Suite Deals

Rapid prototyping, additive manufacturing, and the design software they require are rapidly reshaping product development

By Pat Toensmeier

Rapid prototyping is synonymous with additive manufacturing. The digital process, also known as 3D printing, is especially valuable because it inverts the economics of product development by generating rapid design iterations at a greatly reduced upfront cost than conventional solid-modeling methods since it requires no molds or dies. With its ability to eliminate parts through the use of complex geometries and change designs on-the-fly, additive manufacturing (AM) is reshaping the process and economics of product design and—importantly—has the potential to do the same for part production.

AM has been around for decades, mostly as a research and prototype tool. Its growing influence on mainstream design and manufacturing, along with advances in the software suites that developers create and ongoing technology gains in processing and materials (including metal and ceramic), is significant enough that analysts forecast major growth for the process. One consultant, Knowledge Sourcing Intelligence, reports that the equipment side of the market in 2017 generated sales of $5.9 billion in the U.S. The company predicts a compound annual growth rate of 30.2 percent between 2018 and 2022, when U.S. equipment sales will total $22.2 billion.

Significantly, AM is a cornerstone of the emerging “digital factory,” in which automation, artificial intelligence, and powerful cloud-based computing systems will drive product design and manufacturing.

Experts say the digital factory with all its connectivity and technologies will in the future allow rapid product development and thus faster time to market, customiza-

Siemens researcher Christoph Kiener examines the prototype of a burner tip for power plants that’s 3D-printed from an undisclosed polymer. The part, created by generative design, is built in layers with interwoven vanes for heat dissipation, much like a natural organism. Courtesy of Siemens
tion of products based on end-user needs, and on-demand manufacturing services. Capital requirements for product development and manufacturing will be less than in conventional factories and, with fewer low-skilled workers due to the high level of automation that will exist, production economies will swing in favor of local companies and away from low-labor-cost vendors offshore.

**Complex Shapes Are No Problem**

Driving the growth of AM in the evolving digital environment of design and manufacturing are a new generation of complex and powerful software suites that maximize the benefits of the process for prototyping and, increasingly, serial production.

Software developers are adopting design capabilities that will make extensive use of algorithms, artificial intelligence, and eventually deep neural networks to optimize part shapes, reduce material use and weight, and precisely distribute mechanical properties according to application needs. In many cases, these software programs will maximize AM’s ability to produce parts in complex geometries that render unorthodox but extremely functional designs.

“Because additive manufacturing can create crazy organic shapes, it is making design professionals smarter and more agile in product development,” says Rani Richardson, director of Catia technical sales and lightweight engineering at Dassault Systèmes. “Instead of geometry driving part function, the function dictates part geometry.”

Complex shapes, in fact, have no downside in AM design or production. “A 3D printer takes no more time, energy, or material to fabricate a complex shape than it does to fabricate a simple shape—and it may even take less time to make an intricate lattice than it does to make a solid block of the same dimensions,” writes Jon Bruner, director of The Digital Factory at Formlabs, and his colleague Balázs Kisgergely, in a report about the company’s Digital Factory conference in 2017.

Formlabs builds printers, develops software, and supplies materials for AM. It hosted Digital Factory conferences in 2017 and 2018 at which experts discussed technologies and innovations in design and manufacturing. (Bruner says a third conference is planned in 2019, with details to come at the conference website https://digitalfactory.xyz/.)

New AM software is also addressing the economics of serial production. The cost curve rises in AM once a design is qualified because, unlike most fabrication processes, polymer or otherwise, it is not yet an affordable manufacturing option for high-volume output—i.e., production runs of more than a few hundred or a few thousand parts. Among the problems: its complex geometries cannot be reproduced in mainstream processes like injection molding; cycle times are slow due to the layer-by-layer part build; and serial manufacturing requires the use of multiple printing machines to achieve relatively low volumes (thousands or tens of thousands of parts) in a timely manner.

Until recently, most industrial-scale printers have also been expensive, costing well into the hundreds of thou-

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*The Formlabs “ecosystem” for desktop printing includes design software, Form 2 printer, and a part-finishing stand. (Inset) The ability of AM to achieve complex geometries is evident in this “beehive” printed on a Form 2 benchtop stereolithography printer from Formlabs.*

Photos courtesy of Formlabs
sands of dollars per unit and occasionally more than $1 million, an investment that limits their use to large companies. This is changing as vendors unveil desktop and benchtop industrial 3D printers that cost around $10,000 and sometimes less. Formlabs, for example, recently introduced Fuse 1, a selective laser sintering benchtop printer, with a starting price of $9,999.

Most industries accept the tradeoffs of high equipment costs and low throughput because the design freedom and material reduction possible with AM, coupled with low-volume demand for specialty parts, suit the process for product development and manufacturing. Notable examples include custom components for aerospace and medical which do not demand high production volumes.

AM’s potential in manufacturing—and thus its value to the digital factory—is growing as developers add features to design software. Foremost among these features is advanced computational capabilities that will, among other benefits, allow generative design, a relatively new approach to product development that uses algorithms and artificial intelligence to rapidly compute hundreds and even thousands of designs for review according to an outcome-based series of performance requirements.

**The Computer as Designer**

Conventional software is based on explicit design, where a developer enters the specs of a proposed part that he or she has in mind for an application and, using analysis tools in the software, comes up with a finished product that often closely resembles the original concept.

Generative design, in contrast, works with a list of performance requirements entered by a product developer and calculates what type of design, materials, and other features work best in a product. The designs generated by the software may resemble what a designer or engineer had in mind, but are often radically different in appearance, as the software calculations optimize shapes, dimensions, and distribution of material for application needs.

How rapidly can these designs be generated? Brian Frank, senior product manager for generative design and simulative offerings at Autodesk, notes that one customer who tested the company’s new generative design software said it produced 300 designs worth evaluating in just one day. With conventional design software, the customer said it could take three months for engineers to develop five to 10 designs worth evaluating.

Since a report published in 2016 by *UX Magazine* stated
that 90 percent of conventional product development has a chance of not being financially successful, it makes sense to increase the chances for success by generating more designs to analyze.

This thought is echoed by Tom Chi, co-founder of Google X and founder and emeritus partner of Prototype Thinking. Chi says trying as few as 20 different approaches in product development can increase the chance of success to 64 percent from 5 percent, while experimenting with 50 different approaches raises the chance of success to 92 percent. “It’s almost like you can’t fail,” he adds.

Autodesk is one of only a few software developers to offer generative design—at least right now. It released a cloud-based generative capability for commercial subscribers of its Fusion 360 software on Oct. 7. The capability derives from the company’s experimental Dreamcatcher project, which began five years ago.

One influence on the emergence of generative design software is what former Autodesk chief executive officer Carl Bass terms “infinite computing.” Speaking in 2017 at Formlabs’ Digital Factory Conference in Cambridge, Mass., Bass said infinite computing reflects “the idea that the cost of computing is going to zero.” With designers consequently having access to “as much computing power as [they] want on demand,” the question he posed to attendees was “how would [they] design and engineer things differently?”

Bass noted that in conventional design, “We’ve treated computing as though it were precious, or scarce, and we use as little as possible.” If, however, ongoing technology advances mean that designers have access to all the computing power they need, why not “specify the outcomes instead of the inputs,” as with generative design, “and see if the computer can do it.”

Another supplier of generative design software is Catia. Richardson says the developer has offered it for two years and feedback is positive. “Studies show that designers see as much as 70 percent weight savings when using generative design in part development compared with an average 30 percent reduction with conventional software,” she notes. “Additive manufacturing and generative design are very compatible. The average designer would probably never think of most shapes that the computer is able to make.”

The technology is indeed promising, though experts admit it will require a learning curve and a change in attitude among designers.

“Generative design is a paradigm shift,” says Brian Frank, senior product line manager for generative design and simulative offerings at Autodesk. “We have 30 years of history with conventional modeling software, where designers input their ideas for part design. With generative design we are asking them to document the problems they want to solve and let the software develop solutions.”

Initial experiences with generative design could be frustrating, Frank concedes. Because the software responds exactly to the design parameters that are entered, application challenges that are omitted or overlooked will not be factored into calculations. Any data left out of initial calculations, though, can be added later. Software with artificial intelligence, moreover, will have self-learning capabilities that may automatically compensate for missing data. Once designers and engineers get the hang of generative design, entering full and complete lists of product needs will not be daunting, Frank says.

Importantly, generative design software will address one pressing development need—time. “Engineering teams are under increasing pressure to fine-tune solutions,” Frank remarks. “Few have time to do so, and a lot of design decisions represent quick judgments. Generative design will
empower engineers to explore many designs and the solutions they represent and make informed decisions about which ones work best.”

Some software developers believe the capability will eventually enable efficient, lightweight, and economical multi-component systems design. “Generative design will expand to more than a standalone part,” says Paul Sagar, vice president of product management for CAD (computer-aided design) at PTC and lead on the company’s Creo software team. “Generative design is a little way from the mainstream,” he notes, but when it becomes an integral part of software, “systems design will become a new linkage.”

Optimizing Material Use
In the meantime, most new and updated software programs offer an effective alternative to generative design in topology optimization, which, when paired with CAD and finite element analysis, is becoming a mainstay of many software suites.

The technique mathematically optimizes material distribution in a part to achieve specified loading and boundary conditions. In doing so, writes Aboma Gebisa, a mechanical and structural engineering and materials research fellow at the University of Stavanger in Norway, topology optimization provides a shape and surface that is more natural and complex for application properties than would otherwise be the case.

Topology optimization has been in use for decades. But as Gebisa notes in a conference paper he presented in 2017, it took AM to fully realize the potential of this capability.

This is because conventional manufacturing processes, as noted, cannot produce overly complex shapes. No such barriers exist in AM. As a result, “topology optimization and additive manufacturing are considered [an] ideal couple,” he says.

The effective distribution of material—metal and ceramic as well as polymer—throughout an AM shape with topology optimization yields significant weight-reduction potential in parts. Examples cited by Gebisa in his paper, “A Case Study on Topology Optimized Design for Additive Manufacturing,” include an industrial bracket, which in a redesign lost 40 percent of its original weight (to 42 grams compared with 70 grams), and a steel node for a tensegrity structure whose weight was reduced by 75 percent (to 5 kg from 20 kg).

One notable analysis presented by Gebisa involves a titanium alloy jet engine bracket that was developed by GE Aviation. When redesigned with topology optimization for AM production, engineers were able to reduce part weight by 65 percent, to 0.72 kg from 2.067 kg.

Among the developers that include topology optimization in software is PTC. Sagar says that versions 3, 4, and 5 of Creo software have each been enhanced with a range of AM capabilities, among them topology optimization. PTC is looking at generative design software, as well, he adds, and may include it in future offerings. For now, the next update of Creo software, version 6, should be available in March.

As the per-part cost of AM drops, more products will be marketed. Formlabs developed a system of printing custom ear molds that are used to cast silicone audio earbuds. Courtesy of Formlabs

This array of printed parts shows the potential of AM for diverse applications. Courtesy of Formlabs
or April 2019, and will offer even more AM capabilities.

Siemens NX Additive Manufacturing suite, meanwhile, combines topology optimization with CAD, CAM, and CAE analysis and simulation tools.

A key benefit, says Andreas Saar, vice president and lead for the additive manufacturing program, is that all of these capabilities are available in one data model. “There is no need to switch applications,” he remarks.

The software is “highly automated, but flexible,” notes Aaron Frankel, senior director of marketing for digital manufacturing software. “We tailor its capabilities for the designer and make it easy to learn.”

The topology optimization tool is CAE-based, says Saar. Parts can be displayed in faceted as well as precision geometric models with the use of conversion modeling. Designers and engineers are able to manipulate data as necessary to accommodate the addition of features like holes or threading.

One capability that Siemens offers is HEEDS, a multi-objective optimization tool that permits the analysis of designs based on performance requirements rather than physical parameters—a capability similar to the concept behind generative design.

Using HEEDS (which is not an acronym but a tradename), a designer inputs desired performance data for a part, rather than beginning development the conventional way, with a design concept. HEEDS will analyze the data and conduct simulations to determine how different designs and materials perform in a part. Siemens says this allows users to compare the performance of potential designs and learn, among other findings, which ones provide desirable levels of performance, are most cost-effective in design and

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**Flexible bottles are among the consumer products that could be produced by AM.**

Courtesy of Formlabs

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One benefit of this is the ability to discover design options that not only improve part performance but speed development and reduce manufacturing investment.

**Mainstreaming Production**

All of these capabilities point toward a major goal: “We want to industrialize additive manufacturing,” says Saar. This involves getting designers and engineers to think in terms of AM when they begin the product-development process.

“We’re seeing a shift in the use of additive manufacturing from mostly prototyping to production, and in some cases serial production,” says Frankel. To move the process into the manufacturing mainstream, developers will need to drive a rapid evolution of software tools for AM, and not only on the front end of design. He sees a need for software that checks a part in such production areas as printability, stability in the build envelope, elimination of contaminants in the form of unprocessed powders, and other concerns that affect printing throughput and quality.

“The interesting question is how additive manufacturing and its technologies will drive design,” says Saar. He sees the potential for new types of AM processes to emerge, notably the use of multiple materials in printing, a technique that is beginning to appear with colored polymer powders, and which could soon involve plastics and even polymer/metal and polymer/ceramic hybrids that finetune part properties.

AM is slow when compared with conventional processes like injection molding, thermoforming, extrusion, and other formative procedures. However, Saar and Frankel note that some high-volume product industries are experimenting with AM technologies that could profitably and expeditiously yield production runs of 100,000 or even 500,000 parts. Both decline to identify the companies working in such areas, though they note automotive parts could be one beneficiary of such a major breakthrough.

“The limit [to AM production] is not even close yet,” says Saar. “The speed and quality of the process will improve.”

As the 2017 Digital Factory conference report from Formlabs notes, AM as a manufacturing option only makes sense for high-value, low-volume, highly customized parts. The economics of 3D printing are, however, improving. Bruner and Kiesegely write, “and the cost-per-part threshold is [dropping],” making “it practical to use the technology in incrementally lower-value, high-volume applications.”

Future manufacturing applications for AM could include orthotics, athletic shoes with custom-printed insoles, and even general-purpose plastics parts. At least two shoe companies, Adidas and New Balance, are looking at on-demand printing of customer-sized insoles of rigid polyurethane for athletic shoes.

Formlabs developed a process in which AM is an intermediate step in the production of low-cost custom earbuds that are made to measure for each user. After a customer’s ear canal is digitally scanned in-store, the measurements are transmitted in a file for 3D printing. The resulting hollow mold is used to cast the earbuds, which are made of biocompatible silicone with a lacquer coating.

**Conclusion**

Rapid prototyping and its inextricable link to additive manufacturing and to all of the groundbreaking potential the process offers for product development, is driving the creation of increasingly advanced design software.

The capabilities of these software suites will increase with the growing technological sophistication and outsized impact on plastics and hybrid materials of an important new process category: digital manufacturing. Providing designers and engineers with the ability, through software, to tap such powerful capabilities as generative design, artificial intelligence, and deep neural computing networks will reshape the process and outcome of part development. The result will be products for diverse applications that can be continually, economically, and rapidly upgradable as necessary to enhance their appeal and performance.

AM and rapid prototyping attract deep interest from diverse users. They are such assets to design and product development that they will eventually compel breakthroughs in manufacturing technology that make 3D printing a viable and mainstream option for serial production, and a formative rival to conventional process methods.

**ABOUT THE AUTHOR**

Pat Toensmeier is a Hamden, Conn.-based freelance writer and reporter with more than 30 years of business journalism experience, much of it with Modern Plastics and Aviation Week. Over the years he has specialized in writing about manufacturing, plastics and chemicals, technology development and applications, defense, and other technical topics.
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