By **REINA G. WIATT, CMA, CPA**

MANUFACTURING ENTERS THE THIRD DIMENSION

In the iconic science fiction universe of the various *Star Trek* television series, the 24th Century features a device called a replicator that is capable of creating meals, machine parts, and clothing on demand. Today, three-dimensional (3D) printing has transformed this science fiction prop into a reality and is changing the entire manufacturing landscape.

Created in the 1980s, 3D printing, also called additive manufacturing (AM), was conceived as a faster and more cost-effective method for creating product prototypes. The process consisted of creating a product design using a computer-aided design (CAD) or a similar 3D digital file. A 3D printer deposited successive layers of material on top of one another until the final object was created. The early 3D printers used basic polymers, but technology improvements—especially in the material applications—have expanded the type of printable materials to include plastics, metal, nylon, plaster, ceramics, and, yes, even human tissue cells.

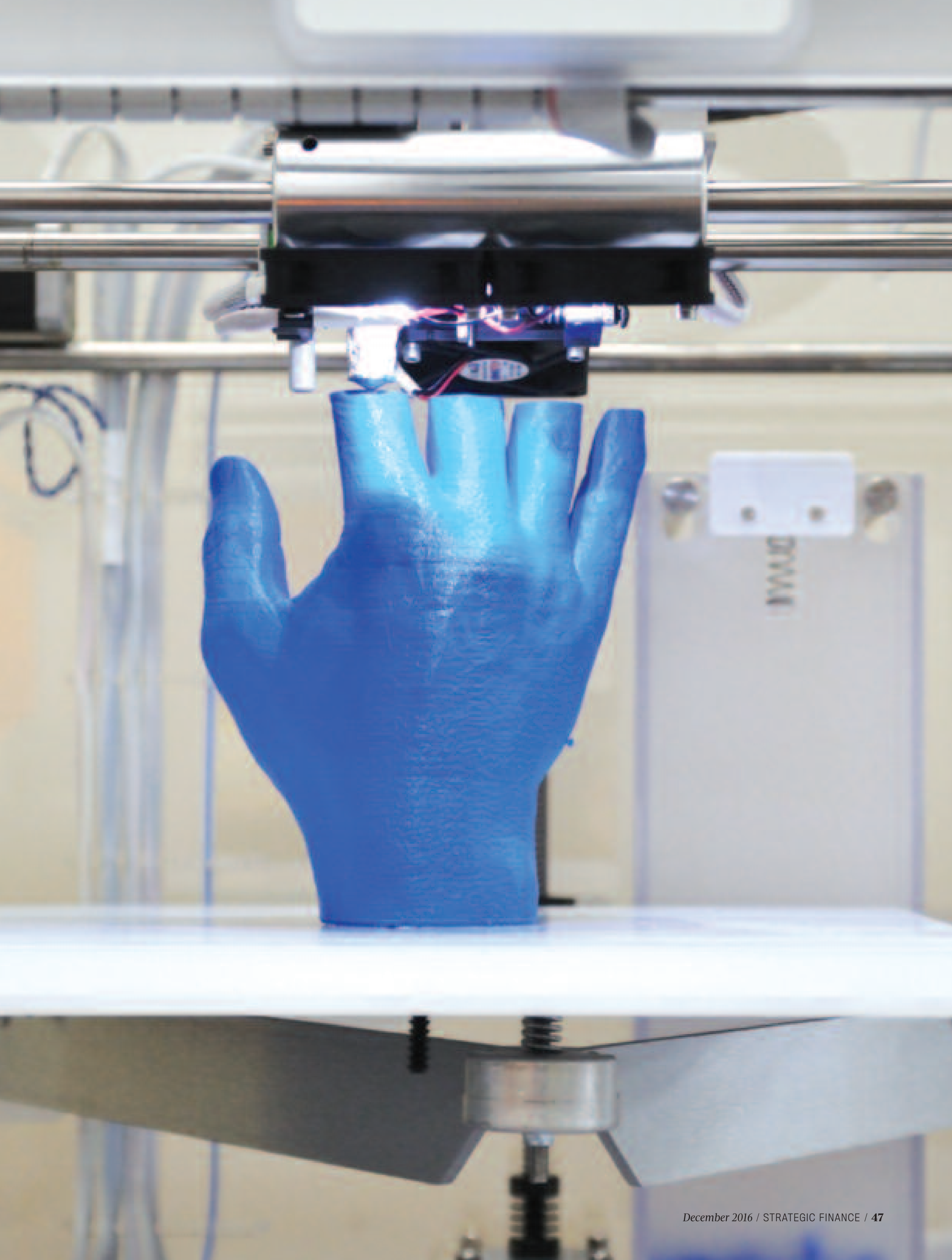


Figure 1:

CURRENT AND FUTURE APPLICATIONS FOR 3D PRINTING

	CURRENT APPLICATIONS	UPCOMING ADVANCEMENTS	FUTURE APPLICATIONS
DEFENSE AND AEROSPACE	■ Aircraft weight reduction ■ Niche, low-volume parts ■ Reduce fuel consumption	■ Applications in space exploration ■ Improve military logistics	■ Printing entire aircraft ■ Printing spare parts on-site ■ Reduce number of warehouse and distribution centers
AUTOMOTIVE	■ Design and prototyping ■ After-market spare parts	■ Customized vehicle design and manufacture	■ Vehicles created using 3D parts ■ Reshore more manufacturing to U.S.
MEDICAL	■ Prosthetics, implants ■ Tissue bioprinting ■ Hearing aids	■ Advances in skin bioprinting ■ Pharmaceuticals production	■ Nanoscale medicine ■ Complex organ printing
INDIVIDUAL CONSUMER	■ More opportunities for hobbyists ■ Customized products	■ In-store 3D printing ■ Co-creation with suppliers	■ Increase in home 3D printers ■ Purchase virtual CAD files to make customized products
SUPPLY CHAIN	■ Reduce lead times ■ Reduce inventory levels	■ Reduce supply chain links ■ React faster to customer demands	■ Ship designs instead of products ■ Redesign global logistics
COMMERCIAL	■ Rapid prototyping ■ Low-volume specialty manufacturing	■ Reduce assembly steps ■ Increase of start-up companies using 3D printing	■ Retooling factories ■ Reskilling workers ■ Adding 3D material silos to manufacturing factories

By changing the digital files' configuration, products can be customized to an individual consumer's tastes and preferences. Once created, a blueprint file can be sent anywhere in the world so that the product can be replicated by a 3D printer. In 2015, at Detroit's annual auto show, Phoenix, Ariz.-based Local Motors Company arrived without a car. Instead, representatives created the latest version of their Strati car on-site using a digital file and a 3D printer. Improving lead times for product prototypes, cutting manufacturing and storage costs, and creating innovative products are just a few of the emerging AM applications for both large- and small-scale manufacturing (see Figure 1).

The growth of 3D technology will surely change the way you, as a management accountant, analyze costs in your organization—and those changes are much nearer than you think. But before I talk further about the impact of 3D printing on you and other financial professionals, let's discuss what this new technology offers.

Design and Inventory Benefits

Designing physical models is a critical first step for testing a new product's viability. Iterative design—a methodology based on a cyclical process of prototyping, testing, analyzing, and refining a product or process—benefits from 3D technology. The conventional design process shown in Figure 2 requires expensive, custom-made tooling, jigs, and molds to create each prototype. Problems that occur during this process can result in costly delays and multiple prototype revisions before a design is approved.

In contrast, 3D printers reduce tooling time and expense by generating low-cost, functional prototypes from a digital source. Feedback, testing, and refinement of product performance are accomplished more quickly prior to tooling up for production. Thogus Products, a custom plastics firm based in Avon Lake, Ohio, purchased 3D Fused Deposition Modeling (FDM) printers to design and manufacture specialty parts. The AM processes resulted in significant savings for Thogus in both lead times and production costs (see Table 1).

U.S. federal laws require many manufacturers to supply spare parts for the full product warranty period, and manufacturers or their supply chain partners often continue making spare parts long after warranties expire. In cases like these, maintaining large inventories of replacement parts requires expensive storage facilities and redundant inventory in multiple locations. If an infrequently ordered part is needed, traditional production technologies make it too costly and time-consuming to produce spare parts on demand. The result is a significant amount of slow-moving or obsolete inventory.

By contrast, 3D printing offers a virtual inventory of

Figure 2:

TRADITIONAL DESIGN AND APPROVAL PROCESS FOR A PROTOTYPE

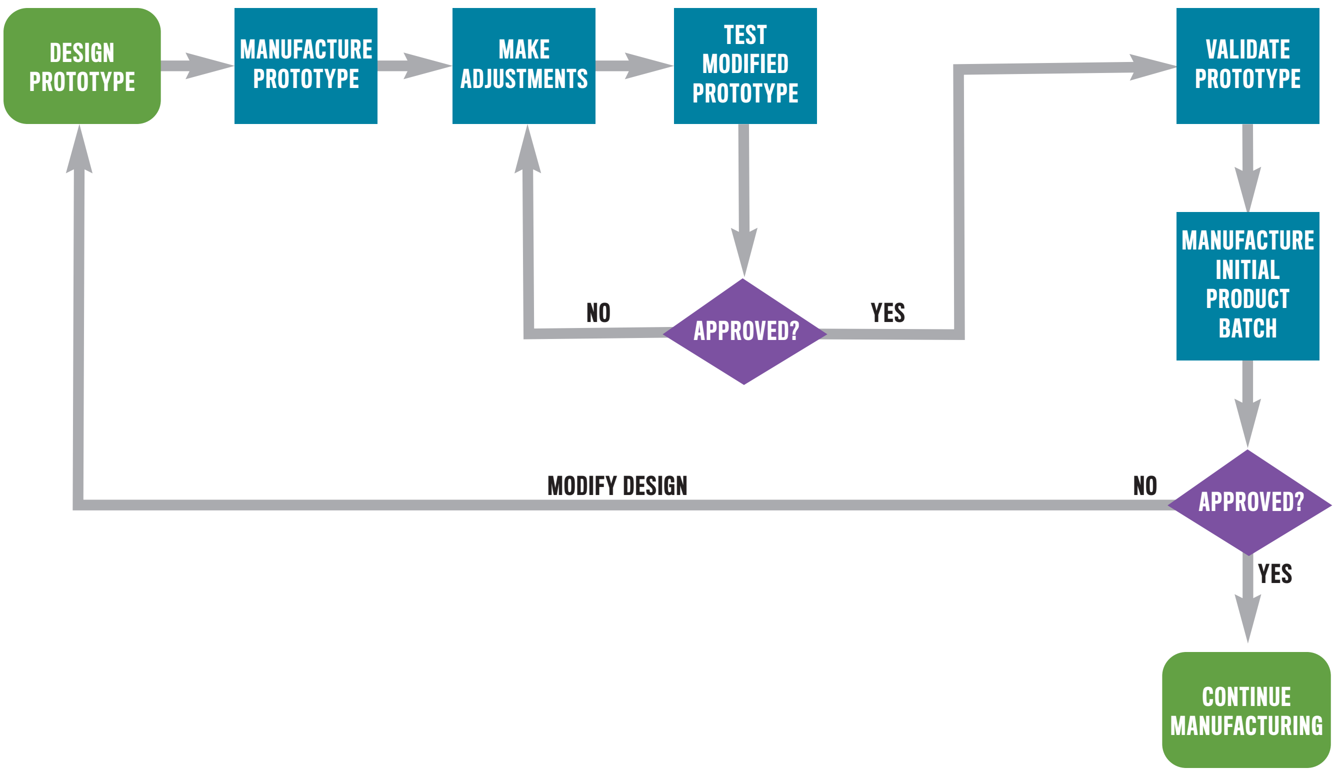


Table 1:

THOGUS PRODUCTS' SAVINGS REALIZED FROM AM

	FDM TECHNOLOGY		ALTERNATIVE METHOD	
PART/TOOL	**COST**	**TIME**	**COST**	**TIME**
End of arm robot	$600	24 hours	$10,000	4 weeks
Automated turntable	$8,800	2 weeks	$50,000	8 weeks
Steel plates	$20	2 hours	$200	2 weeks

Table 2:

OPPORTUNITIES AND CHALLENGES FOR AM INTEGRATION

OPPORTUNITIES	CHALLENGES
Manufacturing parts with complex designs	Intellectual property protections
Reduce prototype and tooling costs	Need to reskill workers
Improve product design	Factory environmental concerns
Increase customization at low cost	Improving supply chains

digital files for each warranty part. As products require repairs, a technician can access the appropriate file and create a new part on demand. Boeing, a leading manufacturer in the aerospace industry, now has more than 20,000 spare parts maintained in digital files that can be printed on demand, whenever and wherever they're needed. Many experts believe that more businesses will replace inventory with digital files and that consumers will one day walk into a store, select a desired repair part, and have a 3D printer produce it in minutes.

As prices for 3D printers decrease and their capabilities increase, more industries are integrating AM into their operations to improve product design, reduce prototype and tooling costs, and increase product customization (see Table 2). Diverse businesses, including aerospace manufacturers, medical research firms, and home-based entrepreneurs, are actively piloting AM technology for low- and medium-volume production and customized products and services.

Impacts on the Supply Chain

Not surprisingly, AM has dramatically improved supply chain logistics. A disruption in any of the links in a traditional supply chain may result in delayed deliveries to distributors, retailers, or both. In contrast, an AM supply chain's fewer links and greater flexibility to build products at the point of consumption reduces vulnerability to risk factors ranging from geopolitical events to natural disasters.

After the initial investment, which, depending on the industry, can be substantial and should be included in any cost analysis, AM can increase production flexibility, reduce transportation costs, and improve the ability to decentralize production. For example, reshoring a portion of manufacturing needs and using 3D printers to manufacture technically complex products can improve time-to-market responsiveness and reduce global transportation costs—which will have a positive impact on business strategy and financial results. The "ACS and Additive Manufacturing" case study shows how Advanced Composite Structures, an aerospace product manufacturer, used AM to solve its tooling and manufacturing challenges, expanding production capabilities while lowering costs and lead times.

3D Printing Takes Flight

Innovation and experimentation are hallmarks of the vast and diverse aerospace industry, which encompasses commercial aircraft, satellites, military defense vehicles (planes/helicopters/drones), rockets, and the International Space Station. In a never-ending search for lighter and more durable components, industry leaders such as Boeing, General Electric, and Lock-

FAST FACTS

$5.1 billion

Value of the AM/3D printing industry in 2015

25.9%

The industry's one-year compound annual growth rate (CAGR)

278,000

Number of desktop 3D printers (valued at under $5,000) sold worldwide last year

62

In 2015, the number of companies that sold industrial-grade AM systems valued at more than $5,000

31

The number of companies in 2011 that sold such systems

Source: Wohlers Associates, Inc., *Wohlers Report 2016*

Local Motors is developing a line of road-ready 3D-printed cars.

CASE STUDY:
ACS AND ADDITIVE MANUFACTURING

Advanced Composite Structures (ACS), a Florida-based company, repairs helicopter rotor blades and produces specialized composite parts for the aerospace industry. Both services require specialized tooling. On the repair side, the company usually uses a mold with a contoured surface to guide the repair. It creates most production components by applying composite laminate strips onto layup tools. Many jobs also require fixtures to locate secondary operations, such as drilling.

In the past, ACS produced layup tools, drill fixtures, and consumable core patterns on computer numerical control (CNC) machines. The company typically paid a machine shop about $2,000 to produce a metal composite mold, with lead times of approximately 45 days. If tooling design problems arose, ACS incurred substantial added expenses and project delays while the tooling was repaired or rebuilt from scratch.

More recently, ACS has switched to producing nearly all of its tools using a 3D Fortus Fused Deposition Modeling (FDM) machine. The FDM technology uses an additive manufacturing (AM) process that builds plastic parts layer by layer using data from computer-aided design (CAD) files. An FDM-created layup tool costs only about $400 and takes as little as a day to produce. The low cost and short lead time allow ACS to easily reconstruct tools that are found to have problems on the manufacturing floor.

For example, ACS recently produced a camera mount used to install a forward-looking infrared camera on a military aircraft. The FDM machine built the layup tool directly from a CAD drawing. ACS also used FDM-built tooling to fabricate a capsule component for a remotely piloted vehicle. In each case, the FDM method offered substantial time and cost savings (see Table 3).

"Tools produced with FDM cost only about 20% as much as CNC-produced tooling," says Bruce Anning, owner of ACS. "FDM tooling can be produced in as little as a single day compared to several weeks for CNC tooling. For the repairs and short-volume production work that we specialize in, tooling often constitutes a major portion of the overall cost. Moving from traditional methods to producing composite tooling with FDM has helped us substantially improve our competitive position."

ACS adopted AM and now uses it for nearly all of its composite tooling needs. On average, 3D-printed layup tools save thousands of dollars and weeks of production time over traditional methods, leaving room for last-minute corrections or changes.

Few technology advances in recent years have had the impact on manufacturing or have attracted as much attention as AM. As possibilities become reality with this technology, industry leaders will continue to use AM to manufacture parts and components with complex geometries impossible to produce through traditional manufacturing techniques.

Table 3:
WHAT ACS SAVES BY USING AM

METHOD	COST	LEAD TIME
CNC Machining	$2,000	45 Days
FDM Technology	$412	2 Days
Net Savings	$1,588 (79%)	43 Days

heed Martin are already integrating AM technologies to improve their manufacturing productivity and reduce costs. In fact, 3D printing technology is ideally suited to the aerospace industry, which requires small-scale manufacturing of specialized parts—engine and turbine components, for example—that have complex geometries and defined aerodynamic properties. Components can now be manufactured more quickly and cost effectively, combining high strength with significant weight reductions (averaging 40% to 60%) to shrink fuel consumption, material costs, and carbon dioxide emissions. Previous efforts to reduce the weight of an aircraft and gain fuel efficiency reduced costs but resulted in structural weaknesses.

With 3D printers, aircraft component prototypes can be developed for even the most challenging geometries in a matter of hours, rather than weeks, and design changes for new parts can be created more quickly for testing.

Combining parts, reducing waste, and increasing the number of 3D-printed inventory parts also are areas of significant savings. For example, GE used AM to consolidate 18 separate parts into a single jet engine fuel nozzle. Lockheed Martin reduced material waste by using a 3D printer to make a specialty bracket from titanium, and the U.S. Air Force has created two high-strength 3D-printed molds as a means to cut holes for replacement air-duct brackets. It's estimated that the Air Force will save $541,000 a year in time and costs from this single application.

As these examples illustrate, the aerospace industry is a true driver for state-of-the-art engineering and reliable manufacturing technologies. Since aerospace is one of the earliest adopters of carbon fiber and one of the first industries to integrate CAD into its designs, there's little doubt that trends in aerospace will be adopted across all manufacturing industries in the years to come.

Computer-generated Skin?

Medical applications of 3D technology have advanced improvements in healthcare as well. In an area where design innovation saves lives, specialized biocompatible materials have allowed 3D printers to create customized hearing aids, implants, and prosthetics. Advances in bioprinting—the 3D printing of biological tissue and organs through the layering of living cells—have the potential to help patients waiting for organ donations and to replace lost tissue from injuries and diseases.

The failure of tissue and organs is an especially critical issue in healthcare. Although still in its infancy, 3D bioprinting offers important advantages to traditional regenerative tissue methods. The Wake Forest Institute for Regenerative Medicine is working toward applying regenerative medicine to battlefield injuries and has developed a custom-designed 3D printer to print ear, bone, and muscle structures, which it is planning to implant into patients. The Institute is also developing a process to attach bioprinted skin directly onto the wounds of burn victims, thereby reducing the need for painful skin graft surgeries.

In addition, the chronic shortage of human organs available for transplant has resulted in long wait lists. Currently, more than 120,000 people in the United States alone are awaiting an organ transplant, according to the nonprofit American Transplant Foundation. This problem could be reduced by using cells from the organ transplant patient's own body to build a replacement organ, which would minimize the risk of tissue rejection and the need to take lifelong immunosuppressant drugs. Last year, Organovo, based in San Diego, Calif., successfully bioprinted a human liver tissue model that remained fully functional and stable for more than 40 days. Although no one has yet successfully printed an organ, the research and testing from pioneering companies like Organovo are promising.

Implants and prostheses are another area where 3D printing holds great promise. These can be made in nearly any imaginable geometry by translating x-ray, MRI, or CT scans into digital 3D print files. The ability to quickly produce custom implants and prostheses solves a clear and persistent problem in orthopedics, where standard implants often aren't sufficient for some patients, particularly in complex cases. For example, a research team in Belgium successfully implanted the first 3D-printed titanium jaw prosthesis. The company that created the technology, 3D Systems (known then as LayerWise), manufactures 3D-printed titanium orthopedic, maxillofacial, and spinal implants, as well as an anatomically correct prosthetic ear capable of detecting electromagnetic frequencies.

3D printing is expected to play an important role in the trend toward personalized medicine. As such, researchers will continue to review existing medical applications and explore new ones. The medical advances achieved to date using 3D printing are significant, but some of the more revolutionary applications, such as complex organ printing, will need more time to evolve.

CLOSER THAN WE THINK

My interest in 3D technology started back in the late 1970s with 3D light-based holograms. Since then I spent more than 20 years in the fiber optic and semiconductor industries watching these technologies evolve. Interestingly, both industries are similar to or are used in 3D printing technology. Computer chip fabrication is very similar to additive manufacturing as layers of different materials are deposited on wafers until the chips are complete. Nanolithography is based on thermal polymers, and if 3D printers could be made to deposit nanoparticle ink on a wafer surface, furnaces and other wafer processes could be eliminated. Optics are also used to create 3D-printed objects. A concentrated light beam draws the object design so that successive layers of material can be deposited to create the finished product.

It has been exciting to work with client entrepreneurs who are adapting 3D technology into their CAD and product designs. New internet-based collaborative service companies are helping my clients to both optimize and create new product ideas. At present, I'm assisting a group of technology companies to form 3D research partnerships and utilize 3D technology for new product development. By next year I hope to publish a case study on their accomplishments.

3D printers are creating innovations that were scoffed at as science fiction only a few decades ago. As I mentioned earlier, TV shows like *Star Trek* featured amazing devices and a vision of what life would be like in the 23rd and 24th centuries. I won't hold my breath that a transporter beam will be invented in my lifetime, but 3D printer technology provides an example of how the future is closer than we think.

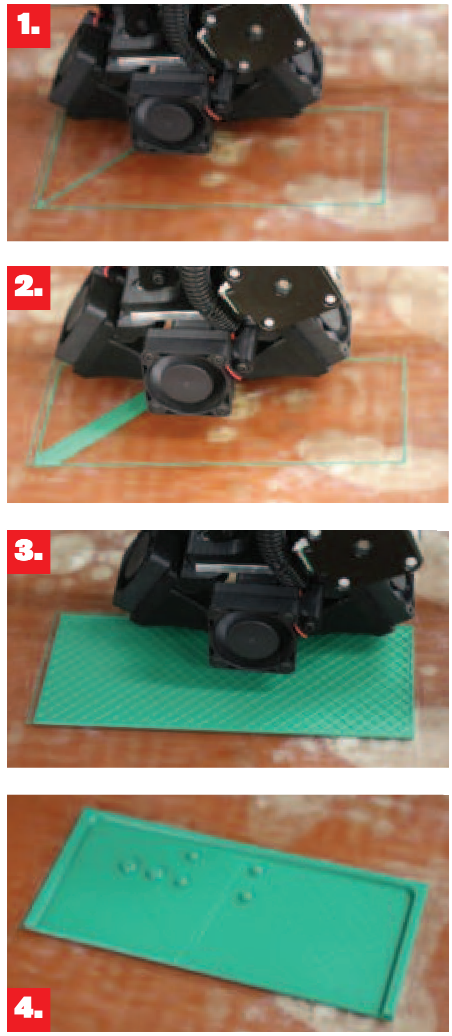
HOW 3D PRINTING WORKS

Conventional printers translate 2D or 3D images into millions of bytes (characters) and then use an electronic circuit inside the printer to print the image onto paper. In contrast, a 3D printer uses additive processes to create a solid 3D object from a digital file.

1. A 3D printer focuses a beam of ultraviolet light onto the surface of liquid material to draw the design or shape of the object.
2. The resin then solidifies and forms a single layer.
3. The process is repeated until
4. the 3D object is complete.

The first stereolithography 3D printer was invented by Charles Hull in 1983. Older printers were limited to using various polymers to make prototypes. Newer printers can simultaneously print and fuse together both flexible and rigid materials in a variety of colors.

Today, 3D printers can create everything from aerospace parts to food products. As 3D printers become faster and create more complex, multimaterial objects, we can expect this technology to expand beyond niche products and services into mainstream manufacturing.



Photos courtesy of the TyRex Group

Coming to a Store Near You

By now you might be wondering: Aren't 3D printing applications solely reserved for large- and medium-scale manufacturing plants? Not at all. Major retailers such as Staples, Home Depot, and UPS have added 3D printing services in select stores for both small-business owners and consumers. Meanwhile, Amazon and eBay have added 3D product "stores" to their websites, and Walmart already offers about a dozen affordable 3D printers on its website. Several models sell for less than $1,000.

The increasing availability of low-cost 3D printers has provided individual entrepreneurs the means to quickly bring their design ideas to market with low production costs and more creative and customized packaging options. Jewelry, hats, shoes, clothing, and art are just a few of the consumer items that have already been printed. Websites such as Thingiverse, Shapeways, and Pinshape enable users to make, share, and customize printable objects and promote creative collaboration. The rapid growth in sales of inexpensive 3D printers will also allow consumers to purchase digital files, add customized features, and then print the products at home.

Years ago, the internet helped small businesses and individuals enter global markets by lowering entry barriers. Now, digital fabrication designs coupled with low capital investments will enable a new generation of entrepreneurs to reach a vastly expanded marketplace and replace the age-old mantra of "Design by Manufacture" with "Manufacture to Design."

Benefits—but Challenges, Too

Given the contrasting cost advantages between AM and traditional manufacturing, many analysts believe a hybrid model will emerge in the short term that will combine the two processes. Although AM allows the manufacture of highly customized, complex parts, companies that make standardized parts in high volumes may not see any cost advantages with AM—at least not anytime soon. Rather, AM will complement existing traditional processes and provide sophisticated solutions by combining complex shapes, reducing new product lead times, and consolidating tooling requirements.

As Table 2 makes clear, both benefits and challenges will arise as commercial AM processes advance from occasional to routine use. Intellectual property rights, worker displacement, environmental concerns, and supply chain disruptions are among the challenges that will arise along the manufacturing continuum. As a result, each company should perform a risk assessment before adding an AM environment to its business.

The proliferation of digitized information has eroded the delicate balance between sharing information and protecting intellectual property (IP) rights. Already plagued by digital piracy and counterfeit products, IP owners are becoming increasingly aware of the potential for widespread infringements that their existing monitoring practices can't detect or control. The impact of this is bound to be costly. With the rise—and anonymity—of 3D printing services and home 3D printers, annual IP losses could exceed $100 billion by 2018, according to Gartner, an information technology (IT) research and advisory firm. (See "Gartner Says Uses of 3D Printing Will Ignite Major Debate on Ethics and Regulation" at http://gtnr.it/2g2zaoP.)

Controversial websites on Pirate Bay and the dark web function as Napster-like platforms that enable users to easily upload and share scanned images of protected designs. These websites have already created 3D printable files called "physibles" for sharing and trading across the global digital black market. As 3D printing becomes more sophisticated and as home 3D printers become more ubiquitous, organizations will need to find new ways to prevent unlawful duplication of their IP-protected objects and designs.

The effects of AM on the workforce must be considered as well. While AM will create many jobs—just as transformative technologies have done in the past—a recent report by the World Economic Forum predicts that the Fourth Industrial Revolution, characterized by the rise of AM, will result in more than five million jobs being eliminated (about seven million lost and two million gained) by the year 2020 among 15 of the world's largest economies. (See *The Future of Jobs* at http://bit.ly/2f8E8kU.)

How can we reduce that number? The workforce will require greater skills in the areas of computing, mathematics, robotics, and engineering. A new kind of human capital will be needed to create future generations of educated, resilient, and flexible workers, blending with reskilled workers and IT functions within an organization.

But the current technological revolution need not become a race between humans and machines. Instead, it's an opportunity for businesses to help workers develop new skills by investing in education and innovation to help them adapt to the new jobs created by AM-related technologies.

Safety First

As more 3D printers and AM processes are integrated into mainstream manufacturing, new safety standards must go beyond the requirements of a traditional metal machine factory. The National Institute of Standards and Technology (NIST) has done extensive research on implementing AM systems and has issued several specific safety protocols covering the handling of metal powders, static electricity prevention, and flammability risks.

Management accountants will need to assist in projecting the costs of safety when implementing an AM platform. For instance, long-sleeved lab coats, goggles, and rubber gloves are sufficient protection to avoid eye and skin irritations for low-reactive metal powders. In contrast, workers who handle high-reactive metal powders (i.e., aluminum or titanium alloys), must wear fire-resistant clothing and respiratory protection. Antistatic footwear should be worn at all times, and each machine needs a grounded antistatic floor mat to prevent fire from static electricity. Finally, because metal powders are flammable—especially aluminum powders—class D fire extinguishers are required near any AM operation.

In addition to providing protective clothing, companies will have to change their environmental, health, and safety (EHS) requirements and train their employees on how to handle additive manufacturing materials. With proper planning, safety assessments, continuous on-site training, and regular inspections, AM capabilities can be implemented easily and safely.

An Enhanced Business Model

AM technologies, especially 3D printing systems, can offer companies strong value and a competitive advantage. By improving their responsiveness to changes in manufacturing requirements, suppliers and collaborators will undoubtedly reshape and strengthen the future supply chain landscape.

Like other emerging technologies, AM is still in its infancy. Its potential applications will affect a broad spectrum of industries and services and will increase the flexibility of companies to reconfigure tooling and products in response to changing consumer demands. AM will also provide the framework to improve existing business models and to encourage new business opportunities through its focus on waste reduction, customization, and faster product availability.

As 3D printing technology increases the ability for organizations like yours to replicate or create objects on demand, AM may forever change our concept of commerce as we know it today. The crew of the starship Enterprise would be impressed. **SF**

Reina G. Wiatt, CMA, CPA, is the president of Wiatt Consulting Services, LLC and a member of IMA's Austin Area Chapter. You can reach her at **trwiatt@swbell.net**.