

Tulle-like DefeXtiles can be 3-D printed with no custom software or hardware

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In this deformation-sensing lamp, the solid supports, textile lampshade, and sensing conductive pads are created as a single print. Credit: Jack Forman

Sometimes, 3-D printers mess up. They extrude too much material, or too little, or deposit material in the wrong spot. But what if this bug could be turned into a (fashionable) feature?

Introducing [DefeXtiles](#), a tulle-like textile that MIT Media Lab graduate student Jack Forman developed by controlling a common 3-D printing defect—the under-extrusion of polymer filament.

Forman used a standard, inexpensive 3-D printer to produce sheets and complex 3-D geometries with a woven-like structure based on the "glob-stretch" pattern produced by under-extrusion. Forman has printed these flexible and thin sheets into an interactive lampshade, full-sized skirts, a roll of fabric long enough to stretch across a baseball diamond, and intricately patterned lace, among other items.

Forman, who works in the Tangible Media research group with Professor Hiroshi Ishii, presented and demonstrated the DefeXtiles research on Oct. 20 at the Association for Computing Machinery Symposium on User Interface Software and Technology. The material may prove immediately useful for prototyping and customizing in fashion design, Forman says, but future applications also could include 3-D-printed surgical mesh with tunable mechanical properties, among other items.

"In general, what excites me most about this work is how immediately useful it can be to many makers," Forman says. "Unlike previous work, the fact that no custom software or hardware is needed—just a relatively cheap \$250 printer, the most common type of printer used—really makes this technique accessible to millions of people."

"We envision that the materials of the future will be dynamic and computational," says Ishii. "We call it 'Radical Atoms.' DefeXtiles is an excellent example of Radical Atoms, a programmable matter that

emulates the properties of existing materials and goes beyond. We can touch, feel, wear, and print them."

Joining Forman and Ishii on the project are Computer Science and Artificial Intelligence Laboratory and Department of Electrical Engineering and Computer Science graduate student Mustafa Doga Dogan, and Hamilton Forsythe, an MIT Department of Architecture undergraduate researcher.

Filaments to fabric

Forman had been experimenting with 3-D printing during the media arts and sciences class MAS.863 / 4.140 / 6.943 (How to Make (Almost) Anything), led by Professor Neil Gershenfeld, director of the MIT Center for Bits and Atoms. Forman's experiments were inspired by the work of a friend from his undergraduate days at Carnegie Mellon University, who used under-extruded filament to produce vases. With his first attempts at under-extruding, "I was annoyed because the defects produced were perfect and periodic," he says, "but then when I started playing with it, bending it and even stretching it, I was like, 'whoa, wait, this is a textile. It looks like it, feels like it, bends like it, and it prints really quickly.'"

"I brought a small sample to my class for show and tell, not really thinking much of it, and Professor Gershenfeld saw it and he was excited about it," Forman adds.

When a 3-D printer under-extrudes material, it produces periodic gaps in the deposited material. Using an inexpensive fused deposition modeling 3-D printer, Forman developed an under-extruding process called "glob-stretch," where globs of thermoplastic polymer are connected by fine strands. The process produces a flexible, stretchy textile with an apparent warp and weft like a woven fabric. Forman says it feels

something like a mesh jersey fabric.

"Not only are these textiles thinner and faster to print than other approaches, but the complexity of demonstrated forms is also improved. With this approach we can print 3-D dimensional shell forms with a normal 3-D printer and no special slicer software," says Forman. "This is exciting because there's a lot of opportunities with 3-D printing fabric, but it's really hard for it to be easily disseminated, since a lot of it uses expensive machinery and special software or special commands that are generally specific to a printer."

The new textile can be sewn, de-pleated, and heat-bonded like an iron-on patch. Forman and his colleagues have printed the textiles using many common 3-D printing materials, including a conductive filament that they used to produce a lamp that can be lit and dimmed by touching pleats in the lampshade. The researchers suggest that other base materials or additives could produce textiles with magnetic or optical properties, or textiles that are more biodegradable by using algae, coffee grounds, or wood.

According to Scott Hudson, a professor at Carnegie Mellon University's Human-Computer Interaction Institute, Forman's work represents a very interesting addition to the expanding set of 3-D-printing techniques.

"This work is particularly important because it functions within the same print process as more conventional techniques," notes Hudson, who was not part of the study. "This will allow us to integrate custom 3-D-printed textile components—components that can be flexible and soft—into objects, along with more conventional hard parts."

Lab @home

When MIT closed down at the start of the COVID-19 pandemic,

Forman was in the midst of preparing for the ACM symposium submission. He relocated his full lab set up to the basement of his parents' cabin near Lake Placid, New York.

"It's not a lot of large equipment, but it's lots of little tools, pliers, filaments," he explains. "I had to set up two 3-D printers, a soldering station, a photo backdrop—just because the work is so multidisciplinary."

At the cabin, "I was able to hone in and focus on the research while the world around me was on fire, and it was actually a really good distraction," Forman says. "It was also interesting to be working on a project that was so tech-focused, and then look out the window and see nature and trees—the tension between the two was quite inspiring."

It was an experience for his parents as well, who got to see him "at my most intense and focused, and the hardest I've worked," he recalls. "I'd be going upstairs at 5 a.m. for a snack when my dad was coming down for breakfast."

"My parents became part of the act of creation, where I'd print something and go, 'look at this,'" he says. "I don't know if I'll ever have the opportunity again to have my parents so closely touch what I do every day."

One of the more unusual aspects of the project has been what to call the material. Forman and his colleagues use the term "quasi-textile" because DefeXtiles doesn't have all the same physical qualities of a usual textile, such as a bias in both directions and degree of softness. But some skeptics have been converted when they feel the material, Forman says.

The experience reminds him of the famous René Magritte painting "The Treachery of Objects (This Is Not a Pipe)," where the illustration of a

pipe prompts a discussion about whether a representation can fully encompass all of an object's meanings. "I'm interested in the coupling between digital bits and the materials experience by computationally fabricating high-fidelity materials with controllable forms and mechanical properties," Forman explains.

"It makes me think about when the reference of the thing becomes accepted as the thing," he adds. "It's not the decision people make, but the reasoning behind it that interests me, and finding what causes them to accept it or reject it as a textile material."

More information: DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion: [dam-prod.media.mit.edu/x/2020/ ... DefeXtiles_Final.pdf](https://dam-prod.media.mit.edu/x/2020/...DefeXtiles_Final.pdf)

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