
HOW 3D PRINTING WILL
CONTINUE TO
TRANSFORM MANUFACTURING
MERGING THE BEST SERVICE BUREAUS TO CREATE THE NEW FACE OF ADVANCED MANUFACTURING.
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INDEX

We can quantify the impact of 3D printing in manufacturing by evaluating the past few decades and, through past advancements, determine how 3D printing will continue to transform, benefit and revolutionize current production business models.

THE CURRENT STATE OF 3D PRINTING

In recent years, 3D printing has come into the media limelight, proclaimed as both the savior of manufacturing in North America and nothing more than a producer of cheap trinkets. Amidst current widespread speculation, 3D printing has proven its relevancy and, judging from its performance on the manufacturing floor these past 25+ years coupled with recent material developments, the technology is heralding a new age of manufacturing. 3D printing, also known as additive manufacturing, is well equipped to transform product development lifecycles with unforeseen design freedom, affordable customization, a manufacturing revolution lowering costs stateside, and encouraging innovation by engineers for unique needs and applications on-demand.

> INSTEAD OF DESIGNING FOR MANUFACTURING, WE CAN MANUFACTURE FOR DESIGN.

Traditional rules for manufacturing—complexity restraints, release points for tools, ten parts bonded to make one single unit—have never applied to 3D printing, but in order to truly benefit from the technology, a paradigm shift in the way we understand design must occur. Instead of designing for manufacturing, we can manufacture for design. Rather than using 3D printing to make simple objects that don't take full advantage of the unique benefits of this technology, 3D printing should be viewed in light of distinct, challenging and custom objects.

To begin this shift in the industry's broader understanding of 3D printing, we must evaluate current manufacturing challenges and the areas in which 3D printing complements and transcends production today, through master patterns, jigs and fixtures, prototypes, manufacturing aids and end-use components and products.

TODAY'S MANUFACTURING CHALLENGES

OFFSHORING

Current manufacturing challenges revolve around import and export costs, lead times and a shifting market both in North America and overseas. While North America remained a hub of tooling, molding and large-scale manufacturing until around the late 1970s and early 1980s, offshoring large volume production has become the widespread trend of the past two decades. In a 2012 article on insourcing, *The Atlantic* reports, "Manufacturing jobs peaked in 1979 at 19.6 million. They drifted down slowly for the next 20 years...but since 2000, these jobs have fallen precipitously."[1] A tool made offshore can cost anywhere from $10,000 to $50,000 less than a tool made in the states or Europe, due mainly to significantly reduced labor costs offshore. However, the product development shift overseas meant an increase in manufacturing complications, including lengthened lead times, remote manufacturing locations, high import and export costs, high inventory costs and sole-sourced suppliers. Additive manufacturing is proving to be a valuable solution to many issues that plague the current manufacturing landscape by revolutionizing the way we manufacture and transport products.

"In the past, once we received the 3D render of the design, we'd approve the piece and go straight into molding [overseas]. The problem was, if the mold came back with a feature we didn't like, it would be another six weeks to fix the problem and re-mold," explains Ross Danis, Creative Director at Tri-Coastal Design. "A couple months ago, it was suggested I

[1] Fishman, Charles. "The Insourcing Boom." *The Atlantic*, November 28, 2012.

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introduce 3D printing in the middle of our product development process. Now, if we have to make changes, the changes are occurring to 3D printed prototypes rather than the actual mold of the [product]; in that sense, we save a lot of time and money if we have to make changes."

RESHORING

Technology leaders, including Ford, Nike, GE and NASA, are rapidly adopting 3D printing within their product development structures. *Wohlers Report*, one of the highest regarded and most comprehensive annual reports covering the 3D printing industry, revealed in their 2014 report, "the market for 3D printing, consisting of all products and services worldwide, grew to $3.07 billion last year".[2] This growth, according to *Wohlers*, is the highest in 17 years. According to a 2014 survey carried out by PricewaterhouseCoopers —an international services network for professionals—67% of the 100 industrial manufacturers surveyed are using 3D printing in some way, with 25% stating they plan to implement 3D printing in the near future.[3] GE in particular is leading the way in taking full advantage of the benefits offered by 3D printing and North American manufacturing, and, with revenues over $140 billion, their market approach is closely followed.

[2] Terry Wohlers. "Wohlers Report 2014 Uncovers Annual Growth of 34.9% for 3D Printing and Additive Manufacturing Industry: Industry Exceeds $3 Billion Milestone." Wohlers Associates, May 1, 2014. http://wohlersassociates.com/press63.html

[3] Chris Sulavik, Michael Portnoy and Thomas Waller."3D printing and the new shape of industrial manufacturing." PwC in conjunction with Manufacturing Institute. June 2014. http://www.pwc.com/us/en/industrial-products/assets/3d-printing-next_manufacturing-chart-pack-pwc.pdf

> 67% OF THE 100 INDUSTRIAL MANUFACTURERS SURVEYED ARE USING 3D PRINTING IN SOME WAY, WITH 25% STATING THEY PLAN TO IMPLEMENT 3D PRINTING IN THE NEAR FUTURE.[3]

In the 2012 article, "The Insourcing Boom", *The Atlantic* interviewed GE on their then recent reshoring plans: "...the unchallenged logic of the global economy was that you couldn't manufacture much besides a fast-food hamburger in the US. Now, the CEO of America's leading industrial manufacturing company says it's not Appliance Park [the GE appliance manufacturing plant in the US] that's obsolete – it's offshoring that is."[4]

Around 2009, GE began reshoring their appliance division back from offshore production facilities to GE's Appliance Park production facilities in the U.S.,[5] re-joining GE's energy and aviation plants scattered stateside. GE's appliance division was sold this year to Electrolux, a swedish company.[6] Notably, Electrolux has confirmed Appliance Park headquarters will remain unchanged, indicating their shared confidence in a technology-driven America able to remain competitive in a global manufacturing environment.[7] The mass adoption of 3D printing is one of many factors comprising current industrial manufacturing evolutions, which cannot be separated from the greater conversation of manufacturing; globally, 3D printing is cementing itself into industrial production cycles.

> 3D PRINTING OFFERS FAST ITERATIONS WITH EXCELLENT PRECISION, TOLERANCE AND REPEATABILITY.

THE BENEFITS OF 3D PRINTING

Rapid prototyping a product via 3D printing prior to hard tooling is a key solution to long lead times and expensive machined or handmade prototypes. 3D printing offers fast

[4] Charles Fishman. "The Insourcing Boom." *The Atlantic*, November 28, 2012. http://www.theatlantic.com/magazine/archive/2012/12/the-insourcing-boom/309166/
[5] Jackie Northam. "As Overseas Costs Rise, More U.S. Companies Are 'Reshoring'." NPR, January 27, 2014.
[6] Chris Isidore. "GE's iconic U.S. appliance brand goes Swedish." CNNMoney, September 8, 2014. http://money.cnn.com/2014/09/08/news/companies/ge-appliance-sale/
[7] Rick Rothacker, Ely Portillo and Steve Lyttle. "Electrolux CEO: Charlotte to remain headquarters after GE deal." Charolette Observer, September 8, 2014. http://www.charlotteobserver.com/2014/09/08/5158837/electrolux-to-buy-ge-appliances.html#.VD7JTPldXzg

iterations with excellent precision, tolerance and repeatability. Designers and engineers have discovered they can produce prototypes to feel, test fit against other parts in an assembly in a matter of days, show to their sales and marketing teams and perform engineering evaluation—all at a relatively low cost in North America. Designers don't have to begin tooling to receive a functional part in their hands and check its size, feel and function. This way, when the first tool is created, designers are confident it will quickly produce the optimum product without increased lead time due to tool changes.

> "ADDITIVE MANUFACTURING OFFERS DESIGNERS A CHANCE TO TAKE BIG RISKS WITHOUT BIG COST AND TIME IMPLICATIONS."

By localizing manufacturing, 3D printing alleviates manufacturing challenges, providing first look prototypes, allowing failure early in the design cycle and providing real time product review with the customer before beginning final production.

TRAINING A 3D WORKFORCE

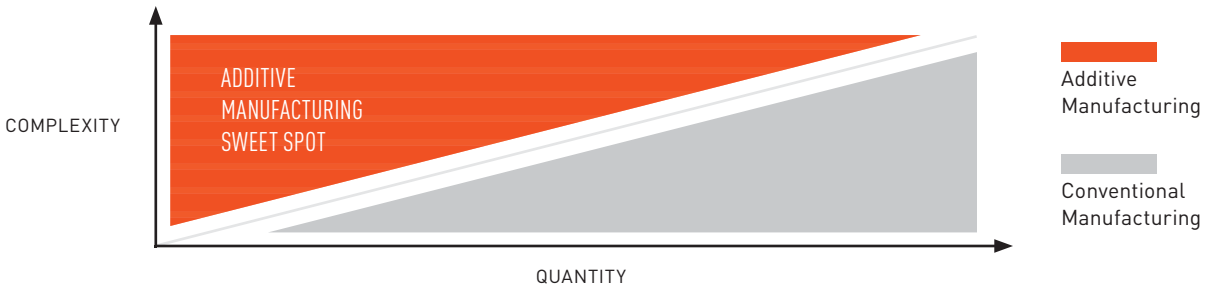
Another key challenge in manufacturing today is the availability of a skilled workforce in North America; answering this challenge begins early with childhood and young adult education. Desktop 3D printing in classrooms can help to greatly encourage young students' interest in STEAM (Science, Technology, Engineering, Arts and Mathematics); a 2013 study done by the United Kingdom Department for Education found that "3D printers have significant potential as a teaching resource and can have a positive impact on pupil engagement and learning".[8] 3D printers provide students with an unrivaled hands-on experience in engineering and design. Additive manufacturing applications cross into math, science, design and computer classes. By garnering student interest in manufacturing at a young age, we are poised to revitalize the workforce, engage more bright minds across more platforms and keep innovation strong.

[8] "3D printers in schools: uses in the curriculum." Department for Education UK, October 2013. pg 22. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251439/3D_printers_in_schools.pdf

While there are numerous challenges imposed on today's manufacturing environment, additive manufacturing has inherent advantages which will overcome these obstacles by improving access to local options, accelerating speed to market, improving quality of designs and thereby reducing the overall cost of manufactured goods.

ADDITIVE MANUFACTURING AS A COMPLEMENT TO TRADITIONAL MANUFACTURING

Additive manufacturing has filled an innovation gap left by traditional manufacturing methods. By providing superior geometries for parts, improved quality, better consistency and streamlined production as both aids and as final end-use products, 3D printing has improved upon involved hand layup, machining, molding and milling manufacturing methods more traditionally used. However, these manufacturing processes still offer substantial benefits with large, simple geometries that don't challenge complexity.



COMBINING TRADITIONAL AND ADDITIVE MANUFACTURING

Machining excels at tight tolerances and large components and will continue to be the best production option for many applications. 3D printing is a complement to traditional manufacturing processes, working hand in hand within the manufacturing industry to provide optimization to product inception and execution. Conversely, additive manufacturing benefits from the capability of traditional CNC machines and mills to machine plastic and

metal parts to tolerance and perform secondary operations on parts such as tapping holes and threads. 3D printing will not replace traditional manufacturing in the foreseeable future; rather, it is a complement to CNC machining, investment casting, hard tooling and injection molding capabilities, providing more advanced and sophisticated manufacturing solutions.

> ADDITIVE MANUFACTURING IS FREQUENTLY USED TO MAKE HIGH FIDELITY, QUICK TURNAROUND MASTER PATTERNS WITH EXCELLENT SURFACE DETAIL FOR SILICONE TOOLS AND INVESTMENT CASTING.

In addition to providing previously impossible manufacturing options, 3D printing has played a critical role behind the scenes for traditional manufacturing—beyond prototyping and complex production parts. Additive manufacturing is frequently used to make high fidelity, quick turnaround master patterns with excellent surface detail for silicone tools and investment casting. 3D printed master patterns combined with cast urethane (soft tooling) processes offer less expensive patterns than similarly complex machined patterns and can be ready in as little as a day, greatly improving lead times.

USING 3D PRINTED MASTER PATTERNS COMBINED WITH CAST URETHANE

3D printing is also used as a solution for investment casting patterns[9], affording excellent burnout and better shape retention than wax patterns of the same size. Its function as an investment casting pattern results in much more intricate, accurate metal parts for art, medical, aerospace and industrial applications.

Tooling inserts and manufacturing aids have also benefited from 3D printing capabilities[10], providing perfect fit options without a high machining cost for a one-off part. Metal 3D printing has made a significant impact in the tool itself for smaller parts by providing internal, conformal cooling lines and custom tooling components[11], speeding up efficiency and accuracy during the injection molding process.

"We used the 3D printed unit to set up the production line," says Thermal Imagining Company, FLIR. "Prior to having all the parts injection molded and released, our production team used the 3D printed model to figure out an optimal way to assemble the unit."

> "PLASTIC 3D PRINTING HAS PROVIDED JIGS AND FIXTURES TO INCREASE QUALITY, SPEED AND EFFICIENCY OF TRADITIONAL PRODUCTION LINES, AGAIN COMPLEMENTING TRADITIONAL MANUFACTURING METHODS."[12]

Companies across the world have incorporated additive manufacturing aids into their production line to streamline workflow and reduce the amount of labor required for production. In fact, at Stratasys, we have incorporated over 100 additive manufactured jigs and fixtures to aid our internal production line.

Just as 3D printing provides unfathomable design freedom, so too does it offer endless application solutions to support and improve traditional manufacturing processes.

[9] Terry Persun. "PAC 12 Trophy Design." Product Design & Development, December 1, 2012. http://www.pddnet.com/articles/2011/12/pac-12-trophy-design
[10] Christina M. Fuges. "Rebuild, Don't Replace." Modern Machine Shop, August 18, 2014. http://www.mmsonline.com/articles/rebuild-dont-replace
[11] Tim Ruffner. "Conformal Cooling Using DMLS." Medical Design Technology, June 5, 2012. http://www.mdtmag.com/articles/2012/06/conformal-cooling-using-dmls
[12] Kyle Maxey. "3D Printing's Hidden Value: Jigs and Fixtures." Engineering.com. June 4, 2014. http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/7702/3D-Printings-Hidden-Value-Jigs-and-Fixtures.aspx

A NEW SOLUTION FOR SHORT RUN PRODUCTION

IMPROVED INVENTORY AND DISTRIBUTION MANAGEMENT

In the case of current production, tooling for a new product is typically housed within a company's inventory to be pulled for further development. Inventory space—for the tool, aids to produce the product and/or product itself—is an important consideration that must be factored into the investment for the product in its entirety. The

> "DIGITAL FILES AFFORD IMMEDIATE DESIGN CHANGES WITHOUT INCURRING ASTRONOMICAL COSTS."

virtual inventory inherent in 3D printing is poised to transform the structure of tooling and inventory by eliminating physical product inventory, tools and tooling aids. Providing files available on-line for downloading and printing "transform the retail supply chain and manufacturing sectors…higher-income countries would be less reliant on production in low-wage areas for cheap manufacturing," writes Freddie Dawson in a recent article for *Forbes*. "Distribution would shift…with items made on an as-needed basis."[13] Rather than digging up a shelved product which may no longer be relevant to current market interests or trends, a file of the part is retrieved. That file can then be sent directly to a service bureau for manufacturing, no tooling or molding required. Parts are manufactured on-demand for tailored low volume production. Digital files afford immediate design changes without incurring astronomical costs. If a design or feature change is required, it can be implemented in real time and incorporated into your product within days, if not hours, rather than having to re-tool and re-mold.

[13] Freddie Dawson. "How Disruptive is 3D Printing Really?" Forbes, September 30, 2014. http://www.forbes.com/sites/freddiedawson/2014/09/30/how-disruptive-is-3d-printing-really/

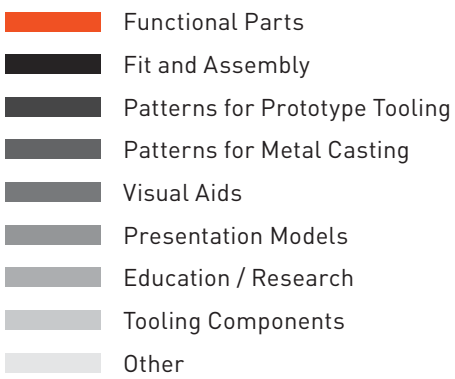
ADVANCING 3D PRINTING

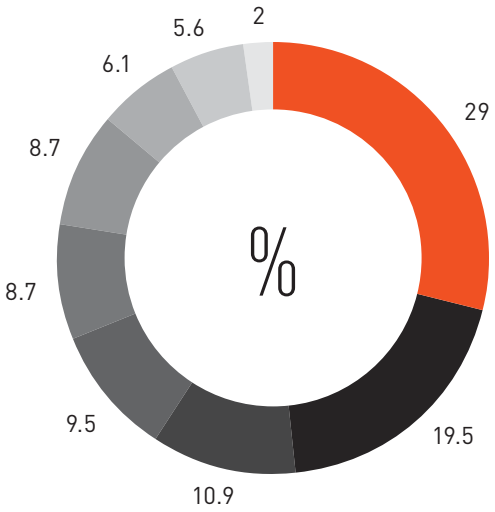
In recent years, 3D printing materials have improved significantly. Today, a product can be additive manufactured in multiple materials simultaneously with production grade materials, many of which are already commonly used in injection molding. 3D printing provides aerospace fire retardant (FR) and heat, smoke toxicity (HST) rated materials as well as FDA approved materials for certain medical applications. In the world of bioprinting, stem cells and tissue are 3D printed in the lab; biomedical engineers have 3D printed artificial blood vessels at Brigham and Woman's Hospital in Boston[14]; scaled down organs are printed to test vaccines[15]; research continues to further the endless medical possibilities 3D printing promises. Materials advancements will further open the door for 3D printing adoption.

> TODAY, A PRODUCT CAN BE ADDITIVE MANUFACTURED IN MULTIPLE MATERIALS SIMULTANEOUSLY [...]

This was clearly evident in the 2014 *Wohlers Report*. Of the 111 companies surveyed worldwide by Wohlers Associates, the majority listed additive manufactured parts used as functional end-use and functional prototype parts[16]. Material advancements are an indication of the rising demand for short run production of end-use 3D printed parts.

HOW DO YOUR CUSTOMERS USE PARTS BUILT ON YOUR **ADDITIVE MANUFACTURING EQUIPMENT?**





Graph Courtesy of Wohlers Report 2014

[14] Tanya Lewis. "3D-Printed Blood Vessels Could be Used for Transplants." LiveScience, June 3, 2014. http://www.livescience.com/46067-3d-printed-blood-vessels.html
[15] Joe Miller. "'Body on a chip' uses 3D Printing organs to test vaccines." BBC News, September 17, 2013. http://www.bbc.com/news/technology-24125678
[16] Terry Wohlers and Tim Caffrey. Wohlers Report 2014. Colorado: Wohlers Associates, 2014, pg 20.

We may see the trend of customized short run production parts continue to rise in this industry, and the market interest in personalized 3D printed objects would indicate such a move. This is where additive manufacturing in short run production truly excels: Projects requiring immediate turnaround, low volume function parts, and projects encompassing smarter design and engaging customization.

DESIGN FREEDOM FOR IMPROVED EFFICIENCY

One of the most recognized benefits of additive manufacturing is the design freedom it affords during product development and end-use manufacturing. Complicating the basics of a new product can enhance its functionality.

For example, a duct with complex 3D printed features built directly into the unit can now distribute heat better, or transfer air more efficiently, while being half the weight of its predecessor; aerospace significantly benefits from such consolidation. The duct is now more

COMPLEX INTERIOR FEATURES CAN BE BUILT DIRECTLY INTO 3D PRINTED PARTS—CONSOLIDATING WEIGHT AND PART COUNT.

efficient and has reduced part count and weight, reduced labor considerations and reduced bonding agents which results in a more optimum product development process. Complicating the interior of medical equipment, for example, by incorporating intricate shelving or attachment units, allows the manufacturer to implement more software, making the end device smarter, or store and seamlessly process samples within one single device thanks to the improved housing executed in a single build. Without 3D printed units within master patterns or as part of the end product, many anatomical models medical professionals use today would not have been possible; but now, they are implemented seamlessly thanks to 3D printing's ability to mimic organic forms in fresh ways. Additive manufacturing reduces part count while enhancing the functionality of the product, providing designers with the time to re-design more frequently with reduced overhead cost and ultimately deliver the most successful product, as opposed to the product time and money allotted.

> "ADDITIVE MANUFACTURING REDUCES PART COUNT WHILE ENHANCING THE FUNCTIONALITY OF THE PRODUCT."

NEW MANUFACTURING OBSTACLES

As with all revolutions, there are hurdles ahead that will influence the landscape of manufacturing. Barriers to entry continue to fall; 3D printers have lowered in price and 3D CAD software is becoming increasingly less complicated as consumers desire to become designers themselves. Libraries of 3D CAD files, such as GrabCad and Thingiverse are overflowing with thousands of ready-to-print models. Inevitably, there will be a shift in the way we understand and communicate intellectual property. When everyone has the ability to create any design they dream up, authorship lines can blur. However, it's not all worrisome copyright infringement woes.

3D PRINTING AND INTELLECTUAL PROPERTY

Trying to control who owns the right to manufacture what – e.g. an artist designs a 3D CAD model of a mug displaying a familiar looking mermaid and sells the design online – is a difficult issue to tackle, but it has spurred the evolution of better products and new business models. Hasbro is a prime example of a company embracing today's blurred copyright lines. Hasbro has created an online platform for designers to share their 3D printable fan art and even sell that art to other fans. Instead of attempting to shut down the spread of fan-made figurines, Hasbro welcomed the opportunity to accelerate the development of a platform for fans to legally share, buy and create Hasbro property.[17]

> "[...] IT HAS SPURRED THE EVOLUTION OF BETTER PRODUCTS AND NEW BUSINESS MODELS."

3D printing is putting product development into a new field of open source widespread design engagement, and the opportunities for even better products tailored to niche markets is thrilling.

FUSED DEPOSITION MODELING UTILIZES THERMOPLASTIC MATERIALS TO CREATE ROBUST PARTS AND PROTOTYPES.

[17] Elizabeth A. Harris. "Hasbro to Collaborate with 3D Printing Company to Sell Artwork." New York Times, July 20, 2014. http://www.nytimes.com/2014/07/21/business/hasbro-selling-my-little-pony-fan-art.html?_r=2&referrer=

PAST SUCCESS, FUTURE VISION

3D printing has been behind the scenes for decades, speeding manufacturing by providing functional prototype and production parts in hundreds of industries to optimize product development and product execution. "Back in the 1980s," says Terry Wohlers, author of *The Wohlers Report*, "no one knew where this industry would go or how large it would become, although a number of us believed that it would grow to become very big. In some ways, the technology has not progressed as much as some of us expected, but it is only now getting the attention and investment it deserves."

> "EVERYTHING [...] HAS BENEFITTED FROM 3D PRINTING"

Life as we know it is entirely influenced by 3D printing and continues to benefit as 3D printing methods and materials improve and designers adopt the most intricate manufacturing tool to date. Everything—from that holiday soap dispenser to medical guides to ducting on aircraft—is benefiting from 3D printing thanks to its design freedom, affordable customization, fast turnaround providing immediate prototypes for evaluation, and behind the scenes work as a master pattern, jig or fixture and manufacturing aid. Manufacturing, medical, education, aviation—a plethora of industries—will continue to further adapt to this technology because it spurs invention, encourages the improbable and impossible, affords infinite customization to meet the individual's needs and provides the means to improve and change our lives through optimum product and application development.

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