Fabrication technology in the fourth dimension

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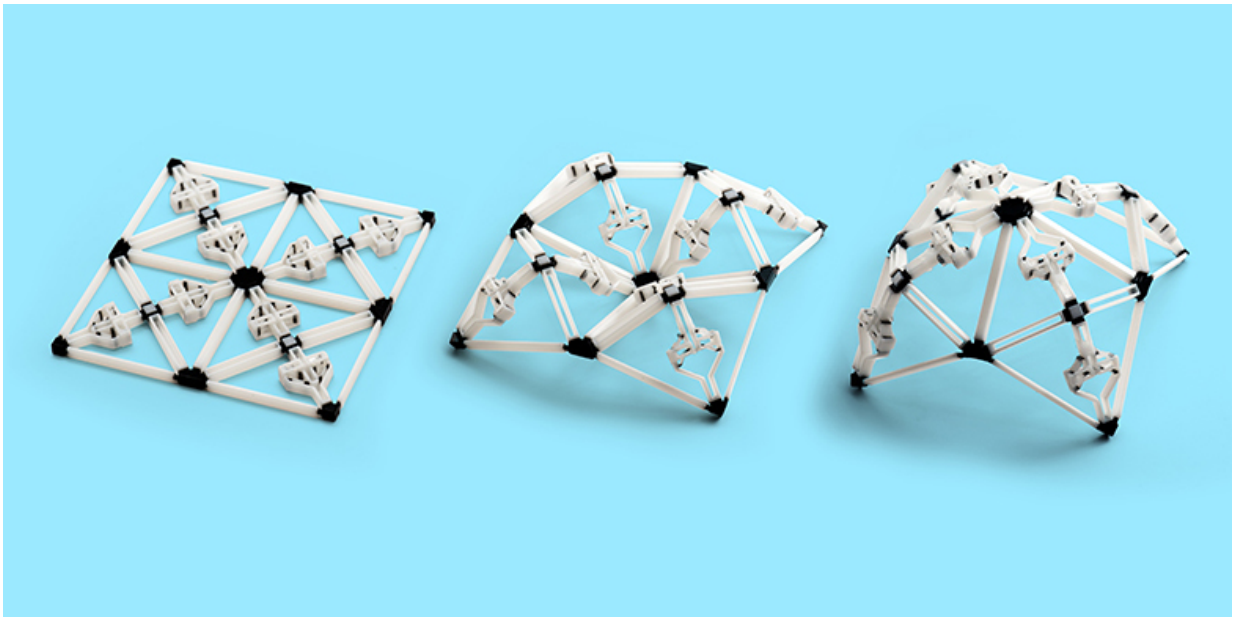


This object is printed flat (left) and can later be altered in two stable and load-bearing forms (middle and right). Credit: ETH Zurich / Tian Chen

Scientists use the term 4-D printing to refer to the simple production of objects that can transform their shape at different times. Researchers at ETH Zurich have now taken this approach one major step further by developing a construction principle that can produce load-bearing and predictable structures.

3-D printers have become a standard fixture in many research laboratories – and now a select number of researchers are already looking to add yet another dimension to the technology: time. Kristina Shea, head of the Engineering Design and Computing Lab at ETH Zurich, is one of these scientists. 4-D printing creates moveable and shape variable objects such as flat components that can be folded into three-dimensional objects at a later point, or even objects that can change their shape as a function of external influences.

Professor Shea and her group have now taken this approach one step further by developing a construction principle that allows them to control the deformation. "The flat structures we produce do not change their configuration randomly, but rather exactly in the way we design them," says Tian Chen, a doctoral student in Shea's group. The structures can also support weight. The ETH scientists are the first to create these kinds of load-bearing 4-D printed objects.

Element with two states

The structural principle depends on an actuating element developed by the scientists to take on two possible states: retracted or extended. The researchers combined these elements to create more complex structures. As the individual elements can assume only one of the two specific states, the researchers can predict the stable three-dimensional form of the overall structure. This also allows structures that can take on several stable forms. And as the researchers have also developed simulation software, they can predict accurately the shapes and the force that must be applied to produce the deformation. This helps them in the design of objects.

The scientists printed their structures with a professional multi-material 3-D printer, which can print objects from up to 40 different materials. The objects created by the ETH scientists comprise two of them: a rigid

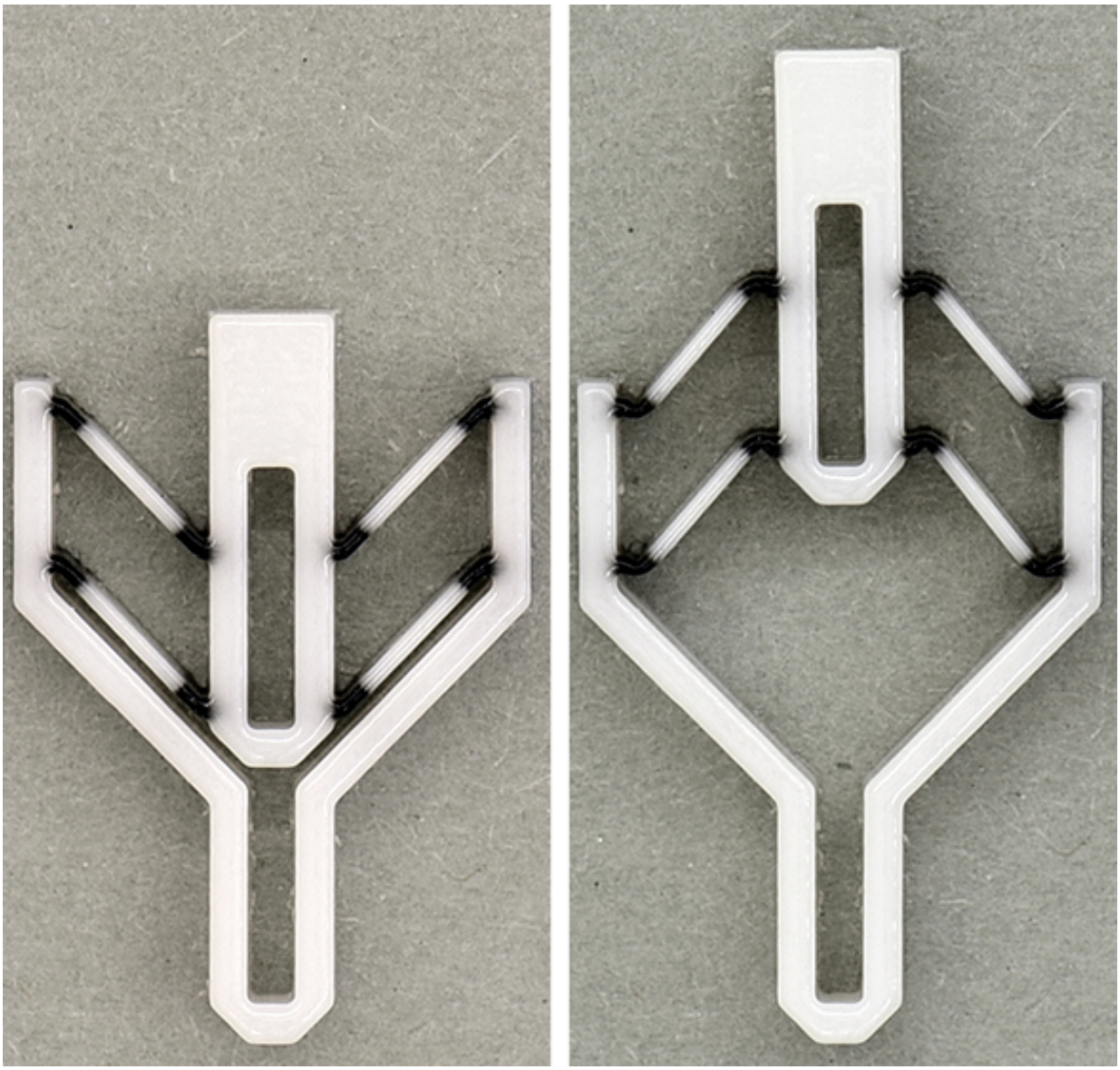
polymer that makes up most of the structure and an elastic polymer for the moving parts. The researchers print all parts in a single step.

Efficient and fast

"4-D printing has several advantages," says Shea. "Printing a flat initial form with rigid and elastic sections in a single step is highly efficient. It would be much more complex and time-consuming to produce the three-dimensional object or assemble it from separate components." Plus, the flat structure saves space in transport and can then be deployed at the final destination. Similar approaches have been used in aerospace for quite some time now; for example, to transport structures into space in a compressed space-saving state.

Aerospace is thus one possible application for 4-D printing. But the scientists are also considering the simple construction of ventilation systems, systems for opening and closing valves or medical applications, such as stents.

Currently, the scientists are reconfiguring these structures by hand, but they are working on a drive for their elements that will extend the structures in reaction to temperature. They also say it might be possible to control the structures using pneumatic tubing (compressed air) or swelling materials that change shape depending on humidity.



A single actuating element in its stable (left) and load-bearing (right) state. It consists of a rigid (light) and elastic (dark) polymer. Credit: Chen et al. Scientific Reports 2017

More information: Tian Chen et al. Integrated Design and Simulation of Tunable, Multi-State Structures Fabricated Monolithically with Multi-

Material 3D Printing, *Scientific Reports* (2017). DOI: 10.1038/srep45671