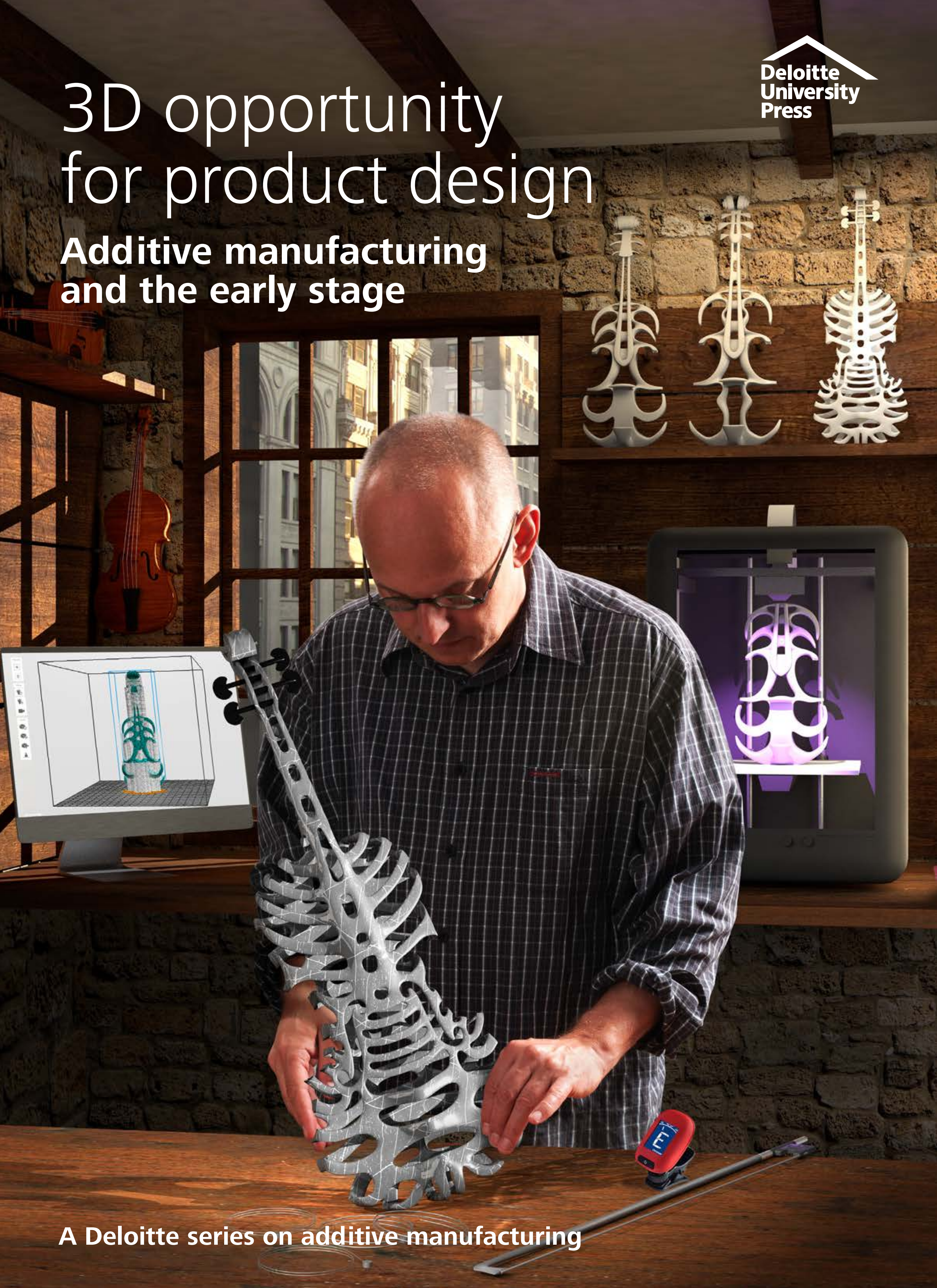
3D opportunity for product design

Additive manufacturing and the early stage

Deloitte University Press



A Deloitte series on additive manufacturing

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Deloitte Consulting LLP's Supply Chain and Manufacturing Operations practice helps companies understand and address opportunities to apply advanced manufacturing technologies to impact their businesses' performance, innovation, and growth. Our insights into additive manufacturing allow us to help organizations reassess their people, process, technology, and innovation strategies in light of this emerging set of technologies. Contact the authors for more information, or read more about our alliance with 3D Systems and our 3D Printing Discovery Center on www.deloitte.com.

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Introduction

IN many ways, Detroit's 2015 North American International Auto Show was the same as it is every year. Giants of the automobile industry filled a formidable convention center with futuristic concept cars, sports cars, and luxury sedans. Droves of gawking consumers and reporters, in turn, huddled around the latest fruits of assembly lines that have been evolving and expanding since the early days of the Industrial Revolution.

But this year, Phoenix-based Local Motors showed up to the world's biggest auto show without a car. Instead, representatives took their place among the paragons of automobile design and proceeded to print—yes, print—the latest version of their Strati, the world's first 3D-printed car.[1] Founded in 2007, Local Motors set out to reinvent the process of designing and manufacturing a car, crowdsourcing design and technology, and establishing "microfactories" to bring forth the final products. The company is using additive manufacturing (AM) to replace the economies of scale that can stymie the commercialization of new products with economies of scope that can help get products to market faster and cheaper—and test and launch new ideas as quickly as designers can draw them up.[2]

Many analysts tout AM's potential to influence the ways companies can produce and deliver products to customers (figure 1). AM already touches a myriad of industries—including aerospace and defense, automotive, consumer products, industrial products, medical devices, and architecture—and the market size for AM systems and support

AM is an important technological innovation that helps manufacturers break existing performance tradeoffs in two fundamental ways. First, AM helps reduces the capital involved in achieving economies of scale. Second, it can increase flexibility and reduce the capital needed to achieve scope.

Capital versus scale: AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the barriers to entry for manufacturing in a given location.

Capital versus scope: The flexibility of AM can facilitate an increase in the variety of products a unit of capital can produce, reducing the costs typically associated with production changeovers and customization and/or the overall amount of necessary capital.

Changing the capital-versus-scale relationship has the potential to influence product designs and help improve the ways supply chains are configured. These impacts can enable companies to choose between four tactical paths to deploy AM across their businesses:

Path I: Companies do not radically alter their supply chains or products, but they may explore AM technologies to help improve value delivery for current products within existing supply chains.

Path II: Companies take advantage of scale economics offered by AM to help transform supply chains for the products they offer.

Path III: Companies take advantage of the scope economics offered by AM technologies to enable new levels of performance in the products they offer.

Path IV: Companies alter supply chains as well as products in pursuit of new business models.

products/services ballooned by 35 percent to an estimated $3.1 billion in 2013.[3] But no discussion of AM's role in a value chain can be complete without an understanding of how these technologies can enhance the ways manufacturers and designers develop their offerings, in everything from strengthening weak supply chain links to fabricating near-instant prototypes. A closer look at the product development and design (PDD) process reveals several avenues for manufacturers trying to improve performance, innovation, and growth to leverage AM.

Figure 1. Framework for understanding AM paths and potential value

Graphic: Deloitte University Press | DUPress.com

PDD and the AM framework

BECAUSE the design and development process typically has such a pervasive impact on the products a company offers, its fit within the AM framework is a nuanced one, offering value that potentially stretches across all four paths.[4] Taking a structured approach to thinking about how AM fits within the business, however, can help to contextualize these nuances and identify the impact of AM in various activities and paths to value. More broadly, the technology's twofold impact encompasses rapid prototyping (RP) and the more emergent concept of digitally optimal design (DOD).

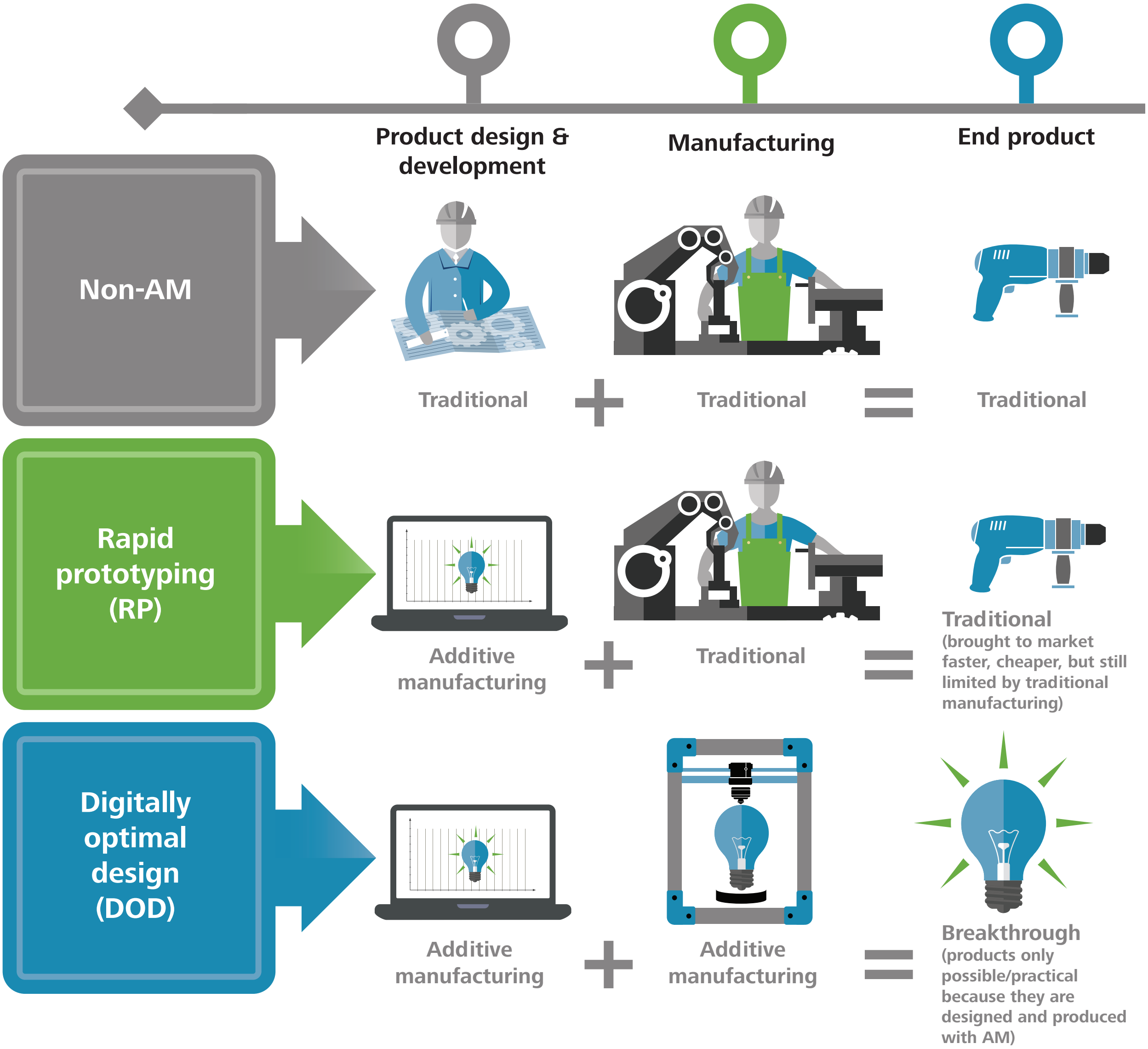
Throughout a large portion of its 30-year history, AM was almost entirely used in **rapid prototyping** applications.[5] Indeed, such was the close association between AM and rapid prototyping over the past three decades that the two terms were often used interchangeably—notwithstanding that they are not strictly synonymous.[6] Rapid prototyping remains an important use of AM; however, in more recent years, AM has found applications throughout the value chain. Today, RP can accelerate the development process while reducing costs by using 3D printing to create prototypes—without necessarily considering how final-part production might incorporate the technology.

Digitally optimal design, in contrast, takes final-part production very much into account: During the design phase, organizations would purposefully develop products intended for end use on AM systems. DOD can enable totally new products and features that take advantage of the AM process's capabilities. Furthermore, DOD enables transformative changes to existing product development and design processes, such as the ability to easily and cheaply redesign products and the ability to use nontraditional sources of design information, including 3D scanning. While DOD adoption is still nascent, some industry researchers are already hailing its potential competitive impacts: In 2014, Gartner stated, "Design reuse, faster product launch and introduction, better aftermarket services, improved product quality, and greater consistency between contract manufacturers all indicate [the] high competitive value" of AM in manufacturing operations.[7]

During the design phase, organizations would purposefully develop products intended for end use on AM systems.

Figure 2 illustrates the differences between traditional PDD, RP, and DOD. For traditional PDD and RP, essentially the same product ultimately reaches the marketplace. The difference is that, with RP, companies tend to be able to deliver new products faster and cheaper, thanks to AM's ability to create new design alternatives with less investment in setup, tooling, and machine changeover. The DOD alternative illustrates the use of AM in production as well as within PDD. This use in production opens up entirely new avenues for the PDD process, enabling the delivery of components

Figure 2. Comparison of non-AM, RP, and DOD product design and development processes



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that may have been previously impossible or impractical to produce using traditional manufacturing and design methods.[8]

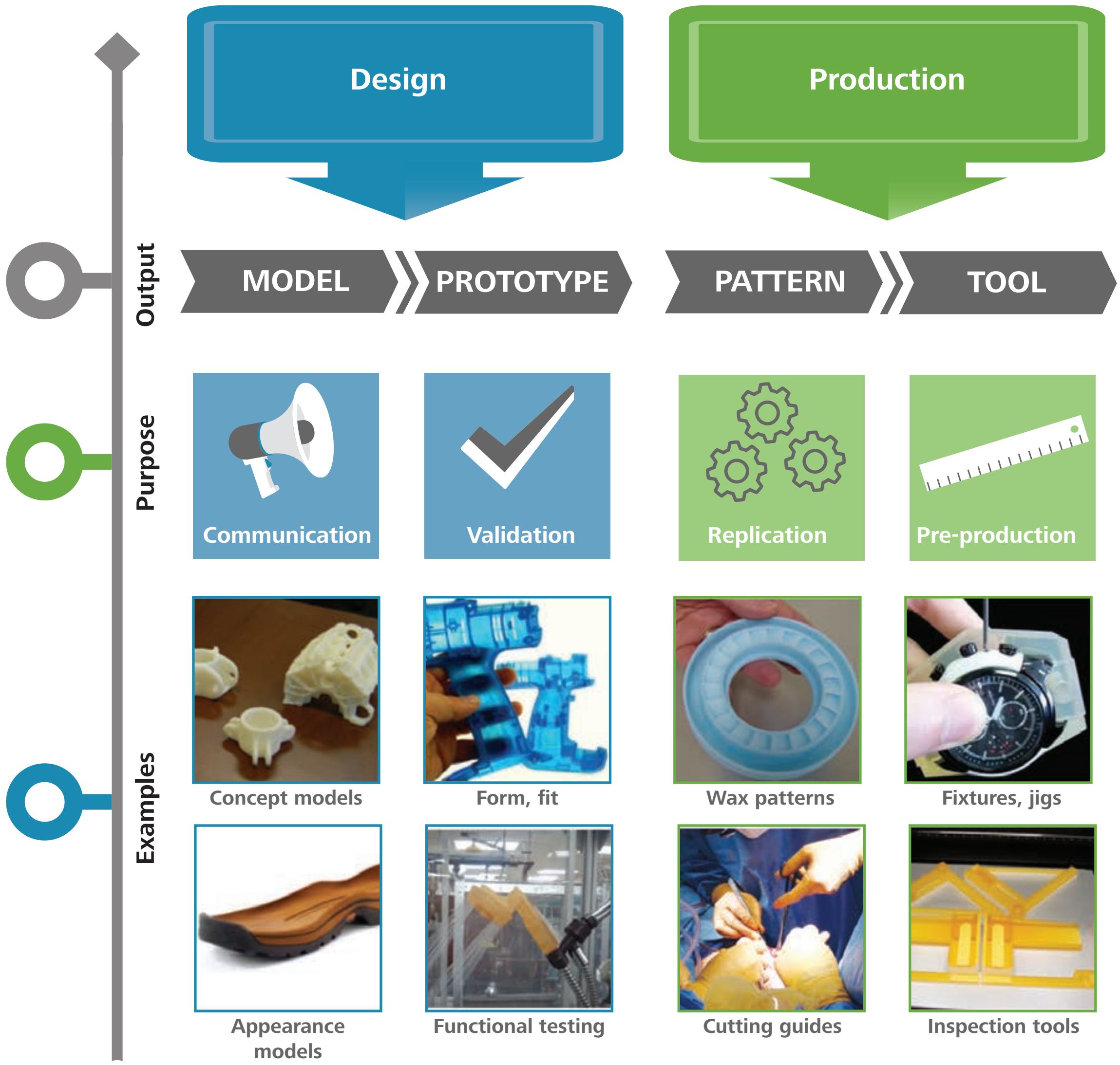
Rapid prototyping is located within the "stasis" (i.e., path I) quadrant of Deloitte's AM framework. This is not to suggest that RP cannot offer benefits in other quadrants but, rather, that the overall impact of RP will not necessarily revolutionize the end products or the manner in which they are delivered.

DOD, on the other hand, represents a less straightforward application, since the ability to manufacture what was previously impractical or impossible suggests that design, too, can strive for what was once impractical or impossible. AM designers can now design for performance with less regard for traditional limitations of design for assembly or manufacturing.[9] This new design frontier may be one of the AM movement's most exciting elements, because it opens up routes to the "product enhancement" and "business model evolution" quadrants of Deloitte's framework.[10]

AM in designing and prototyping for traditional manufacturing

AS noted above, product design has predominantly used AM to communicate and design products that are produced using traditional manufacturing methods, an application that falls firmly in the "stasis" (path I) quadrant. Figure 3 identifies four ways

Figure 3. Rapid prototyping can produce AM outputs for four distinct purposes



Images provided courtesy of 3D Systems (NYSE: DDD). Used with permission.

Graphic: Deloitte University Press | DUPress.com in which 3D printing can be used to support traditional manufacturing through both the design and production stages. The bulk of AM sales, including both machines and services, has traditionally been driven by design and communication needs in support of traditional manufacturing; however, part creation through AM increased to 28 percent of end-use applications in 2013, continuing AM's trend toward production use.[11] Despite AM's growing production prowess, the design and prototyping markets still offer considerable space to grow in the coming years: One analyst projects that the prototyping/prosumer/education penetration rate, currently 9 to 23 percent, will rise to 29 to 76 percent in 2017.[12]

Early adopters of AM for design in support of traditional manufacturing were mostly automotive and aerospace companies, and these early adopters remain invested in the technology. Nearly three years ago, for instance, Ford began putting a 3D printer on every engineer's desk, making the technology integral to R&D efforts.[13] However, AM's usage in PDD has now gone far beyond traditional manufacturing giants. As Autodesk technology futurist Jordan Brandt recently explained regarding shifts in design, "The hardware, software, and materials are all combining. It's hard to differentiate between them now. To innovate in one, you have to innovative in all three."[14] Further adoption of AM technology in this capacity appears inevitable as investment costs decline and as more companies recognize the numerous potential benefits of incorporating 3D printing in the design process.

Compared to other methods, AM can offer several benefits in creating prototypes and models, bolstering a product's value by increasing the efficiency and effectiveness of the design process. These benefits generally arise in three areas:

Compared to other methods, AM can offer several benefits in creating prototypes and models, bolstering a product's value by increasing the efficiency and effectiveness of the design process.

- Saving time in the development cycle
- Reducing costs in the development cycle
- Enhancing the final product's quality and design

The first two benefits highlight AM's advantages over many conventional methods of creating prototypes and models. (Unsurprisingly, there is a strong connection between time spent and money spent in the development process, but for the purposes of this article, we are classifying each as a stand-alone benefit.)

The third benefit tends to be more difficult to quantify, but it originates from the fact that AM enables companies to iterate more prototypes within a pre-existing budget; this can lead to more testing, which likely yields better product designs. Additionally, AM helps make it easier to conquer the typical distance between designers and product stakeholders (customers, manufacturers, packaging, etc.), as users can send prototypes as CAD files to be printed elsewhere.

Saving time

Typically, using AM in the design process can save time in three ways: by dramatically shrinking the time between design creation and prototype, by reducing the effort and schedule impact caused by iterative design work, and/or by increasing organizational alignment to accelerate decision making.

First, AM can largely eliminate delays in waiting for prototypes. Traditionally, creating prototypes involves custom tooling, coordination with external suppliers, and multiple handoffs that could invite miscommunication and introduce risk. By allowing a designer to print directly from a digital file, early-stage prototype creation can become a fast and effective part of the development process.

AM can also substantially reduce rework effort, since delays caused by multiple design iterations—each starting the process over—typically waste a substantial amount of time. Removing the need for tooling changes and incorporating seamless prototype creation enables rapid design iterations with little incremental impact.

Finally, incorporating 3D printing into the design process not only enables technical validation, but can also accelerate alignment within the broader organization on a new design—a key success factor often overlooked toward the end of a design process. Using AM can allow engineers to explain and demonstrate a new design to a variety of geographically dispersed stakeholders—complete with physical models—even at remote sites.

AM has helped multiple companies save time in the design process. For example, Turbine Technologies (a US-based manufacturer of educational laboratory equipment) integrated MultiJet printing into its prototyping process to help reduce the effort and schedule impacts on PDD processes, long reliant on complex, investment-grade wax prototype casting. In particular, Turbine Technologies was able to print turbine wax mold patterns in 18 hours as a single component, in contrast to its 170-hour traditional multi-tool process requiring 170 hours. The company was able to directly translate these time gains into competitive advantage and, as a result, landed a key defense contract.[15] AM rapid prototyping can also save time by accelerating decision making. One athletic apparel company, for example, has been able to streamline its product evaluation process from four to six weeks to just one to two days.[16]

Reducing costs

In addition to streamlining schedules, using AM in the design process can drive substantial cost savings through insourcing, inexpensive prototypes, and reduced change orders.

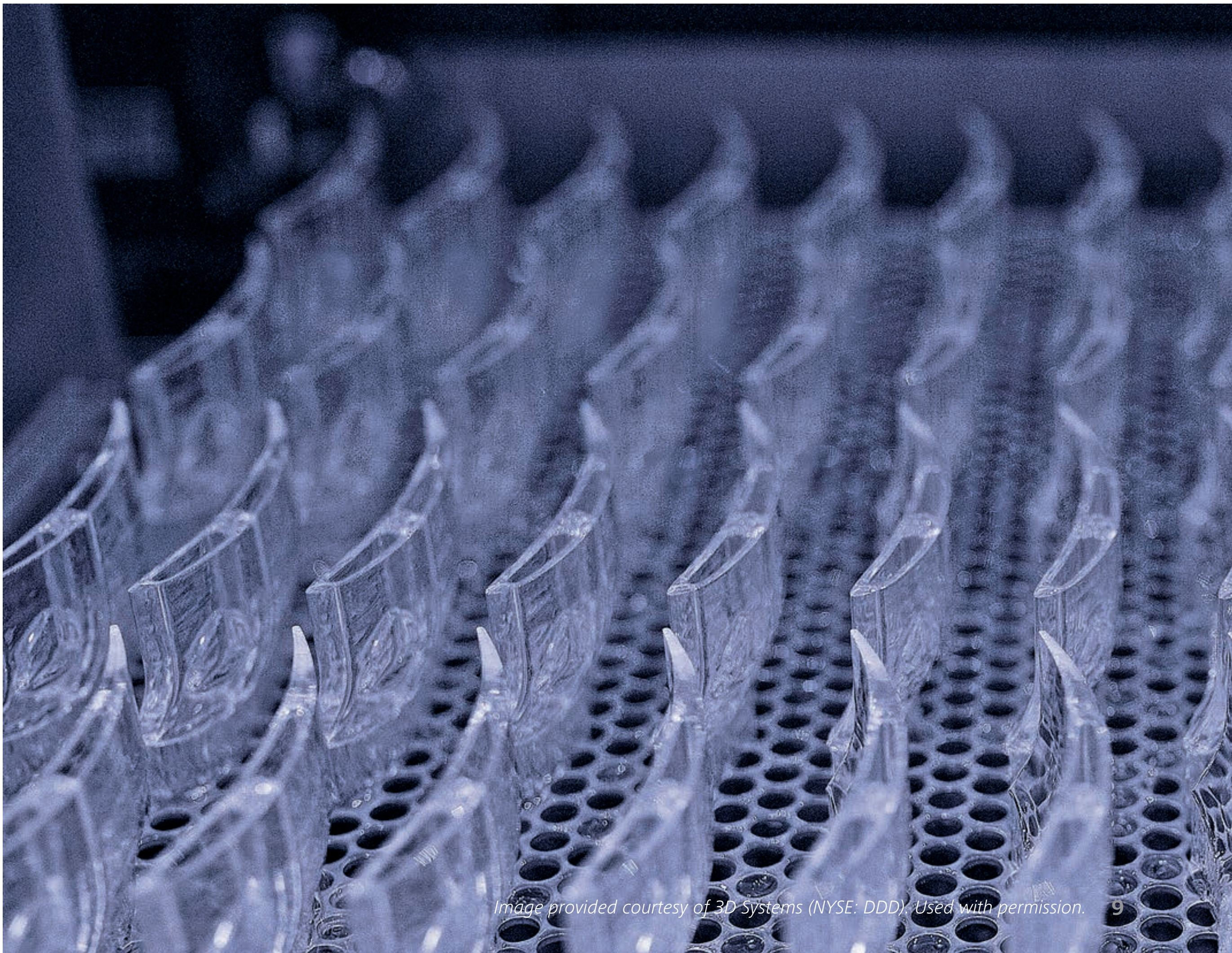
Insourcing the creation of prototypes through AM can offer direct cost savings that go beyond the cost of material for a model. The development time required to prepare for traditional manufacturing methods (including creating manufacturing prints and layouts, programming CNC machines, and designing tooling) can largely be eliminated, as can the need to communicate and coordinate with an external design shop when the designer can print a prototype in-house. For example, when one NASCAR race team adopted fused deposition modeling (an AM technology) to produce prototype parts for wind-tunnel testing, the team was able to slash testing costs by 89 percent and reduce development time by two-thirds.[17] In addition, AM can dramatically reduce a prototype's total material cost, as elimination of scrap and lack of tooling creation often offsets the higher per-volume costs of raw materials.

Enhancing quality and design

Aside from accelerating the design process, additive manufacturing can lead to better designs, helping to develop products with enhanced quality, performance, and manufacturability. Faster prototyping typically means that a team can go through more design and review cycles during the development phase. Furthermore, AM's ability to help reduce barriers to testing concepts can cultivate an increase in designers' entrepreneurial behavior—they can, for example, proactively share printed pre-prototype models to gauge market acceptance for consumer products, experiment with more radical designs with little risk, and test more frequently so they can avoid negatively impacting the more conservative design progression.

AM can also bring forth better products by helping designers to engage with a range of stakeholders inside and outside the company—and with each other. Printed models, as opposed to images, are self-contained, concretely defined, and more universally understandable as physical objects. Models may help stakeholders to align on concepts and design earlier in the product development process, while customers can be more involved in design and even co-create. Proper Group International, for example, prints models to identify potential issues in design submissions from its automotive customers.[18]

Finally, a company can incorporate AM's enhanced ability to address errors and add improvements without needing to invest time and money in changing tooling. As a result, companies can more rapidly respond to market and customer demands, fix design flaws, and counter competitive evolution.[19]



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Designing and prototyping for full AM production

MOST manufacturers are only beginning to realize AM's full potential as a source of operational freedom that can liberate design as well as final production. Replacing traditional manufacturing with AM introduces wide-ranging design freedom by reducing some constraints typically imposed by concerns for manufacturability and assembly. Returning to figure 1, some companies are leaving the "stasis" quadrant and reaping two fundamental benefits of AM-enabled DOD: simplified manufacturing and reduced design constraints.

Simplified manufacturing

AM-enabled DOD can deliver production capabilities that reduce some of the constraints typically associated with traditional manufacturing methods.

Improved part characteristics: AM can reduce the incremental cost of increasing a design's geometric complexity, allowing designers to incorporate elements including complex curvatures, nonstandard and varying wall thickness, and low-density volumetric filling. Sometimes, the difference is dramatic: For example, GE's LEAP engine uses a printed nozzle that is 66 percent lighter and approximately five times more durable than current nozzles.[20] Likewise, Airbus prints hinges for jet-engine covers that weigh half as much as traditionally tooled hinges.[21] In the automotive world, Lightning Motorcycle is developing a better swing arm for its electric vehicle. Lightning's original swing arm, which attaches the motorcycle's rear wheel to the frame, was a heavy chunk of milled aluminum pipe; an optimized version of the part couples additively manufactured plastic with aluminum ends to save weight as well as material.[22]

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Mass customization: Perhaps most applicable to consumer-facing businesses, mass customization enables each customer to receive a version of a product created exclusively for him or her. For example, Disney and other retailers are using AM to create premium-priced vanity avatars.[23] Some medical and dental device companies are also using AM to tailor products to individual customer specifications, as is home improvement retailer Home Depot.[24]

Decreased system complexity: 3D printing can help reduce complexity and enhance quality by printing systems as single parts rather than individual components that would require assembly. Boeing used to produce more than 20 distinct parts for each environmental control system duct, which then required additional tooling and welding. Now, the company manufactures these ducts in a single piece, thus eliminating the need for entire assembly lines while enhancing quality and reducing inspections, inventory, and maintenance—not to mention time and material waste.[25]

> Most manufacturers are only beginning to realize AM's full potential as a source of operational freedom that can liberate design as well as final production.

Nontraditional sources of design information: As product designs become increasingly digitized, the potential opportunities and risks of reverse engineering become more prevalent. For example, through 3D scanning, the Smithsonian is creating full-scale 3D prints of unique historical pieces so people can print the artifacts at home or enjoy copies at local libraries and museums.[26] Scanning can also present opportunities for customization at the point of use—for instance, to provide custom repair patches for military vehicles damaged in the field.[27] But along with these demonstrated benefits, digital design information can increase the importance of IP management and protection.

Reduced design constraints

Designing for AM can help reduce the constraints that traditional manufacturing methods impose on scale and scope. An organization can usefully reexamine virtually every production consideration for design.

Production location: With AM, design and manufacturing can be performed virtually anywhere, so companies can dramatically reduce the logistics, cost, and complexity of moving products from manufacturing locations to end users. Even self-design—using a distributed structure for all aspects of product development through manufacturing—becomes possible.

Tooling constraints: Product design may no longer be constrained by mold and tooling requirements. Incremental changes result from relaxing traditional design standards, but AM can help make revolutionary designs possible.

Batch size: A truly single-unit minimum batch size allows on-the-spot production of short-run components as users wear them down in the field or imagine ways to customize them.

Waste: Material waste tends to become less of a concern as designers and manufacturers find ways to complete tasks with less material and energy, and as AM components replace tooled parts.

On the other hand . . .

WHILE 3D printing is expanding the frontiers of product design, this newfound freedom introduces significant challenges. In this emerging manufacturing paradigm, companies should revisit three questions and their potential implications:

> AM technology is contributing to a decrease in the experience and training requirements for designers, thus opening the field to automation as well as to entry by nonprofessionals.

Who designs? AM can introduce an apparent paradox regarding designers' responsibilities and capabilities: The levels of experience and expertise needed to design a product are simultaneously increasing and decreasing.

The need for increasing expertise is driven in part by the proliferation of viable design options and the implications for product functionality and value delivery. As the ability to manufacture becomes increasingly commoditized, many designers are finding themselves generating a higher portion of created value relative to manufacturing. As a result, good design is generally becoming more valuable. For example, designers at one industrial bakery took advantage of the freedom offered by AM to create a new manifold design that increased production yield beyond conventional process limitations.[28]

At the same time, AM technology is contributing to a decrease in the experience and training requirements for designers, thus opening the field to automation as well as to entry by nonprofessionals. As faster and cheaper prototyping enables iterative design and testing, companies may become less reliant on expertise that gets it right the first time. In one case, two people with no formal aeronautical design training used a highly iterative AM-based process to develop a functional UAV airframe.[29] Open design competitions and self-directed design work are creating opportunities for hobbyists to supplement in-house product development groups; indeed, embracing such potential sources for ideas may prompt companies to reconsider the role of design in a product development process.

Likewise, in particular applications, scanning and electronic data sources can automatically generate custom product designs with minimal input from design professionals. This possibility is already apparent in medical devices, where custom-formed hearing-aid inserts are automatically designed for production based on 3D imaging.[30] As 3D scanning technology advances to keep pace with AM output possibilities, automated design approaches will likely fall within reach for many industries, often necessitating a fundamentally changed design process.

Even as AM technology lowers the barriers to entry for designers in terms of experience and training, companies incorporating AM capabilities should adjust their organizational skill sets. Gartner's 2014 *Hype Cycle for Leaders of Manufacturing Strategies* forecasts:

> *As more advanced manufacturing techniques become mainstream, the skill sets for managing smart machines or 3D printing will start to differ from current job descriptions. Traditional organizational boundaries between IT, line of business, and business functions need to be shed for seamless collaboration.*[31]

In line with Gartner's assessment, Wanted Analytics has tracked rising demand for candidates with AM experience, reporting in September 2014 that the number of job ads requiring workers with AM skills had risen 1,834 percent in four years and doubled in just the previous 12 months. In August 2014, 35 percent of all ads posted for engineering jobs mentioned AM skills.[32]

A final note regarding "who designs" pertains to the emergence of greater crowd participation in general product design and development. The widely heralded arrival of crowdsourcing is influencing diverse areas—product development among them.[33] For example, public input is creeping into Quirky's product design and development processes: The company solicits ideas from an open community of digital members and opens the review process to include both Quirky employees and the wider community. For the winners, Quirky takes over the logistics, supply chain, and manufacturing—but defers to the crowd on product naming, branding, and pricing.

While the Quirky process does not yet directly involve AM processes in end-part production, the company uses AM to rapidly produce prototypes of proposed products from

Image provided courtesy of 3D Systems (NYSE: DDD). Used with permission.

its Manhattan headquarters.[34] Additionally, AM is part of the wider ecosystem of "maker" elements that helps empower and excite a community of amateur designers to participate in Quirky ventures.

How do designers design? Product design principles for AM generally lack the consensus enjoyed by "design for cost" and "design for manufacturing and assembly" principles, and software tools to aid nontraditional design approaches are not yet mature.[35]

Because AM can help reduce the cost of testing a product design, information on what works can emerge more quickly than in traditional consensus-based manufacturing practices. For example, an unexpected application of biomimetic structures—using structures from the natural world to enhance product designs—is the creation of artificial shark skin using AM to improve low-drag fluid conduits and nautical vehicle surfaces developed using conventional manufacturing capabilities.[36]

As software tools evolve to support AM, they will also likely have an impact on how manufacturers execute designs. The major CAD/CAM drafting software packages used in design for traditional manufacturing have not yet incorporated a wide set of AM-compatible features.[37] Smaller niche software vendors are developing new approaches, including algorithms to design complex repeated structures (e.g., organic honeycomb filling) based on stiffness parameters, support for generating free-form organic shapes that do not conform to current design standards, and structural analysis methods for assessing the strength and stiffness of non-homogeneous solid models.[38]

How do designers determine economic viability? AM technology can complicate the economics of product design and manufacturing, prompting a broader consideration of costs.[39] In assessing product costs, it is insufficient to merely compare the cost of traditional manufacturing and AM. An appropriate assessment should also account for a new design's enhanced functionality—for example, fuel savings from lighter aerospace components can outweigh higher per-part costs. For manufacturers, capital assets and required working capital are easily observable, but economic viability analyses should also quantify the value of eliminating manufacturing constraints on scale and scope.

Attempts to quantify supply chain economics should also account for the value of flexibility, responsiveness, and risk management. Some automakers, for example, are currently investigating mass customization as a tactic to compete with low-cost producers.[40] Military hospitals often see the value of responsiveness to unpredictable demand, with time-sensitive patient outcomes and inconsistent access to supplies.[41] Finally, the value of risk management—for example, reducing line stoppages for short parts—can be assessed only by taking a broader perspective of true economic costs throughout production, not just the cost of creating a part.

Analysts should also consider business model economics when assessing AM's economic viability in a design function or, especially, in a broader role. The value of a new business model is often difficult to determine, but those conversations are critical. Likewise, leaders should consider eroding barriers to entry and unexpected opportunities.

The paradigm of design for digital production

DIRECTIONAL solutions to AM's inherent challenges are introducing a "digitally optimal design" paradigm, with important implications for the future of design and manufacturing.

Design may become more participative, but a core set of highly skilled practitioners will likely emerge. "AM engineers" may emerge as a distinct functional skill set, though inventive amateurs and hobbyists are likely to continuously surprise and push these skilled professionals. As AM technologies help reduce design constraints and kindle new capabilities, many designers in and out of organizations will become increasingly entrepreneurial and experimental.

The decreasing cost of design, prototyping, and testing—and the diminishing need for formal education and certification—can help make these activities increasingly accessible to hobbyists with home 3D printers. As a result, companies can incorporate much higher customer involvement in design, including prototyping and testing, and design customization and modification at the points of production and use will likely become more prevalent. Some dentists are already producing dental crowns at their desks,[42] and some UPS stores are developing the capability to print designs from walk-in customers.[43]

Participative design is also fostering new business models. Google, for example, is launching Project Ara, which allows users to select their own combinations of parts to suit their individual needs and replace and upgrade parts instead of buying new phones. A number of these parts will be 3D-printed.[44]

A stable set of design principles will likely emerge by type of material and method of AM; these principles are expected to evolve alongside AM technologies. Several new design principles are already taking root as leading practices:

Companies can incorporate much higher customer involvement in design, including prototyping and testing, and design customization and modification at the points of production and use will likely become more prevalent.

Companies can seek to capitalize on AM's benefits for product design by considering the following steps:

- Determine which potential benefits of incorporating AM into the design process—saving time in the development cycle, reducing costs in the development cycle, and/or enhancing quality and design of final products—are your greatest priority in the short term, to help create a strategy for effectively implementing AM to accomplish your most critical design objectives.

- Determine which potential benefits of incorporating AM into the production process—simplified manufacturing and/or reduced design constraints—are your greatest priority in the short term, to help create a strategy for effectively implementing AM to accomplish your most critical production objectives.

- Consider which steps of your design and/or production process could be most easily augmented with AM, and where doing so would have the greatest impact.

- Consider your company's current progress in terms of integrating rapid prototyping into the design and development process, if any. If applicable, determine whether it is appreciably improving your delivery cycle—in terms of both costs and speed. Examine any inefficiencies to ascertain where enhancements can be made. If it is not being used, consider where within the design process rapid prototyping might have the greatest impact.

- If you have not made the change to digitally optimal design, review your current design and production processes to determine where—and if—it can fit in (consult figure 3 in this article), and whether it would make sense to do so.

- Analyze the impact that greater integration of AM into design and production processes may have on your talent needs and desired capabilities, to plan ahead for any organizational, training, and talent needs.

- Based on your current position within the AM framework, determine where you would like your organization to go. Doing so can help determine whether rapid prototyping or digitally optimal design is a better fit for you, and help create a roadmap for building the appropriate AM capabilities.

- Redesign parts to take advantage of AM capabilities

- When designing parts, complexity and geometry are generally less expensive than in the past

- Consider novel sources of design inspiration (e.g., biomimicry), and increase your functional objectives: strength, weight, efficiency, etc.

- Look for opportunities to reduce part counts and manufacturing requirements

The economics of AM may come to include products, supply chains, and customer experience. As AM helps reduce the cost of complexity, companies should develop an increasingly holistic view of their customers. And AM's expanded economic scope may encourage companies to capture value from each step in their supply chains.

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