3D Printing

Time-to-Adoption Horizon: Four to Five Years

Known in industrial circles as rapid prototyping, 3D printing refers to technologies that construct physical objects from three-dimensional (3D) digital content such as computer-aided design (CAD), computer aided tomography (CAT), and X-ray crystallography. A 3D printer builds a tangible model or prototype from the electronic file, one layer at a time, using an inkjet-like process to spray a bonding agent onto a very thin layer of fixable powder, or an extrusion-like process using plastics and other flexible materials. The deposits created by the machine can be applied very accurately to build an object from the bottom up, layer by layer, with resolutions that, even in the least expensive machines, are more than sufficient to express a large amount of detail. The process even accommodates moving parts within the object. Using different powders and bonding agents, color can be applied, and prototype parts can be rendered in plastic, resin, or metal. This technology is commonly used in manufacturing to build prototypes of almost any object (scaled to fit the printer, of course) that can be conveyed in three dimensions.

Overview

3D printing is already pervasive in a number of fields, including architecture, industrial design, jewelry design, and civil engineering. The earliest known examples were seen in the mid-1980s at the University of Texas at Austin, where the Selective Laser Sintering was developed, though the equipment was cumbersome and expensive. The term 3D printing itself was coined a decade later at the Massachusetts Institute of Technology, when graduate students were experimenting with unconventional substances in inkjet printers. 3D printing appeared in the very first *NMC Horizon Report*, published in 2004, and since then, it has helped the U.S. Department of Defense to inexpensively create aerospace parts, architects create models of buildings, medical professionals develop body parts for transplants, and much more.

During the process of 3D printing, the user will start by designing a model of the desired object through software such as CAD. Once the design is sent to the printer, the materials — either plastics or metals — are dispensed through a nozzle, gradually deposited to eventually form the entire object. Additive manufacturing technologies change the way the layers are deposited as some objects call for the material to be softened or melted. Selective heat and laser sintering, for example, require thermoplastics, while electron beam melting calls for titanium alloys. In the case of laminated object manufacturing, thin layers must be cut to shape and then joined together.

In the past several years, there has been a lot of experimentation in the consumer space — namely within the Maker culture, a technologically-savvy, do-it-yourself community dedicated to advancing science, engineering, and other disciplines through the exploration of 3D printing and robotics. Those involved in the many Maker communities around the world emphasize invention and prototyping. The MakerBot (go.nmc.org/maker) is a 3D desktop printer that allows users to build everything from toys to robots, to household furniture and accessories, to models of dinosaur skeletons. In 2012, MakerBot Industries released the Replicator 2, with a higher resolution compatibility and build volume. Relatively affordable at under $2,500, the MakerBot has brought 3D printing to the masses; the technology had previously only been found in specialized labs.

The resurgence of 3D printing has also been aided by online applications such as Thingiverse (go.nmc.org/

thingv), a repository of digital designs for physical objects where users can download the digital design information and create that object themselves, instead of starting from scratch. The museum community in particular has capitalized on this service, creating and sharing replicas of artwork, sculptures, and fossils.

In early 2013, the world's first 3D printing photo booth will open in Japan (go.nmc.org/omote), and reservations can be made online by anyone. Making 3D printing accessible to all is a trend that is also emerging in higher education. The University of Nevada, Reno's DeLaMare Science and Engineering Library recently became one of the first academic libraries in the U.S. to allow students, faculty, and the public to use 3D printing and scanning tools (go.nmc.org/delamare). As the technology becomes cheaper and more prevalent in public buildings at universities, access will no longer be an obstacle for the widespread adoption of 3D printing. Currently, however, the machines and tools are limited to participants in specialized projects and students enrolled in specific courses.

Relevance for Teaching, Learning, or Creative Inquiry

One of the most significant aspects of 3D printing for education is that it enables more authentic exploration of objects that may not be readily available to universities. While 3D printing is four to five years away from widespread adoption in higher education, it is easy to pinpoint the practical applications that will take hold. Geology and anthropology students, for example, can make and interact with models of fragile objects such as fossils and artifacts. Through rapid prototyping and production tools, organic chemistry students and those studying x-ray crystallography can print out models of complex proteins and other molecules, similar to what can be seen in 3D Molecular Design's Model Gallery (go.nmc.org/molec).

While it has become easier for faculty and students to work with these models, some of the most compelling progress of 3D printing in higher education comes from institutions that are using the technology to invent brand new tools. Researchers at the University of Warwick recently created an inexpensive, 3D printable, electrically conductive plastic that enables electronic tracks and sensors as part of the 3D printed model (go.nmc.org/3dp). The goal is for engineering students to be able to design and print products with the circuitry system already built into the model.

As 3D printing gains traction in higher education, universities are designing dedicated laboratories and initiatives to explore creative uses of the technology. The Fab Lab program (go.nmc.org/fablab), for example, was started in the Media Lab at MIT as a learning and maker space for digitally-enabled fabrication, equipped with laser cutters, 3D printers, circuit boards, and more, and the project has now scaled to create similar laboratories all over the world.

The exploration of the 3D printing process from design to production, as well as demonstrations and participatory access, can open up new possibilities for learning activities.

The exploration of the 3D printing process from design to production, as well as demonstrations and participatory access, can open up new possibilities for learning activities. In medical schools, rapid prototyping has been helping participants produce anatomical models based on the images from MRIs and CAT scans. Doctors are able to better strategize surgeries when exploring these models. Medical schools and programs are also in the process of building artificial body parts. Scientists at Heriot-Watt University in Edinburgh, for example, are using human cells to 3D print artificial liver tissue for laboratory use, which could ultimately make the testing of new drugs more efficient and reliable than traditional methods by using human organ models instead of live animals (go.nmc.org/artili).

Similarly, a young girl afflicted with a rare neuromuscular condition was given 3D-printed appendages that enabled her to move her arms with greater ease (go.nmc.org/magica). While this type of product development has already taken root in specialized schools and research labs, it is beginning to appear at a broader number of universities across the world, justifying the placement of 3D printing on the far-term horizon.

A sampling of applications of 3D printing across disciplines includes the following:

> **Archaeology.** Harvard University's Semitic Museum is using 3D printing technology to restore a damaged ancient artifact from their collection. By 3D scanning existing fragments of the Egyptian lion's legs, researchers are able to create computer models that will be used to print a scale foam replica of the complete sculpture, though it initially was missing its body and head: go.nmc.org/semit.

> **Art and Design.** The Emily Carr University of Art and Design is exploring ways to speed up design and production in textiles, foundry, and ceramic construction with a built-from-scratch 3D printer that only cost them $500: go.nmc.org/mat.

> **Mechanical Engineering.** Two mechanical engineering students from the University of Virginia fabricated and assembled one of the first 3D printed planes ever flown. As part of their internship with the MITRE Corporation, they learned how to rapidly prototype and test scale models of aerial vehicles in a fraction of the time and cost it would have taken before the availability of 3D printing: go.nmc.org/fly.

3D Printing in Practice

The following links provide examples of 3D printing in use in higher education settings:

3D Model Workshops
go.nmc.org/vic
At Victoria University of Wellington, the Schools of Architecture and Design held a 3D model workshop with metalwork and woodwork machinery areas and a range of 3D digital fabrication and other modeling equipment.

3D Printing at Purdue University
go.nmc.org/strong
Purdue University researchers are working with Adobe's Advantage Technology Labs to develop a software application that creates more durable 3D printed objects. Through structural analysis the program identifies problematic areas and offers solutions to create stronger objects using a minimal amount of raw material.

Adding a "3D Print" Button to Animation Software
go.nmc.org/beast
Computer scientists at Harvard University are developing an add-on software tool that makes it possible to print 3D action figures from computer animation files. The research, conducted in collaboration with graphics experts, enables animators to create replicas of otherworldly creatures by finding the location of joints and gauging the correct size and friction to make them move and pose.

Think[box]
go.nmc.org/thinkbox
Case Western Reserve University's new invention center, Think[box], is a space for anyone to creatively tinker, complete with 3D printers, laser cutters, and tools for students to create their own printed circuit board or computerized embroidery.

ThinkLab
go.nmc.org/thinklab
The ThinkLab is a Makerspace at the University of Mary Washington for hands-on creative inquiry and learning with a variety of high-tech tools, including a 3D printer. In one project students used the 3D printer for prototyping, designing, and creating makeshift solutions to business problems.

For Further Reading

The following articles and resources are recommended for those who wish to learn more about 3D printing:

3D Printing: The Desktop Drugstore
go.nmc.org/dedru
(Katharine Sanderson, *BBC News*, 26 September 2012.)
This article explores how 3D printing can revolutionize

the medical industry through the printing of body organs, pharmaceuticals, and custom prosthetics. Although many projects are still in the research stage, this emerging technology provides hope for lower cost medical solutions for remote areas of the world.

7 Educational Uses for 3D Printing
go.nmc.org/7ed3d
(Nancy Parker, *Getting Smart*, 14 November 2012.) There is a vast array of uses for 3D printers in education, including drafting in architecture courses, creating 3D art in graphic design, developing body part models for biology, and more.

The Future of Higher Education: Reshaping Universities through 3D Printing
go.nmc.org/reshap
(Jason Hidalgo, *Engadget*, 19 October 2012.) From libraries to laboratories, 3D printing is becoming more ubiquitous across college campuses. The University of Nevada, MIT, and Columbia are just a few universities utilizing 3D printers to engage their students in how to rapidly prototype designs, understand molecular shapes, and more.

Making It Real With 3D printing
go.nmc.org/making
(Drew Nelson, *InfoWorld*, 11 December 2012.) This article highlights the emergence of open source 3D printers which got their start in 2007 and have now developed into lower cost, more efficient models as users share, copy, and improve upon the model designs.

NASA Turns to 3D Printing for Self-Building Spacecraft
go.nmc.org/nasa
(Jeremy Hsu, *Technews Daily*, 13 September 2012.) NASA's SpiderFab project is studying the feasibility of 3D printing in space. The author of this post describes how this type of research could lead to the era of rockets equipped with 3D printers and raw materials, manufacturing massive telescopes, satellites, and space antennas while in orbit.

The New MakerBot Replicator Might Just Change Your World
go.nmc.org/mbot
(Chris Anderson, *Wired*, 19 September 2012.) MakerBot's Replicator 2 was released in September 2012, signaling the maturation of the desktop 3D printing market because of its accessible price, simplified software, and improved resolution. This article profiles the MakerBot company, their development, and the ecosystem they have helped create.

Science in Three Dimensions: The Print Revolution
go.nmc.org/kurz
(*Kurzweil*, 5 July 2012.) This article brings to light the capabilities of 3D printers for scientific research, and the way they are democratizing the ability to create custom models. Examples include models of complex molecular systems and 3D printed collagen to construct scaffolds for growing cells.

What Can be Made with 3-D Printers?
go.nmc.org/whacan
(*The Washington Post*, 4 January, 2013.) A photo slideshow reveals a series of objects that were created from 3D printers, including an iPhone case, a shoe, a model of a Les Paul guitar, and more. People of all ages created these items — even a high school student — demonstrating how 3D printing has become more accessible and easier to manage.