3D PRINTING CARVES NEW PATHS

By Greg Varhaug

In 2012, *The Economist* ran an article about a company that could supposedly 3D print a live pet, such as a dog, to exact customer specifications. It turns out that the article on bespoke pets was an April fool's joke by the magazine's editors: we still lack the means to create living creatures from inanimate raw materials.

In the months leading up to the joke, *The Economist* had run a series of fascinating stories about ongoing technical advances in medical uses for 3D printing. For instance, they had previously reported on Organovo's release of the first commercial bio printer, which works by extruding groups of cells to create skin or blood vessels for use in research. The same article states that human organs have already been successfully produced using specialized 3D printers. You can understand why, to some people, printing live pets might have sounded momentarily believable.

A lot has changed in the world of 3D printing in just the last three years. Public awareness of the technology is increasing. The machines have become very popular, especially with young people. The public is discovering 3D printing as a new kind of creative outlet, inspiring the invention of all sorts of unique and imaginative items. Sales of the machines have increased steadily, some models selling out completely.

Consumers now have more choices among printer brands, models, and features, in a wide range of prices. The range of competing choices will increase as new printer startups come on line. The number of materials available for printing, and the number of materials suppliers, are also increasing.

3D printer sales began as a business-to-business enterprise. Now that office supply stores like Office Depot and Staples are selling them, 3D printers and printed products are being marketed directly to household and educational consumers as well.

MORE FINISHED PRODUCTS

3D printing for prototyping—creating nonfunctioning models—has been around for years. Its use in prototyping will continue to grow. But there is also a trend towards printing more usable finished products.

According to Terry Wohlers, a consultant who has followed trends in the 3D printing business for more than a decade, the percentage of additive manufacturing used to create finished parts, as opposed to creating models and prototypes, has risen steadily over the past ten years. The *Wohlers Report 2013* shows that in 2003, the percentage of product and service revenues

from additive manufacturing used to create finished parts was only 3.9 percent. As of 2013, that number has grown to 28.3 percent. That trend is likely to continue in the coming years.

Since commercial printers were first introduced, hobbyists have found many clever uses for things printed in ABS plastics, or the sandstone-like plaster materials used in powder-bed printers. But more importantly, a new generation of industrial-grade 3D printers offers new alternatives to processes like injection molding, casting, welding, or milling. Printed parts probably can't match the tensile strength of parts made by forging—but GE has recently started printing turbine blades, a part that is usually forged, for use in their jet engines.

No one believes 3D printing will replace current manufacturing techniques anytime soon. At present, additive processes represent an insignificantly small percentage of worldwide manufacturing. But it's an area that's reportedly been growing by double digits for several years. Additive manufacturing processes are proving cost-effective for certain items, usually those produced in small numbers. Even with the very high cost of raw materials for printing in durable metals, manufacturers are finding instances where the design flexibility of printing is cost-effective compared to conventional processes.

BIOMEDICAL ADVANCES

Biomedical companies were among the first to find practical uses for 3D printing. Surgeons now print models of their patients' livers, kidneys, hearts, and skulls, so they can better examine them and better plan their operations. 3D printing has also been useful in helping to speed up and cut the costs of prototyping new medical devices.

More recently, 3D printers have been used to create finished, end-use medical products, like dentures and prosthetics, which have to be custom-fitted to the patient. Surgeons are also using printers to make prosthetics for complex facial reconstructions. A number of medical procedures involving 3D printing, such as 3D printed bone in place of metal plates for treating skull injuries, have been approved for use by the FDA.

There are stories in the press about people with no medical background who have created working prosthetics. Conventional custom prosthetics can cost many thousands of dollars. An American businessman was able to print a prosthetic hand for a Sudanese boy injured by a bomb, at a cost of about $100. Another man in Massachusetts recently printed a similar prosthetic for his 12-year-old son. And a 16-year-old in Kansas printed a prosthetic hand for a nine-year-old on a printer at the local public library.

PRINTING JEWELRY

3D printing enthusiasts who wanted something they could produce and sell naturally gravitated to making jewelry, but they didn't start with printing finished pieces. Jewelers first

adopted 3D printing to create molds for casting soft metals. This kind of jewelry is inexpensive to make, and so can be sold cheaply. This has led many people to take up the business.

Industrial-grade printers can make jewelry out of metals or alloys. They can also perform metal plating. Some jewelers have invested in these high-end machines; others are designing their own jewelry but outsourcing the actual printing to companies with industrial-grade printers. Shapeways and Sculpteo are two popular services that will print your piece and sell it through their site. Kraftwurx, based in Houston, offers similar services.

3D printed ring, Shapeways.com

CREATING NEW BUSINESSES

For manufacturing entrepreneurs, 3D printing has demonstrated its value in making prototyping faster, easier, and cheaper. This benefit alone affects companies in a variety of fields, since every consumer product starts out as a prototype. New businesses are starting precisely because the drop in the costs of prototyping, as well as in making production molds, provides the critical cost advantage to make those businesses financially viable.

People who have embraced the technology will tell you that it has changed their entire outlook on the process of production and design. Companies like GE are examining many of their manufactured parts to identify those that could be better handled by additive processes. This is a natural consequence of adopting the new technology, since additive manufacturing makes a wide array of possible design options equally simple. It often reduces the number of parts that have to be created separately and assembled later. It reduces or completely eliminates the need for many finishing steps, like additional machining.

The possibilities of 3D printing are still limited by the number of materials that can be used in the process. But the number of available materials is increasing every year. The high cost of printing materials, compared to conventional manufacturing, may be only a temporary drawback. The prices of most materials are expected to drop over time for a variety of reasons, including increased competition and the expiration of certain patents.

Shapeways' Duann Scott, whose company title is "design evangelist," notes that some patents affecting the price of materials for 3D printing will expire this year, which is expected to dramatically lower printing costs. He points out that one patent, for fused deposition modeling (FDM), expired not long ago, leading to an immediate drop in the cost of machines using the FDM process.

PRINTING IN METAL

An important improvement in recent years is in the ability to print with metals. Stratasys makes some of the machines being used by GE to print engine parts. Morris Technologies, recently acquired by GE, makes printers that produce titanium turbine blades for use in GE's jet engines. The design advantages of additive manufacturing enable the creation of lighter airplane parts, making planes both cheaper and greener. GE is printing a number of other internal engine parts.

Titanium parts manufactured with 3D printers do not have a tensile strength as high as parts that are forged. Some metal 3D printers are basically robotically controlled arc welders. Other high-end 3D printers use sintering and other advanced fabrication methods to make parts from steel, titanium, and aluminum. It's a

powder-bed process in which lasers etch precise patterns into a bed of metal powder, in a process similar to that used by a Z-Corp printer. Then the bed is lowered and a new layer of powder is distributed and etched by the laser.

A team at NC State University has created an extruder for creating metal beads and filaments, working at room temperature. The team believes it could be useful in building electrical components.

THE ECONOMIC VIABILITY OF ADDITIVE MANUFACTURING

How do the costs of additive manufacturing compare to those of conventional manufacturing? EOS and Airbus Group Innovations recently released a study that compares the costs of manufacturing a particular standardized airplane part using a conventional steel casting process to the costs of using DMLS, an additive process in which lasers are used to sinter titanium. The study looks at both the financial and environmental costs of producing and using the part over its entire lifetime.

The firms compared the costs of raw materials, metal powder for the sintering process, and steel for castings. They compared the energy used, as well as the carbon footprint, in both manufacturing processes, including the energy cost of processing the raw materials. That means comparing the energy needed for a laser to melt metal to the energy it takes to heat a furnace for casting steel. The steel part then requires additional machining that the laser-sintered part doesn't.

Printing opens up all sorts of design possibilities that are otherwise cost-prohibitive. Some shapes are more difficult and expensive to cast than others. The titanium part, made by an additive process, is designed very differently from the same part cast in steel. Additive manufacturing processes bring down the costs of design geometries that would be expensive to produce with conventional processes. Additive processes change the economics of producing complex designs.

The study found that using the titanium parts in place of the steel made each plane 10 kg lighter. When you're buying jet fuel to transport those 10 kg, the savings add up over the life of the plane.

Owners of 3D printers often claim that their printers have paid for themselves because of the money

3D printed heart, wonderfulengineering.com

they've saved. Many of these owners point to replacement parts they have been able to create at home. 3D printing replacement parts can increase the life of some products where the only other alternative is to trash the entire unit. Thingiverse, a website where people share files of 3D objects they've designed, offers many examples of this phenomenon. One person made a replacement part for a broken camera tripod. Someone else printed a replacement part to fix a broken snow-blower.

Other industries are finding uses for the technology. For example, at Xerox's PARC, they are using 3D printers to make solar cells. (Printers can themselves be powered by solar cells.) At MIT, they are printing solar cells onto paper and cloth that can then be folded multiple times and still function. NASA has been using 3D printers in its design processes, though the agency still relies on traditional methods to produce working parts. The first 3D printed car comes to us from KOR EcoLogic. They hope to produce the car they call the Urbee beginning this year; the car's body and interior will be 3D printed by Stratasys printers.

Is 3D printing friendly to the environment? It depends. 3D printers use a large amount of energy; it takes hours to print even a small object. Manufacturers are working to increase the energy efficiency of their machines, but there are energy-saving advantages nonetheless. One of the ways in which 3D printing can save energy is by helping to keep production close to consumption. Another environmental concern is that most 3D printers generate small amounts of indoor air pollution. The move to biodegradable plastics, like PLA made from cornstarch, may help to offset pollution from plastic wastes.

CREATING JOBS OF THE FUTURE

Some people believe that additive manufacturing will lead to a U.S. "manufacturing renaissance," but there is no real prospect for employing a large percentage of the U.S. working population in manufacturing. Manufacturing today is largely automated. The model of an economy based on jobs in manufacturing is a thing of the past. Nevertheless, an economic benefit exists to manufacturing in the United States, whether or not it creates new jobs. Making more products in the United States drives down our trade deficits with countries like China.

Additive technology is certainly creating new opportunities for entrepreneurs looking to create innovative products. It also opens up opportunities for niche businesses that create products customized to meet the needs of individual consumers. As the number of materials supported by 3D printing increases, so will the range of consumer products that can be individually customized. This technology is leading the way to a true democratization of manufacturing. N

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3D PRINTING SERVICES

With 3D printing, all of the creative aspects of design are handled through 3D design software, similar to CAD. The end product is a computer file that tells the printer what to print. The actual production is a technical matter that's left up to the machine.

In some situations, a person may need a 3D printer, but not have enough time or funds to buy one, assemble it, and learn to use it. That's why many people are turning to third-party services to print the objects they create. Third-party printing services allow you to create your own objects using 3D software, then have them printed for a set price in the medium you specify. Industry consultant Terry Wohlers believes much of the near-term growth in 3D printing will be in the area of printing services. These services allow businesses to produce items on an "as-needed" basis.

Shapeways is the best known of these services. Shapeways started in 2007 and catered mostly to those wanting rapid prototyping. As the range of materials has increased to include stainless steel, sterling silver, bronze, alumide, acrylics, and food-grade glazed ceramics, the emphasis has shifted to creating finished products. They also allow users to open their own online shops through their website.

Sculpteo, a French company, was founded in 2009 and began offering their services online in 2011. They print in most of the same materials offered by Shapeways. Sculpteo also provides a way to market your pieces. You can create an online shop through their site, integrate with your existing shop, or become an affiliate.

Kraftwurx, with its headquarters in Houston, offers services similar to those of Shapeways and Sculpteo. Kraftwurx works with a network of 3D printing companies for final production, reducing shipping costs and carbon footprints.

UPS recently purchased several Stratasys printers and will begin offering on-location 3D printing services aimed at small business customers.