

A Novice's Guide to 3D Printing

Making the Process Less Magical and More Understandable

By Kim Brand

Few manufacturing news stories get picked up by the mainstream media, let alone make it to the cover of *The Economist* magazine, which called 3D printing the “Third Industrial Revolution.” The media also fixated on a gun which could be made with an inexpensive 3D printer. No wonder I get asked if 3D printing will put machine shops out of business.

To paraphrase Mark Twain, the demise of traditional manufacturing, at the hands of 3D printing, has been greatly exaggerated.

First off, let's get the name correct. There is very little about 3D printing that resembles printing. Those in the know refer to it by its proper name: Additive Manufacturing (AM). That umbrella term collects many technologies under one metaphor and more accurately describes what's going on. Slowly, layer by layer, parts are ‘grown’ on these machines by adding or solidifying material according to instructions derived from a three dimensional model of the part designed on a computer. Described this way 3D printing is less magical, but more understandable.

3D Printing is Growing

Terry Wohlers, 28 year veteran 3D printing industry analyst, reports that the market for AM products and services worldwide grew at a compound annual growth rate of 35.2 percent to \$4.1 billion in 2014, expanding by more than \$1 billion over 2013. Nearly fifty manufacturers produce industrial-grade AM machines — those selling for more than \$5,000.

It would be hard to estimate the comparable sales for the market for subtractive manufacturing, but *Modern Machine Shop* (mmonline.com/articles/american-manufacturing-on-the-rise) reports that “machine tool sales should rise to \$7.442 billion in 2014, an increase of 19 percent over 2013.” But wait — that only includes the sales of machine tools. The AM products and services sales



3D Systems' ProX 400 is capable of printing in more than a dozen alloys, including stainless steel, aluminum, cobalt chrome, titanium, and maraging steel.
Photo courtesy of 3D Systems.

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figures include not only the cost of the machines but also the value of the products produced on the machines. With global manufacturing representing 15 percent of a \$70 trillion economy, AM represents 0.04 percent of the manufacturing economy.

Despite its potential for enormous growth, it is a vanishingly small factor in the manufacturing business today.

There is an alphabet soup of AM methods which have been devised over the past 30 plus years. The big players are 3D Systems and Stratasys, which have a combined capitalization of \$4.15 billion and have been gobbling up competitors and service bureaus and accumulating patent portfolios at a tremendous rate. Unfortunately for them, their stock prices have declined nearly as fast lately. The industry is cautiously anticipating the entry of Hewlett

Packard in 2016 with a new technology that is said to be more capable. We'll see.

3D Printing is Cool

For sure, 3D printing can make really cool things. Because it produces parts directly from a design file it eliminates front-end investment (dollars and time) in tooling and fixturing. Rapid prototyping, quicker design iterations, and 'lot size one' manufacturing are key benefits. Designers can focus more on function and less on fabrication. Making parts in layers, rather than whittling away at the outside, allows for the creation of complex internal structures, like cooling channels or weight reducing honeycombs that yield savings in materials and reducing waste. Supply chain benefits include part consolidation; a multi-part assembly can now be made in one piece. That reduces investment in quality control (QC), inventory, and labor.

Early adopters of AM include industries that make high value/low volume products: aerospace and medical devices are two. The former values weight savings, the latter is interested in bio-mimicry. Both leverage the ability of 3D printing to make complex or unique parts in short lots. (But both have long certification cycles, which have frustrated rapid adoption.) Marketing departments love 3D printing to create replica parts when production lines don't exist. 3D printed parts, molds, and mold masters for short-runs put R&D cycles on steroids reducing time-to-market and enhancing competitive advantage.

New Tools, New Rules

These new tools impose new rules. For one, gravity is not your friend. Most of the additive technologies require the introduction of support structures, which keep cantilevers and cavities from collapsing under their own weight during manufacture. Designing these supports requires attention to their material cost, build time, orientation of the part in the build space, and removal methods. This not-so-minor detail requires experience and experimentation and adds value to an AM service bureau relationship.

Checking the size and shape of those internal cavities frustrates legacy QC methods so a new generation of metrology is needed. Another QC conundrum is process control. Less is known about how varia-



Six materials for 3D printing. New material choices are contributing to the growth of additive manufacturing. Photo courtesy of 3D Systems.

tion in the 3D printing process affects part quality. In performance or safety critical applications there remain many unknowns.

'Near-net' printing is a strategy that combines AM and traditional machining to achieve a result better than either can produce on its own. Some 3D methods leave

3D printing with metals is akin to welding and for best results is performed in inert environments, usually argon.

parts with unsuitable finishes that require post-processing. We like to say that industrial 3D printing is a team sport.

Heating and cooling introduced in some AM processes produce stress and those stresses can warp or deform the product. Steel parts require post-process heat treating to relieve these stresses . . . not to mention that steel parts emerge from DMLS systems welded to the build plate and usually require EDM (electrical discharge machining) to remove.

Of note to the gas industry, 3D printing

The Alphabet Soup of Additive Manufacturing

FDM: Fused Deposition Modeling was patented by Stratasys in 1989. Stratasys bought Makerbot in 2013 for over \$400 million. This technology has become wildly popular with hobbyists as patents have expired and a 'gold rush' of companies and individuals have begun to make low-cost printers that fabricate parts from ABS (acrylonitrile butadiene styrene, a common thermoplastic polymer — Legos are made from the same material), PLA (polylactide, a biodegradable thermoplastic aliphatic polyester derived from renewable resources), and a range of other thermoplastics. Think: a glue gun controlled by a robot financed on Kickstarter.

FFF: Fused Filament Fabrication is the equivalent of FDM but the term is unrestrained by the trademark Stratasys owns on FDM.

SLA: Stereo Lithography was patented by 3D Systems in 1986. This method uses photopolymers exposed to UV light or lasers to harden tiny elements of a liquid goo, which, when aggregated, create a solid object.

SLS/DMLS/SLM: Selective Laser Sintering/Direct Metal Laser Sintering/Selective Laser Melting are processes that use focused lasers to melt powders (plastic or metal) into tiny pools of material, which then cool and aggregate into parts. The battle for patent rights may continue until they have all expired.

CJP: ColorJet Printing was invented at MIT in 1993 and marketed by ZCorp until it was acquired by 3D Systems in 2012. In this process a layer of powder is infused with a liquid binder and cured to create the part. This method is notable because it works like a color inkjet printer.

Polyjet: Invented by Objet Geometries in 1998, Polyjet was acquired by Stratasys in 2011. It is a 3D printing system that uses two or more photopolymer resins deposited in tiny droplets, like an inkjet printer, that are mixed in real-time and cured with UV light to create a solid object. The Polyjet technology can create over 100 types of durable plastic materials including hard, soft, clear, and full color.

with metals is akin to welding and for best results is performed in inert environments, usually argon. (See “The Role of Industrial Gases in 3D Printing of Metal Parts,” on page 20 of this issue for more on this topic.)

One shortcoming of AM is the fairly sparse selection of materials — several dozen of all types are available in total for the industry across technologies. The choices represent a broad cross-section and most users will be satisfied with the options, but compared to the diversity of materials available for subtractive it may be a deal killer for your project. Characterization of new metals, for example, can take more than a year and cost \$1 million. Also, the materials are likely to be developed, certified, and marketed by the industrial AM equipment vendors. This situation creates lock-in and reduces competition for consumables, which are a significant portion of finished part cost.

Finally, the rate at which parts are produced today using AM methods is pitifully slow. Creation of solid volumes by 3D printers is very inefficient — like coloring in large areas of an outline with a crayon over and over. This fact eliminates the use of 3D printing in many high-volume in-



With a 3D printer you can prototype a design and hold the results in your hand in just days. Photo courtesy of Stratasys

dustries. 3D Parts Manufacturing’s EOS DMLS system can build at a maximum rate of eight hours/inch at a 20 μ layer height. Production rates of hours per inch of ‘Z’ height are typical.

Now the Good News

Turning ideas into parts may be a bit of an exaggeration, but it’s not far from the truth. With a 3D model and an inexpensive FDM printer you can prototype a design and hold the results in your hand — today! (Well, in a few days for sure.) Companies are using 3D printing as a communication tool to share product design details with vendors to reduce errors and lead times. A 3D printed sample can create credibility for a new product idea or convince a prospect you mean business or persuade an investor your invention will work. Manufacturers are considering the use of 3D printing to produce parts near the point-of-use and on-demand to slash logistics costs. For example, NASA is operating a 3D printer in space to evaluate parts production where spare parts just can’t be inventoried.

3D printing is used by clinicians to create assistive devices that overcome disabilities or reproduce the function of missing limbs. Bio-printing technologies are being developed that work with living cells to replace organs and body tissues.

New material choices, simpler operation, and lower prices will contribute to continued dramatic growth of 3D printing.

Schools are using 3D printers to inspire students to think. There is nothing so engaging or motivating as seeing a thing you’ve designed take shape right before your eyes. We’ve witnessed dramatic turnarounds when kids gain confidence through the experience of making something, no matter how imperfect. Pride of ownership fuels a ‘fix it’ attitude. The next generation of students will consider access to 3D printing as common as PCs — and we can hardly imagine what they will create.

New material choices, improved production readiness, simpler operation, better reliability, and lower prices will

3D Printing Uses



3D printed metal part. Photo courtesy of 3D Systems

‘Lot size one’ manufacturing: Medical devices, rapid prototyping, visualization, marketing

Impossible geometries: Making shapes that can’t be made any other way

Part consolidation: Turning assemblies into single parts

Masters and short run molds

Desktop manufacturing: Rapid iteration

Education: Inspiring STEM careers

contribute to continued dramatic growth of 3D printing across all industry sectors.

If you want one of something, if it includes ‘crazy’ geometries, or if you want to make it on your desktop today, then 3D printing is the best new thing to happen to manufacturing since electricity. Only time will tell if it deserves being described as the “Third Industrial Revolution.” But for many companies, consumers, and students it is inspiring new thinking about product design, unleashing creativity, democratizing ‘making,’ and keeping publicists, patent attorneys, and pundits very busy!

References:

“History of Additive Manufacturing” (wohlersassociates.com/history2013.pdf), Wohler’s Associates (wohlersassociates.com), and Metal-AM (metal-am.com). ■

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