3D-printing robot enables sustainable construction

May 18 2022, by David Nutt

Credit: Cornell University

The Bovay Civil Infrastructure Laboratory Complex, located in the basement of Thurston Hall, has a new tenant: a roughly 6,000-pound industrial robot capable of 3D printing the kind of large-scale structures that could potentially transform the construction industry, making it more efficient and sustainable by eliminating the waste of traditional material manufacturing.

The process of 3D printing—also known as additive manufacturing—has already led to breakthroughs in product prototyping and biomedicine. When it comes to large construction projects, however, many questions remain about how 3D-printed structures will perform in the real world.

With its ability to test and validate fabricated materials and structures of all types and sizes, the Bovay Lab is particularly well-suited to put large-scale 3D printing through the motions—and the stresses and the strains.

Cornell is now one of only a handful of universities in the U.S. to have such a system. Not only will it enable College of Engineering faculty to do robotic construction research, it will also give students hands-on experience in the fast-growing technological area within civil infrastructure, according to Derek Warner, professor of civil and environmental engineering.

"Robotic masonry (brick laying), printing with recycled plastics and printing with metal at a large scale are all exciting areas with lots of room for growth, both in terms of science and understanding, as well as technology and engineering," Warner said. "The scaling of many of the phenomena controlling the build processes are such that they need to be studied at a scale near to that in which they will be used. The same applies to some of the phenomena controlling performance. Plus, there are always the unknown surprises that occur when up-scaling early-on with a new technology."

The IRB 6650S Industrial Robot system arrived in February, and for the last several months the lab has been training to use the robotic system—which is essentially a long, swiveling arm—and run a number of medium-size test prints, including benches and planters, even a large letter C in the Cornell typeface.

"The robotic system is versatile and flexible," said Sriramya Nair, assistant professor of civil and environmental engineering. "One of the ways we are using it is for 3D-printing of concrete, but it can be used in other ways, too. You can attach a welder or laser system. You can stack bricks or tie rebar. Many tedious processes can be automated."

The robot is set on a 12-foot-long track, with a circular reach of about 12 feet, for a total coverage area of up to 8 feet by 30 feet, although the lab doesn't anticipate printing anything quite that large, according to James Strait, manager of tech services for the Bovay Lab.

Operating the system is a team effort. One group of people mixes a pre-batched mortar and stirs in additives, such as a superplasticizer that reduces the water content of the mix and improves its flow through the hose. Another group operates the robot's controller to regulate how much admixture runs through the system. When the admixture reaches the robot's extruder head and nozzle, a hardening additive is introduced so the material thickens as it is poured.

Getting the consistency right can be a challenge. Call it the Goldilocks dilemma.

"The bottom layers need to be rigid enough to hold the next layer that's being printed. But they can't be so rigid that when you print the next layer on top, it doesn't stick to it," Strait said. "You need to make the adhesion in there, but you can't have it so soft that it squishes out."

The process is labor intensive, but when done successfully, 3D printing eliminates the need for casting molds and also allows for the creation of unconventional shapes—optimizations that waste less material.

"Any time you pour cast-concrete, like for a sidewalk, you have to set up all the molds. It takes labor, materials, you have to stake it all down. All of that stuff takes a lot of time," Strait said. "Every change you make to a concrete structure, you have to modify the mold or get a new mold and spend labor doing that. That is a lot more difficult than going to a computer program and saying, "You want this rounded?" Click. A couple of hours and you're done."

Nair plans to incorporate the system into a new class she is teaching in the fall, Sustainability and Automation: The Future of Construction Industry, which will help prepare students for the coming changes in their field.

"We are giving them an opportunity to learn something that's cutting edge and happening right now," Nair said. "The more they know, the more they can be champions of change, but also know what the limitations could be."

For now, the system is 3D printing with mortar, which is technically a paste with aggregate up to 4 millimeters in size. Anything larger than that could jam and damage the pump system. However, Nair's team intends to build their own extruder head to print steel-fiber-reinforced concrete, which uses larger aggregate, that can withstand heavier loads. That will pave the way for the lab to 3D print full bridge components and test them.

Nair also hopes her group can create its own mixture to print with, rather than relying on the manufacturer's premixed material.

"The carbon footprint of these materials is very high right now," she said. "So that's another goal, to reduce the carbon footprint associated with 3D-printed materials."

Provided by Cornell University