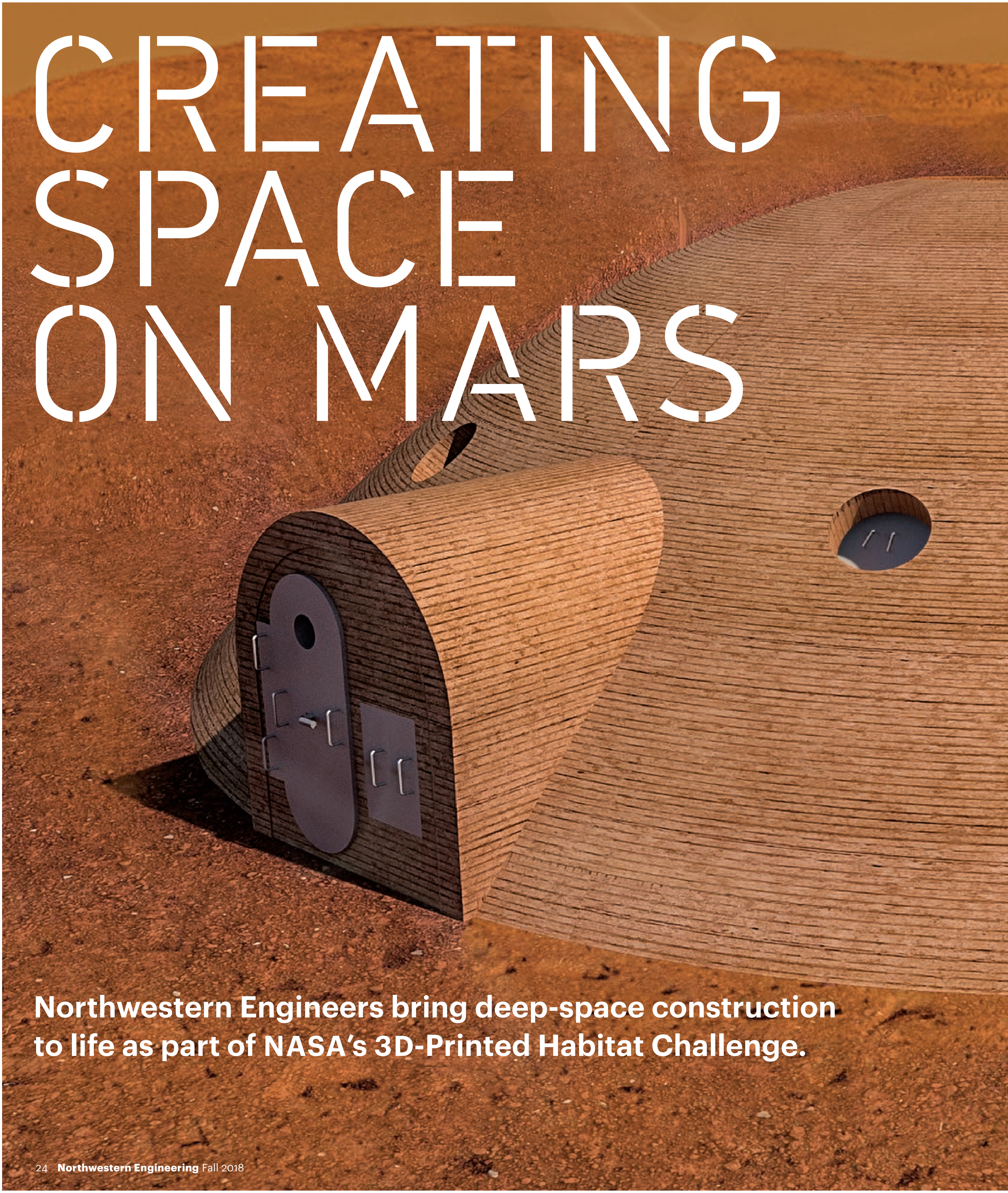
CREATING SPACE ON MARS



Northwestern Engineers bring deep-space construction to life as part of NASA's 3D-Printed Habitat Challenge.

The first humans to visit Mars are likely alive today, and NASA is planning to send one or more of them to the planet by 2040.

While exciting, the plan faces enormous logistical challenges. NASA scientists know that travel between Earth and the Red Planet takes nearly 10 months, and that room on board any spacecraft will be at a premium. What's not known, however, is how the need for basic necessities will be met: What materials are available to create homes and other structures? What tools could be used? How will man-made structures weather the Martian climate?

Though Mars is the planet most similar to Earth, crafting Martian living will require creative and efficient solutions. NASA put out a call for help, inviting thought leaders in industry and academia to the 3D-Printed Habitat Challenge to develop insights and create new technologies to manufacture a home on Mars using materials native to the planet. An interdisciplinary team led by Northwestern Engineers has answered with an award-winning design created with "Marscrete."

top to bottom
LAB, KITCHEN, CENTRAL SPACE

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MATTHEW TROEMNER PhD student

RESEARCH MOVES FROM EARTH TO MARS

In 2014, just about the time NASA launched its challenge, Gianluca Cusatis, Northwestern Engineering associate professor of civil and environmental engineering, was exploring the potential of 3D printing—also known as additive manufacturing—for housing applications here on Earth.

He focused on construction, an industry that has battled stagnant productivity gains for two decades. While 3D-printing technology dates back to the 1980s, its use in construction was limited to creating small mechanical objects. Cusatis points out, however, “You don’t build small objects in civil engineering.

“We spent time learning what people were doing in the field of large-scale 3D printing,” he adds, having led Northwestern’s first workshop on the potential of large-scale 3D printing in 2017. The event brought together designers, architects, and engineers to explore how to print large structures—such as barracks in war zones or temporary housing in disaster areas—quickly and inexpensively with stronger, more durable, and more environmentally friendly materials.

While testing these practical solutions for Earth-bound buildings in difficult places, the team learned of a chance to apply their research to a much more challenging location—Mars. “While we were exploring these opportunities, we learned of the NASA challenge, and thought it was a chance to build enthusiasm for large-scale 3D-printing research on campus,” Cusatis says.

Cusatis turned to Matthew Troemner, an incoming PhD student in his Quasi-Brittle Materials Research Group, to lead the project, and the buzz began. Troemner connected with peers who were studying civil engineering and mechanical engineering and were eager to assist. After realizing the need to broaden its expertise, the team spread the word throughout the University, expanding its ranks to more than two dozen students and faculty with backgrounds in materials science, chemical engineering, journalism, earth and planetary sciences, and political science to work on the NASA challenge.

“You don’t often see such enthusiasm for civil engineering. We’ve always lived in houses and driven over bridges,” Cusatis says. “We don’t view civil engineering innovation as disruptive as cell phone technology. But this project got everyone excited.”

“MARTIAN 3DESIGN” TAKES SHAPE

The Northwestern team entered the 3D-Printed Habitat Challenge in January 2018 during the On-Site Habitat Competition, which tasked participants to create virtual renderings of a 1,000-square-foot house that could be built on Mars with a 3D printer and equipped to house four astronauts for up to one year.

Called Martian 3Design, the team’s habitat combines sound structural engineering principles, building techniques that leverage Martian materials, and an intuitive floor plan that maximizes private and common spaces and resource efficiency. Features of the team’s design include:

- A 3D-printable inner spherical shell and outer parabolic dome that protect the house against the harsh Martian climate
- An interior layout that separates wet rooms (lab, kitchen, bathroom) from dry rooms (bedrooms, workstations) to limit the resources needed for construction
- Two hatch openings, located directly across from each other, which allow habitat units to easily connect to each other and foster community

“Our design initially started with one main entrance, but after we were given requirements from NASA to include a rover hatch, we decided to make the whole habitat symmetrical,” Troemner explains. “If we wanted to expand later on, not only would we have the rover hatch, which is required, but it could also accommodate a natural personnel hatch.”

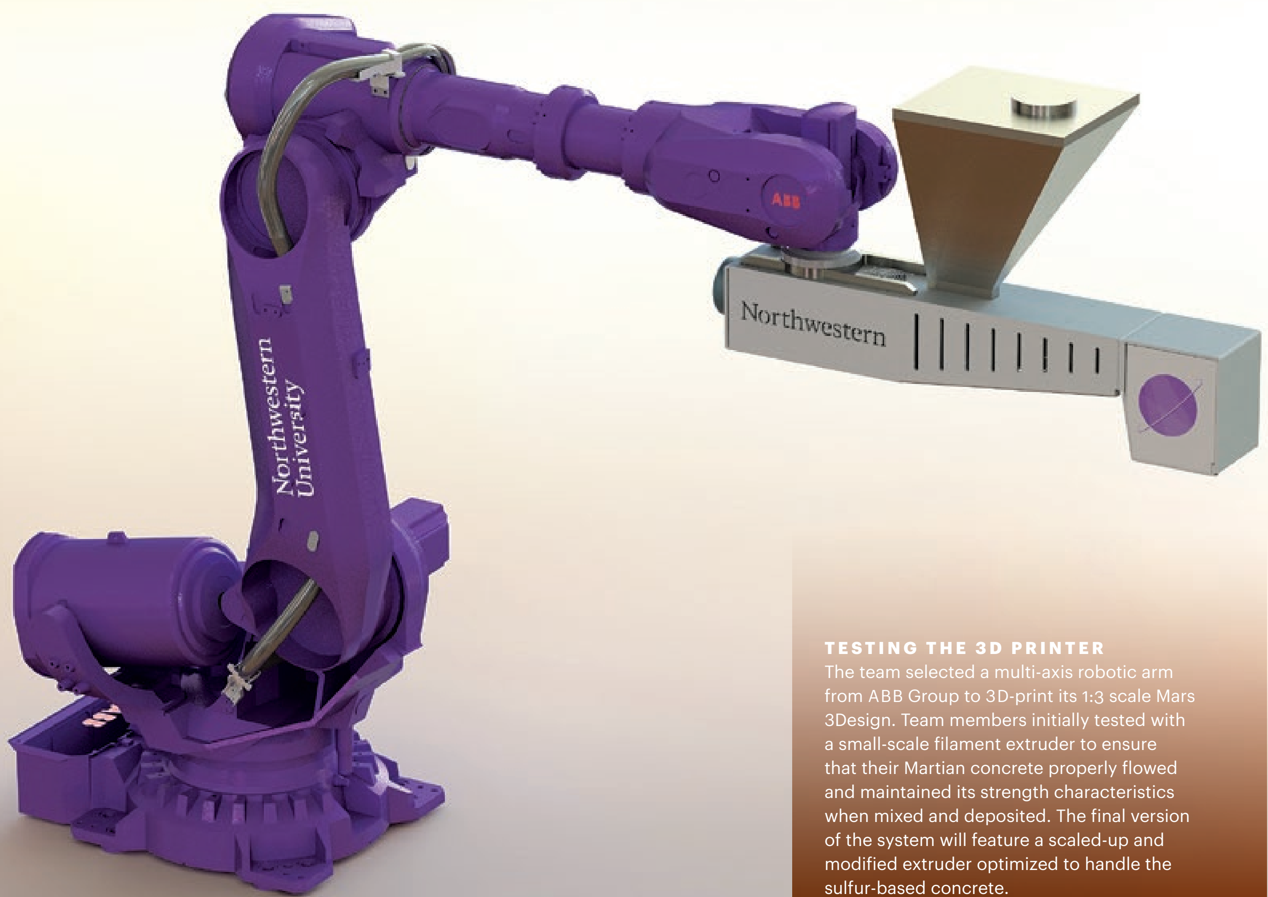
“The thought of building on Mars captures imaginations in a new way. It makes people listen. It’s also an opportunity for us, as civil engineers, to showcase what we can do for our communities here at home.”

GIANLUCA CUSATIS
Associate Professor of Civil and Environmental Engineering

Image courtesy of Michael Goss

MARTIAN 3DESIGN’S OUTER SHELL

In designing the habitat’s outer shell shape, the team met with Donna Jurdy and Seth Stein, professors in Northwestern’s Department of Earth and Planetary Sciences, to brainstorm how 3D printing under Martian conditions would differ from Earth-based construction. The team’s igloo-style design takes into account the planet’s unique wind and gravity loads, as well as the potential for shifting sand dunes and meteorite impacts. “The outer shell acts as a kind of protective structure that is best suited for those loads,” says Matthew Troemmer, PhD student.



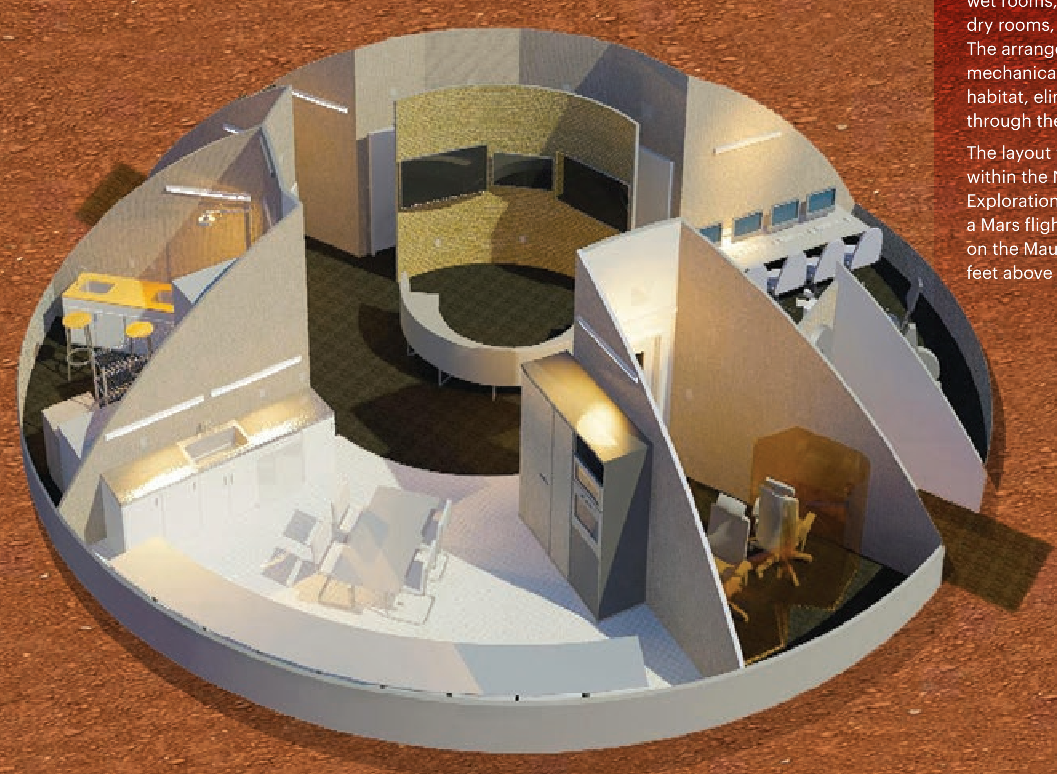
TESTING THE 3D PRINTER

The team selected a multi-axis robotic arm from ABB Group to 3D-print its 1:3 scale Mars 3Design. Team members initially tested with a small-scale filament extruder to ensure that their Martian concrete properly flowed and maintained its strength characteristics when mixed and deposited. The final version of the system will feature a scaled-up and modified extruder optimized to handle the sulfur-based concrete.

INSIDE THE HABITAT

The team's interior design for the 1,000-square-foot Martian habitat separates the space's wet rooms, including the kitchen and lab, from dry rooms, like bedrooms and workstations. The arrangement consolidates plumbing and mechanical units to only one side of the habitat, eliminating excess materials running through the floors and walls.

The layout was inspired by the living quarters within the NASA-funded HI-SEAS (Hawaii Space Exploration Analog and Simulation) project, a Mars flight crew training simulator that sits on the Mauna Loa volcano approximately 8,200 feet above sea level on the Island of Hawaii.



MIXING THE RIGHT "MARSCRETE"
The team's Martian concrete recipe was inspired by previous research from Professor Gianluca Cusatis and Lin Wan-Wendner (PhD '15), a former student in Cusatis's lab. Cusatis and Wan-Wendner created Martian concrete by combining molten sulfur and NASA's JSC Mars-1A simulant, found on the cinder cone of a Hawaiian volcano. With JSC Mars-1A no longer available for testing, the team is using NASA's MMS-1 Mojave Mars Simulant, which possesses even greater mechanical and chemical similarities to dirt on the planet's surface.

The team also connected with Benton Johnson, associate at Skidmore, Owings & Merrill (SOM), one of the world's leading architectural design firms and a partner in Northwestern Engineering's MS in Structural Engineering program. Johnson guided the team through its design ideas, helping evaluate the loading conditions needed for a potential habitat to maintain structural integrity.

"SOM's structural expertise informed a habitat design that let us 3D-print over an inflatable pressure vessel, a structure that would be strong enough to support its weight if there was a loss of pressure in the habitat," Troemner says. "SOM also helped guide the overall shape and layout of our design."

The ingenuity paid off. In July, NASA announced that the Northwestern team earned fifth place and a share of the $100,000 prize in the Level 1 Virtual Design Challenge. Martian 3Design, one of only 18 submissions from around the world chosen to be judged by NASA experts, placed higher than any other university.

"We were ecstatic to learn of our placement," Troemner says. "The recognition was validation of our hard work up to that point and showed what Northwestern students are capable of doing."

NOW, TO BUILD IT

Any design relies on physical tools to bring its potential to life. That's why the team is focused on leveraging existing 3D-printing technology and Mars-local materials to make its habitat a reality. "We experimented to determine what combination of materials we could 3D-print consistently that also met the strength requirements defined by NASA," Troemner says.

The team developed a building concrete composed entirely of materials found on Mars or recycled components of the spacecraft. Dubbed "Marscrete," the concrete combines sulfur—an element abundant beneath and within Martian soil—and NASA's MMS-1 Mojave Mars Simulant, a sand-like deposit obtained from the Mojave Desert that holds similar mechanical and chemical properties to the dirt surface of Mars.

Guided by research on injection molding machines, the group designed a robotic arm-based 3D printer to construct its habitat. The six-axis system is not only more cost-efficient compared to other 3D printers, but it can be prototyped with a modified filament extruder to deposit the sulfur-based Martian concrete.

To operate the printer, the dry materials are loaded into the 3D printer's extruder, where they are compressed and heated. The melted sulfur combines with the Mars simulant and is released as a paste, ready to be arranged into form by the robotic arm.

"The concrete hardens as strong as traditional casted concrete, but maintains properties that work well for 3D printing," Troemner says. "Most 3D-printed concretes have to be pre-mixed or pumped beforehand. This material is unique in that it can be loaded directly into the hopper."

MEANWHILE, BACK ON EARTH

If selected, the Martian 3Design team will travel to the Caterpillar Peoria Proving Ground in Peoria, Illinois, in April for the Habitat Challenge's culminating 3D-Printed Construction Competition. There, the team will use its 3D printer and Martian concrete to build a 1:3 scale model of the habitat envisioned in the Virtual Design Competition.

With NASA expected to announce the final competition's top three finishers, who will share an $800,000 prize, in spring 2019, the team's mission is nearly complete. But in many ways, according to Cusatis, the end is just the beginning. "Our hope has always been to build something that will live beyond the competition and afford us a chance to conduct more meaningful research in this new field," he says.

While large-scale 3D printing is undoubtedly part of NASA's plans to build its first human settlements on Mars, Cusatis believes these same technologies could jumpstart interest and innovation in a field that has long fought against it. "The thought of building on Mars captures imaginations in a new way. It makes people listen," he adds. "It's also an opportunity for us, as civil engineers, to showcase what we can do for our communities here at home."

ALEX GERAGE