 2



space research team of Space Exploration Architecture (SEArch) and Clouds Architecture Office (Clouds AO). The team went for the water deposits beneath the Martian surface as their building material, rather than the soil and rock that lay on top of it.

The team used the spacecraft lander that delivers the construction systems as their habitat foundation. An inflatable membrane is then deployed around it to provide a volume of livable space separated from the Martian atmosphere. Robotic systems then extract water or ice and apply it to the inner surface of the membrane to create a solid structure that protects the astronauts and admits natural light. The light supports the growth of vegetation that, in turn, could be used to produce oxygen.

NASA has estimated that up to five million cubic kilometers of ice could be distributed at or near the Martian surface, so the

proper site selection could provide plenty of raw material. Second prize went to Team Gamma, headed by architectural firm Foster + Partners, which had earlier worked on a lunar habitat design for the ESA. This design relied on inflatable structures covered with Martian regolith, and was distinguished by its sophisticated robotic construction suite: digger

robots to prepare the Martian surface and habitat foundation, transporter robots to collect and deposit the regolith, and melter robots to fuse the regolith into a solid surface with microwave heating. Robot designs allowed each robot type to perform essential functions of the other two for increased mission reliability.

Third prize went to Team LavaHive, which was affiliated with the ESA. This design also used a set of inflatable domes with connecting corridors as its foundation, but added parts recycled from the spacecraft lander as roofing for the main dome. The regolith covering was formed by "lava casting," or melting it into a hot lava and then molding it over the habitat using robots.

Results of the Phase 1 competition have already made an impact within NASA. An engineering team at NASA Langley Research Center in Virginia has contracted with the Mars Ice House team to expand on its building concepts and to test them for future Mars colonies.

"The Ice House project is different from the other designs," noted Roman. "It could be a game changer in many ways."

The LavaHive team is also now working with both the ESA and the German Aerospace Center to further develop their lava casting methods for space habitats, likely for a lunar base.

ON TO THE ENGINEERING

While the first phase of the competition focused on design concepts, the second phase literally gets down in the dirt. A new competition began in October 2016 and will run through August 2017. This phase requires teams to demonstrate that their 3D printing approaches can produce structurally sound building components.

"The skill sets for the winners of Phase 1 are not necessarily the skill sets for Phase 2," said Roman. In fact, the new pool of 17

Team Gamma 2—Entry, descent, and landing scheme for the Team Gamma Habitat modules. Credit: Team Gamma

Team Gamma 3—Artist's conception of an operational Team Gamma Habitat on the planet surface. Credit: Team Gamma

entries includes only four teams from the first phase.

Dr. Tracie Prater of the NASA Marshall Space Flight Center Materials and Processes Laboratory describes the new challenge as a test of 3D printing hardware. Competitors are free to employ modified fixed-volume printing systems with standard Cartesian coordinate control or mobile robots capable of freeform fabrication. They can also modify the extruder heads of their systems to accommodate special printing materials and can prepare materials with laser, inductive heating, or other technologies as needed. Finally, competitors are free to select their materials but scores are adjusted, depending on how closely they resemble real regolith.

Products developed by each team will be put through a series of industrial strength and other tests at the Caterpillar Edwards Demonstration and Learning Center near Peoria, Illinois. Teams must make minimum scores at each stage to move on to the next test.

Phase 3, scheduled for 2018, is a head-to-head “graduation exercise” that requires construction of a complete scaled habitat. NASA’s goal for Phase 2 is to ensure that the products used in that construction will actually work.

OTHER HABITAT RESEARCH

So far, habitat designs are largely based on Martian regolith as the building material. Although available Earth analogs such as basalt or volcanic ash can come close to regolith, the match and, therefore, actual material behavior might not be exact. Other research is also underway to examine these material properties and ensure that the durability of proposed Martian bases is sufficient for the environmental conditions they’ll be placed in.

Alternate materials under study by NASA and others include the blending of polymers with regolith, electrolytic treatments to extract iron and oxygen from regolith, and substituting sulfur from Martian basalt deposits for water when mixing regolith “cement.”

Although Monsi Roman is addressing regolith properties in the competition, she also has reasons for considering a broad range of approaches and materials at this stage. “You get more points, the more your materials are like space materials,” she said, which keeps the competition focused, but “We wanted to make this flexible enough to make it relevant to Earth and space.”

Taking the long view of the competition, she added that “NASA doesn’t just do work in space. If the technologies get pushed, it can potentially mean that housing becomes a lot more affordable and we can even build houses in places that we didn’t think about before.”

PRINTING LIFE IN SPACE

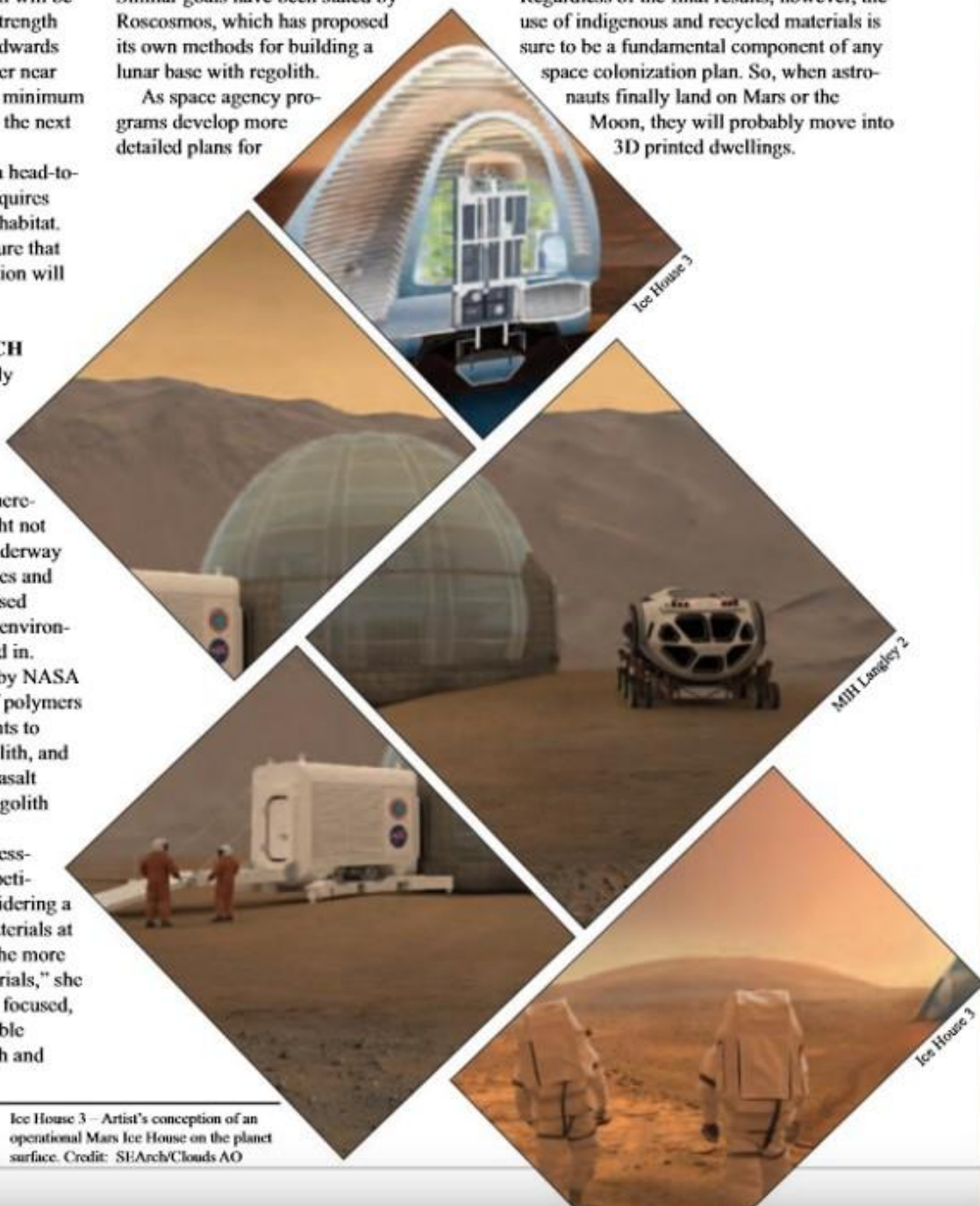
3D printed habitats have already caught the interest of other international space agencies. The ESA has been involved in 3D printing concepts for a lunar base since 2012 through the work of a funded consortium. Its current director, Johann-Dietrich Wörner, has also been a consistent advocate for a “lunar village” using indigenous materials. Similar goals have been stated by Roscosmos, which has proposed its own methods for building a lunar base with regolith.

As space agency programs develop more detailed plans for

a sustained presence on Mars, the logistical and support costs of these plans will come into better focus.

Alternative approaches will require different numbers of launches to deliver their robot construction systems, for example, and some design approaches will require more time than others to complete base construction. Such differences will necessarily impact mission timelines and completion costs. The final strategy for an off-world presence will depend on factors beyond habitat comfort and space.

What form will the final approach take? Will there be only one practical design? NASA will know more when the 3D Printed Habitat competition concludes in 2018. Regardless of the final results, however, the use of indigenous and recycled materials is sure to be a fundamental component of any space colonization plan. So, when astronauts finally land on Mars or the Moon, they will probably move into 3D printed dwellings.



MIH Langley 2—Artist’s conception of the modified Mars Ice Home concept on the planet surface. Credit: NASA

Ice House 3—Artist’s conception of an operational Mars Ice House on the planet surface. Credit: SEArch/Clouds AO