A Grand Challenge for Additive Manufacturing: Can We Print a Robot That Will Walk Out of the Printer?

Hod Lipson[1]

On a slow summer day in August 2000, the *New York Times* printed a story about our 3D-printed robot on its front page. The title read "Robot That Makes Its Own Robots."* The editors assured me and my postdoc advisor at the time, Jordan Pollack, that the only reason they ran this story on the front page was because they had nothing else—absolutely nothing—to publish that day. It was the slowest day in news history.

Nevertheless, it was an exciting day for us. We had been printing complete robots for a couple of months by then, using our Stratasys Genisys. The robots were not designed by us; they were bred, just like a farmer breeds corn. We threw lots of robot components—bars, joints, motors, wires, and neurons—into a large physics simulator. We then set off an evolutionary process: Parts were combined at random, and evaluated for performance. Robots that crawled faster (or "less slowly") than average were copied, with small random variations. After about a week on a 16-processor Onyx computer, the results emerged: a few beautiful machines, designed by evolution.

The winning robots crawled from the virtual world into the physical world through our 3D printer. One of the robots, shown on the cover of this issue of *3D Printing*, was shaped like an arrow. It was printed in its entirety in a single print job, preassembled, with balls inside sockets. Printers at the time did not have soluble support, but a slight twist of the limb caused the internal supports to snap and the joint to break free. As far as I know, those were the first robots to be printed in their entirety.

The excitement of printing a robot was tempered by the fact that we could only print the body. Everything else that makes a robot a robot, like wires, batteries, muscles, and a brain, was manually inserted according to the evolved blueprint. Wouldn't it be great if we could print not just the robot body but also its brain? If we could print the wires embedded in the limbs, with actuators in place? Could a robot walk out of the printer, batteries included? To do this, we would need a multimaterial printer, one that would allow us to experiment with new materials and allow us to cofabricate them into a single functional system, not unlike nature.

It turns out, however, that 3D printing a working robot is easier said than done. Numerous new materials needed to be developed and material compatibility issues needed to be solved. Printable conductive materials are easy to find, but finding those that have good conductivity is challenging. Battery chemistry is well understood, but printing a battery directly inside a robot is tricky. Printable actuatable materials—materials that will move in response to electric stimulus—are even more challenging to find.

We, and other groups since then, have been steadily inching along toward this goal. Printable conductors are now common; batteries have been printed and exceed the energy capacity of standard batteries. We've printed actuatable muscles, and even transistors. But no one has yet printed everything integrated together, and no robot has yet crawled out of the printer, batteries included.

The robots we printed in 1999–2000 were the first step of a journey that would last over a decade. As 3D printing matures, a growing number of researchers are engaged in this grand challenge of additive manufacturing: moving from printing passive parts to printing active, integrated systems.

After 18 months as editor-in-chief of this journal, I hand over the reins to Skylar Tibbits of MIT. Skylar is committed to moving the journal to the next phase of prestige and development, and already has some exciting plans in place. As the director of the Self-Assembly Lab at MIT, he is well known for his work in 3D printing and, now, 4D printing, also known as self-assembling technologies.

I hope that you enjoy this issue of *3D Printing*, and join us as an active participant in the journey to advance 3D printing technologies and their applications. Look for our next issue of the journal, to be published in September 2015.

Hod Lipson

[1]Cornell University, Ithaca, New York.

*www.nytimes.com/2000/08/31/us/scientists-report-they-have-made-robot-that-makes-its-own-robots.html