[4D printing makes objects that assemble themselves when heated]

Zhen Ding at the Singapore University of Technology and Design and his colleagues have now developed a way to rapidly print rigid 4D objects with a commercial 3D printer and a heat source. They created a variety of objects, including a delicate flower that closes its petals, a flat star shape that morphs into a dome, and lattices that contract and elongate. The structures were made from flat 3D-printed strips that were then heated to make them curve

3D printing or additive manufacturing is ongoing revolution in manufacturing with its potential to fabricate any complex object and is being utilized from printing small components to full drones on Naval vessels, printing replacement parts for fighter aircrafts to printing ammunitions, textiles, metals, human organs, clothing, buildings and even food. Now 3D printing is evolving into 4D printing, which is the ability to 3D-print objects that can change their properties, shape or appearance over time [the fourth dimension], or in response to some condition.

The potential applications for 4-D printed objects reaches across scientific disciplines and uses. Window shades that can change to allow more or less light in during the day. Furniture that is packaged flat, but self assembles in your home after purchase; Shoes/clothes/gear that adapt to the user’s performance and the changing environment, thus offering enhanced performance, fit, or style.

Researchers like Lipson think 4-D printing could have a big impact on robotics: Printers could print robots that build printers that build robots. “Material objects could be recycled not by saving some of the materials such as plastic to be melted down and reused, but by commanding the object to decompose into programmable particles or components that then can be reused to form new objects and perform new functions. The long-term potential of PM/4DP thus could be a more environmentally sustainable world in which fewer resources are necessary to provide products and services to a growing world population and rapidly expanding global middle class."

" Now a new disruptive technology is on the horizon that may take 3D printing to an entirely new level of capability with profound implications for society, the economy, and the global operating environment of government, business, and the public," note Thomas A. Campbell.

4D printing

Skylar Tibbits, founder of MIT's Self-Assembly Lab, coined the term "4D printing" in a 2013 TED Talk and showed how a straight plastic strand folded into the letters M, I, T when dropped in water.

4D printing, where the fourth dimension entails a change in form or function after 3D printing, is one recent example of PM that allows objects to be 3D printed and then self-transform in shape and material property when exposed to a predetermined stimulus, such as being submerged in water or exposed to heat, pressure, current, ultraviolet light, or other energy source.

"Rather than construct a static material or one that simply changes its shape, we're proposing the development of adaptive, biomimetic composites that re-program their shape, properties or functionality on demand, based upon external stimuli," said Anna C. Balazs, a chemical engineering professor at University of Pittsburgh. The U.S. Army Research Office has awarded $855,000 to three universities to make advances in 4D printing.

Professor Marc in het Panhuis’s team at the ARC Centre of Excellence for Electromaterials Science, located at the University of Wollongong, have built an autonomous valve that opens in warm water and closes in cold water. The valve is made out of four types of hard or soft hydrogels – networks of polymers – fabricated at the same time using a 3D printer. Inside the valve’s structure a series of actuators respond to hot or cold water to open and close the valve.

4D printing makes objects that assemble themselves when heated

The most common materials used in 4D printing, shape-memory polymers, normally require at least five steps to make them into adaptable objects. Hydrogels are simpler to use, but too soft to fashion into rigid structures. Zhen Ding at the Singapore University of Technology and Design and his colleagues have now developed a way to rapidly print rigid 4D objects with a commercial 3D printer and a heat source.

The strips, which can be printed in less than a minute, are made from layers of a stiff shape-memory polymer paired with a rubbery elastomer – a polymer with elastic properties. When heated to 45°C, the shape-memory polymer component relaxes and allows the elastomer to bend. As the strip cools, the shape-memory polymer stiffens again and locks the object into its new, curved configuration.

One limitation to the technique is that it permanently fixes the structure in place after one heating cycle, says Geoff Spinks at the University of Wollongong in Australia. “This rules out applications that require reversible shape changes, like artificial muscles for robots and prosthetics,” he says.

But the method could be used to make complex structures that don’t require such shape-shifting, says Spinks. For example, compact cardiac stents – tubes for placing in blood vessels to keep them open – could open up in an artery in response to body temperature. By fine-tuning the temperature transition point, medicine capsules could also be designed to bend and break open when body temperature rises with infection. And flat-pack furniture could assemble itself when heated.

Technological Challenges

Thomas A. Campbell, Skylar Tibbits and Banning Garrett in “The Next Wave: 4D Printing and Programming the Material World”, list several PM technical challenges that need to be addressed in the coming years include :

- **Design—**How do we program future CAD software to encompass PM with multiscale, multi-element and dynamic components?
  • **Materials**—How do we create materials with multifunctional properties and embedded logic capabilities?
  • **Adhesions between voxels**—How can we ensure that adhesion among voxels is comparable to normally fabricated systems, while simultaneously allowing reconfigurability or recyclability after use?
  • **Energy—**How can we generate, store, and use passive and abundant energy sources to activate individual voxels and PM?
  • **Electronics**—How do we efficiently and effectively embed controllable electronics (or electronic-like capabilities) at the submillimeter scale?
  • **Programming**—How do we program and communicate with individual voxels both physically and digitally? How do we program variable state-changes (3+ physical states)?
  •**Adaptability to different environments**—How do we

program and design environmentally responsive voxels?
- **Assembly**—What external forces would be needed to cause macro-scale self-assembly of voxels?

Kevin Ge Qi a materials scientist, works with shape-memory plastics at the Singapore University of Technology and Design points to two big challenges:
"Currently, the major challenge for 4-D printing is the material," he says. Most of those used in traditional manufacturing are not suitable for 3-D or 4-D printing, he says. That's why he and other researchers are trying to develop a catalog of materials – and combinations of those materials – that should prove useful.

Another obstacle is size. Most commercial 3-D printers that use different materials can make objects no smaller than a few centimeters. But that's too big to be useful for most medical applications, he says. "If we want to advance the technology to biomedical devices, the size needs to be about a few microns or even smaller." (A micron is one-millionth of a meter.)

References and Resources also include

https://www.newscientist.com/article/2127713-4d-printing-makes-objects-that-assemble-themselves-when-heated/