



**If 3D printing has
changed the industries
of tomorrow, how can
your organization
get ready today?**

The trends, sector use cases
and steps to accelerate your 3D
printing journey

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The better the question. The better the answer.
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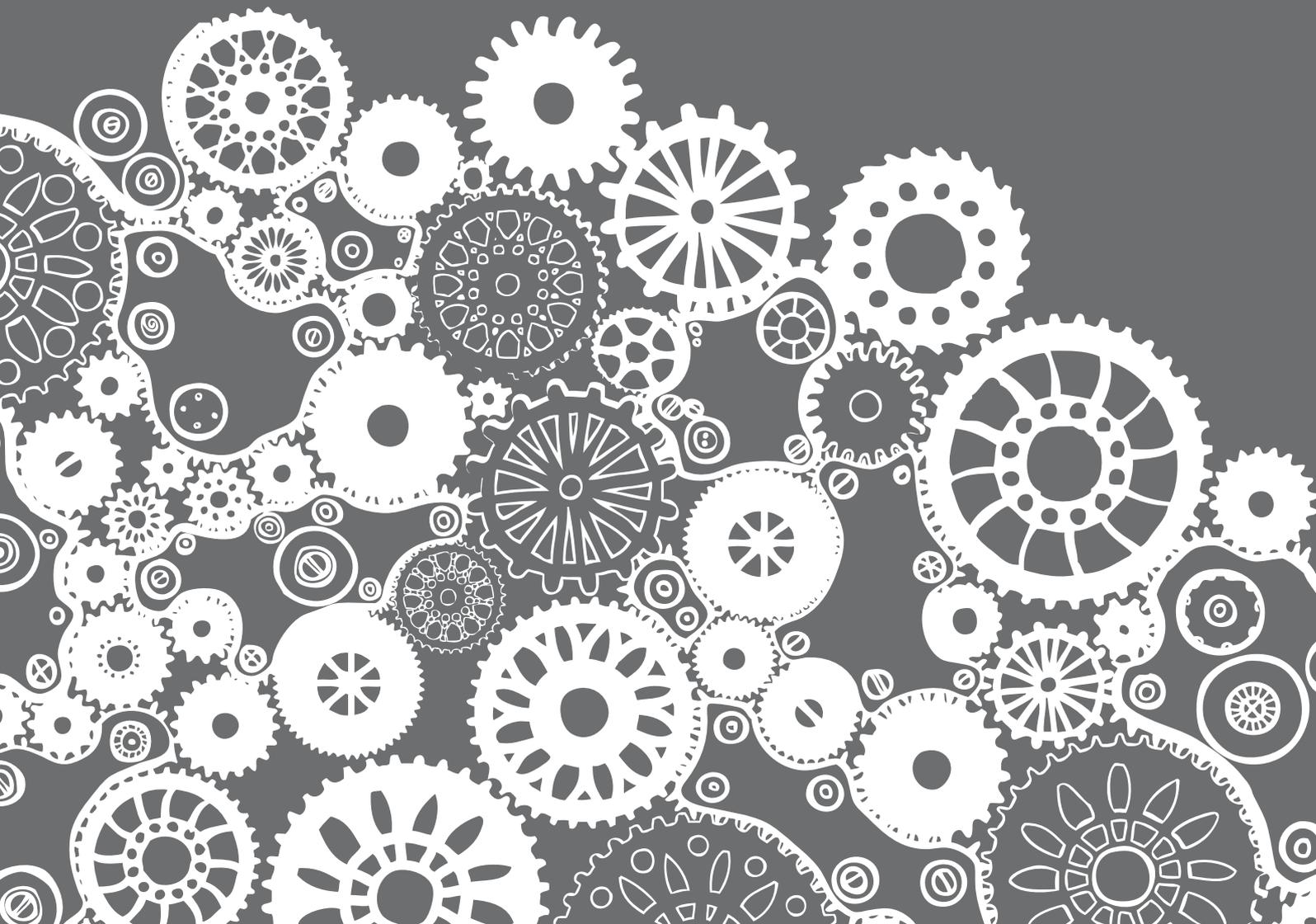
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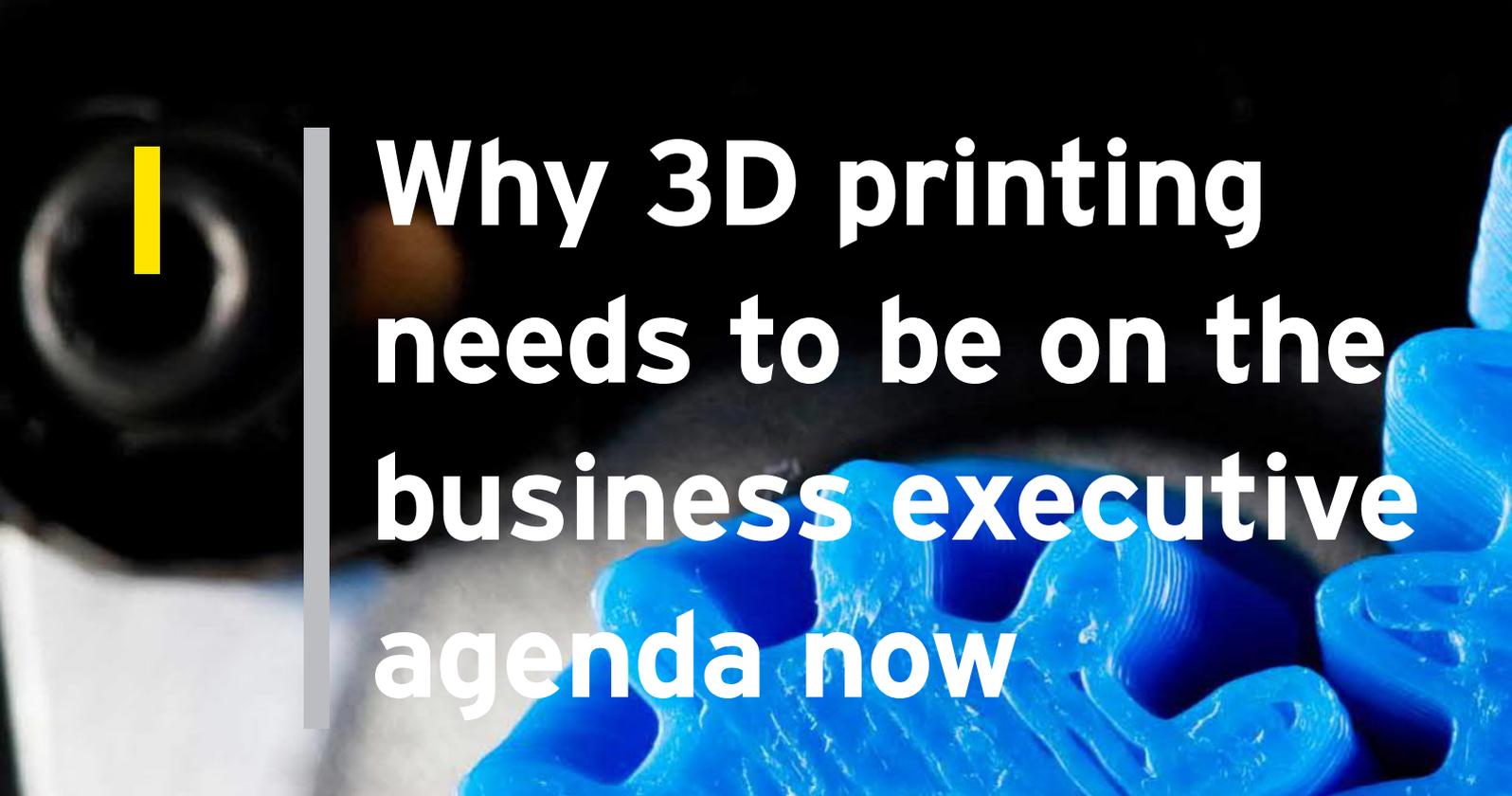
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Why 3D printing needs to be on the business executive agenda now

Additive manufacturing, better known in the market as 3D printing (3DP), has been evolving over the past 30 years. There is growing evidence that the advancements in technology and materials have finally brought it beyond the hype stage. Thirty-six percent of companies are already applying or intend to apply 3DP, according to a recent EY global survey of 900 companies.¹ Aerospace, defense and automotive are the most mature industries in applying 3DP. However, awareness of 3DP and a readiness to leverage it for prototyping, tools, fixtures and even finished products are increasing in other industries, for several reasons:

- ▶ **Quality and speed.** As printer speed has increased, quality assurance tools embedded into printers enable better validation, layer by layer, of whether the printed product is within acceptable tolerances.
- ▶ **Materials availability.** There is now a wide variety of materials and material providers, giving companies more options for producing parts and products. Many manufacturers are collaborating with material suppliers to create their own variations of materials in order to meet their specific requirements or increase quality and throughput.

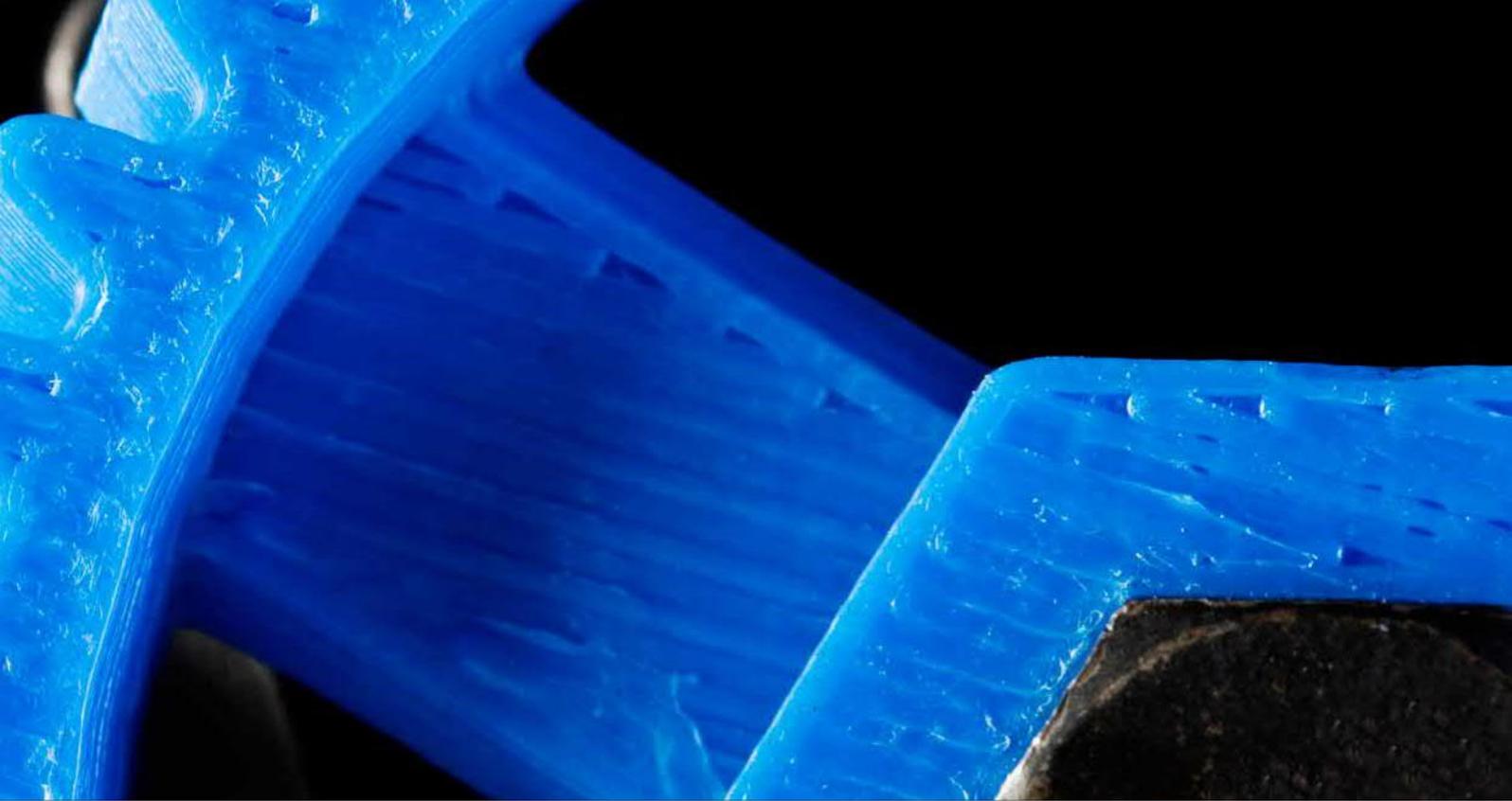
- ▶ **Workforce knowledge.** The newest generation of designers and engineers is more knowledgeable about 3DP.
- ▶ **Executive interest.** The above factors have helped make executives more open to evaluating how 3DP can be embedded into their existing manufacturing processes or used to create entirely new products and processes. And the 3DP discussion is moving beyond “either/or” – either prototyping or finished products. Instead, executives are seeing that 3DP enables both design and production to surpass the limitations of traditional manufacturing.

Senior business executives across industries need to put 3DP on their strategic agendas now, as it can help to realize benefits along a company's entire value chain:

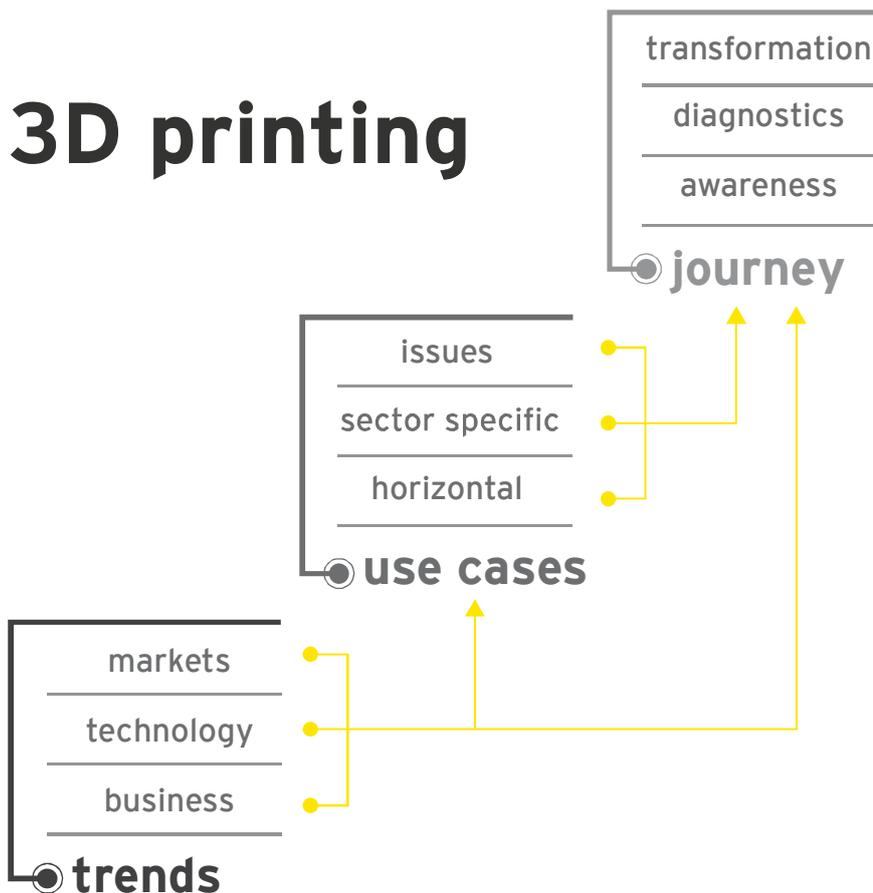
- ▶ **Product development:** Reduced time-to-market and shortened product development design cycles
- ▶ **Manufacturing:** Reduced process time via improved tools and reduced waste
- ▶ **Engineering and maintenance:** More flexible maintenance processes and reduced maintenance costs
- ▶ **Logistics and warehousing:** Reduced inventory, logistics and logistics costs
- ▶ **Aftermarket:** Increased flexibility in delivery of spare parts and reduced costs of spare parts production

The aim of this paper is to help organizations understand the potential of 3DP and the steps required to take action toward, and fully benefit from, the technology. The framework of our discussion is represented in Figure 1.

¹ 2016 EY global 3D printing survey



3D printing



“Many industries have moved beyond leveraging 3DP in experiments and will be approaching an inflection point within the next five years, where executing on 3DP is industrialized into the value chain.”

Gartner Hype Cycle for 3D Printing, 2016, 19 July 2016, G00307807

Figure 1: 3D printing discussion framework



Major trends are shaping the evolution of 3D printing



Favorable business trends

Several trends in the business world have accelerated 3DP onto executive agendas. About one-quarter of global companies already use 3DP, with another 12% considering it.²

The key business trends framing the 3DP evolution are as follows:

- ▶ **Individualization – customer co-creation.** There is a large push in the modern economy for the personalization of manufactured products tailored to consumer needs. Manufacturers have responded by embracing 3DP and in order “To explore opportunities for exploiting 3DP, IT leaders must determine whether the organization has the need or opportunity to shorten the supply chain and reduce inventory by printing parts prior to assembly or close to the point of need.”³

“3D printing technology is one of greatest innovations ever, and it is turning into reality – with a tremendous number of new opportunities and challenges.”

Frank Thewihsen, EMEIA Advisory Supply Chain & Operations Leader, EY

² 2016 EY global 3D printing survey

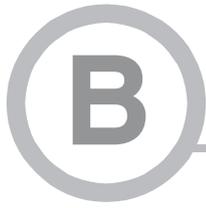
³ Reference from *3D Printing Opportunities and Uses Primer for 2016*, Gartner, 21 January 2016, G00293070. For more information see the Gartner report



- ▶ **Democratization – innovation and development from the masses.** 3DP makes it easier for individuals or collaborative teams to design or manufacture end products and reduces barriers to innovation. The product maker, who may be stymied in a traditional bureaucratic setting with difficult requisition processes and long logistical wait times, would now have options to make products quicker. For intra-company collaboration, design teams can “fax” their parts across the world to work with tangible products. When the needed engineering or design resources are not co-located or even connected virtually, companies have turned to crowdsourcing. An example of crowdsourcing is the 3D Printing Design Quest challenge that GE and GrabCAD launched in June of 2014. To inspire designers from around the world, the companies challenged the public to redesign a metal jet engine bracket to make it 30% lighter while preserving its integrity and mechanical properties.⁴ The contest, which is an example of crowdsourcing innovation made viable by 3DP, was won by an Indonesian engineer.
- ▶ **Sustainability – the circular economy.** There is a global movement toward sustainability for the home and also for corporations of all sizes. 3DP reduces transport costs when the 3D printer is placed close to the manufacturing line. There are also operating cost efficiencies when airplanes are built with lighter materials. That said, as early adopters move to the use of 3DP, there are factors often missing from the cost-benefit analysis: for instance, power and heat are critical for 3DP processes; also, the benefit of easily iterating on designs may increase the amount of unrecyclable waste. As a result, the environmental benefits of 3DP do not come without care and planning, but they are achievable. Airbus, for example, appears to be a very good steward of the environment, as its 3DP processes are reported to have only 5% waste.⁵

⁴ Jet Engine Bracket from Indonesia Wins 3D Printing Challenge, GE Reports, 2013 by Thomas Kellner

⁵ Factory of the future - New ways of manufacturing, Airbus Group, 2016 by Álvaro Frieria, Favila Rocas, Hugo Alloy



Technology improvements

The range of materials that can now be used is vast, including plastics, porcelain, ceramics, stainless steel, carbon, graphene, titanium and other metals. This list is not exhaustive – new variations on materials or alloys are made every day. For parts that a company deems suitable for 3DP, there is a reduction of the supplier base, as the components no longer need to be sourced. There are four different technological trends changing 3DP:

► **Beyond prototyping applications impacts process designs.**

3DP was originally limited to prototyping. Now, 3DP methods such as direct metal laser sintering, selective metal sintering and electron beam melting have advanced 3DP into industrial applications and final assemblies. In considering the application of 3DP, the question companies need to ask is: what network of supply chain assets and what mix of old and new processes will be optimal?⁶ Some processes may benefit from the input of a part that is made on demand with 3DP, but others may not be a fit for 3DP. One thing that 3DP is able to deliver is more data which supports the alignment of existing and new processes. As Richard D'Aveni, author and Bakala Professor of Strategy at Dartmouth College's Tuck School of Business, notes, "When 3D printing is used to manufacture parts, that portion of the process becomes natively digital, with every element of each part produced under the continuous control of software. Contrast that with a conventional stamping or assembly-line process."⁷

► **Lightweight materials.** Honeycombing, another 3DP method, allows especially lightweight parts to be printed. It is possible to create hollow parts or parts with an inner chamber that are connected in a fashion similar to the inside of a bee's nest. If companies or individuals are outsourcing any 3D prints, one big question will be whether the finished product should be solid or not. Some cosmetic pieces may not need the inside to be complete, and hollowed out parts reduce material costs. But the effect on weight could be the most valuable impact for some. Both Boeing and Airbus use 3D-printed materials to reduce the weight of their aircrafts. The most dramatic result of honeycombing is metallic microlattice, a strong metal foam material that is the lightest metallic structure ever made. It is 99% air, consisting of a 3D open-cellular polymer structure made up of interconnected hollow tubes. There may be many applications for this material in the future.

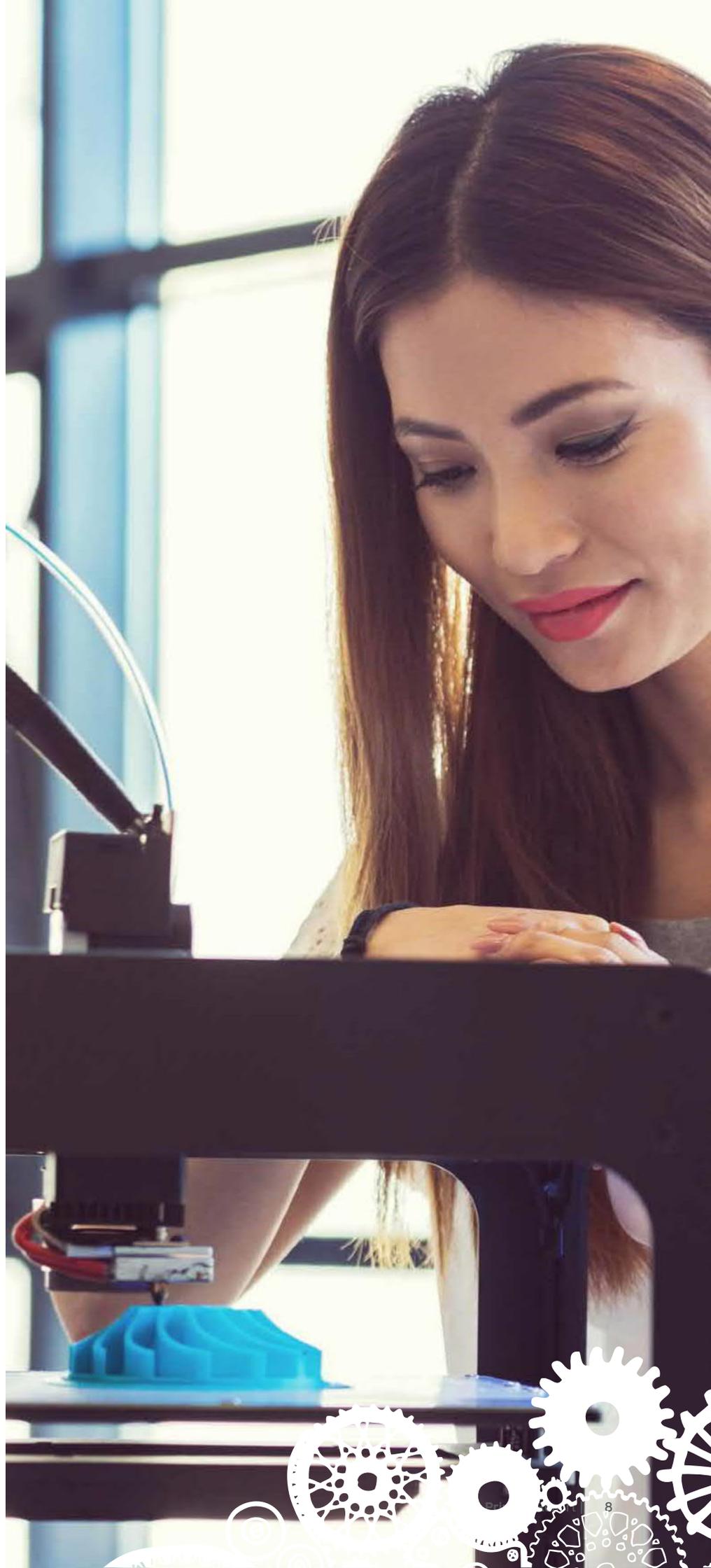
► **Fewer components for complex geometries.** 3D printers are able to make different compositions of metal alloys to suit the end-product needs. The opportunity to test different compositions easily and cheaply can trigger the creation of materials that have not been seen before and may be better suited to meet certain design specifications than traditional materials. One interesting aspect of 3DP is that middleware has the potential to bridge the gap between the design and the 3D printer, meaning that the middleware can use the design parameters as inputs and through the algorithms draw on an optimal mix of source materials for the end product specified in the design. Moreover, there will be an ability to manufacture components with desired mechanical properties. For instance, titanium aluminide (TiAl), used to create turbine blades, is very brittle at room temperature and is difficult to use with conventional manufacturing techniques, such as casting. 3DP allowed GE to produce thicker blades with high speed by using a 3-kilowatt electron gun to accelerate a beam of electrons to melt the powdered titanium aluminide.⁸ Through these types of applications, 3DP will continue to address the need to reduce waste and cost.

⁶ *3D Printing Drives Digitization Further Into Products, Processes, And delivery Models*, Forrester, 2014 by Sophia Vargas, Michael Yamnitsky, Khalid Kark, Frank Gillett, Rachel Dines, J.P. Gownder, John McCarthy, Nate Fleming

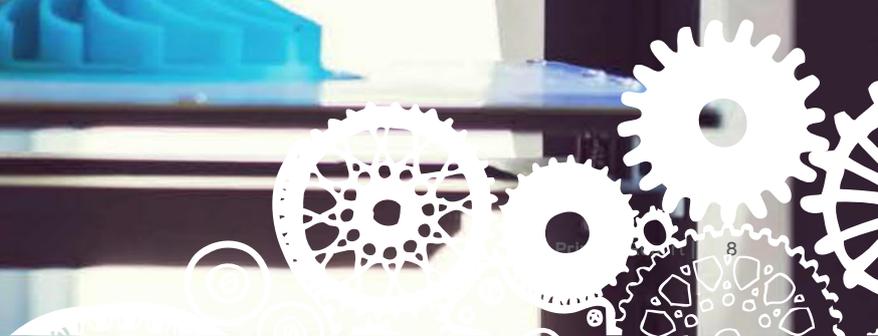
⁷ *The 3D printing revolution*, Harvard Business review, 2015 by Richard D'Aveni

⁸ *This Electron Gun Builds Jet Engines*, GE Reports, 2014 by Tomas Kellner

► **Science and technology advancing materials management.** Bar coding greatly improved tracking and location of parts along the supply chain. Later, RFID technology allowed parts to be found via GPS coordinates. 3D-printed parts will change the inventory mix and alter tracking processes once again. RFID technology will not necessarily become a thing of the past; however, metal powder for printing will be purchased in such large volumes that RFID tags may be the less useful technology to trace powder from the source to use in producing 3D-printed parts. Going further into the future, a team of researchers at Harvard University has extended its microscale 3DP technology to a fourth dimension: time.⁹ Inspired by nature, the 3D-printed particles form different structures based on a reaction to environmental stimuli. This is an example of advancement in programmable materials assembly and enables the ultimate agile supply chain because the programmable material can morph into what is required.



⁹ *Novel 4D printing method blossoms from botanical inspiration*, Wyss Institute Communications, 2016 by Kat McAlpine





An active 3D printing market

Gartner projects that the 3DP market for printer unit shipments will grow at a CAGR of 121.3% through 2019 and exceed \$14.6 billion.¹¹ The suppliers of 3DP products and services can be segmented as follows:

- ▶ **Major industrial companies.** Some of the big players in this space are GE and Siemens. GE, for example, is planning to bolster GE's existing manufacturing operations and help the company build a \$1 billion 3D-printing business by 2020 through acquisitions of Sweden's Arcam AB and Germany's SLM Solutions Group AG¹⁰. Siemens has opened a 3DP facility in Sweden where those with 3D design skills and materials science know-how come together to work on some of the best innovations to bolster Siemens products. Siemens draws on knowledge developed in-house but also via acquisitions of start-ups. Midsize-to-large companies such as Siemens often collaborate with universities and research labs to combine theory with testing. For example, Siemens has partnered with Georgia Tech to improve additive manufacturing.¹² Siemens can leverage this knowledge across its large range of business units, but it can also monetize on this IP by providing services to companies in need of assistance in this space.
- ▶ **Specialized 3D printer vendors.** Most makers of 3D printers have been focusing on a specific technology of additive layer manufacturing. Some of the 3D printer companies have focused on industrial applications. The inventory turn for these large units is not very fast and unsold inventory can become obsolete in this space very quickly. Some of the main manufacturers are Autodesk, EOS, Exone, Stratasys, 3D Systems, Reprap and Ultimaker.
- ▶ **3DP service bureaus.** Some manufacturers of 3D printers also provide the after-sales service and consulting. According to a Gartner survey, when companies decide to outsource a 3D print job to a service bureau, 34% of respondents view quality as the most important criterion.¹³ Some of the options that companies have are: Advanced Manufacturing, Aspect, DiSanto Technology (a Unit of Arcam), Hyphen Services, i.materialise, Ponoko and Shapeways.
- ▶ **Marketplace providers.** Marketplaces are online platforms which act as intermediaries between individuals or firms that own a 3D printer and users who want to manufacture 3D objects¹⁴. They usually provide 3D printing services across a large network of printers in various locations around the world. 3D Hubs, for example, links a file to a printer in one of their 5,000 global hub locations that can

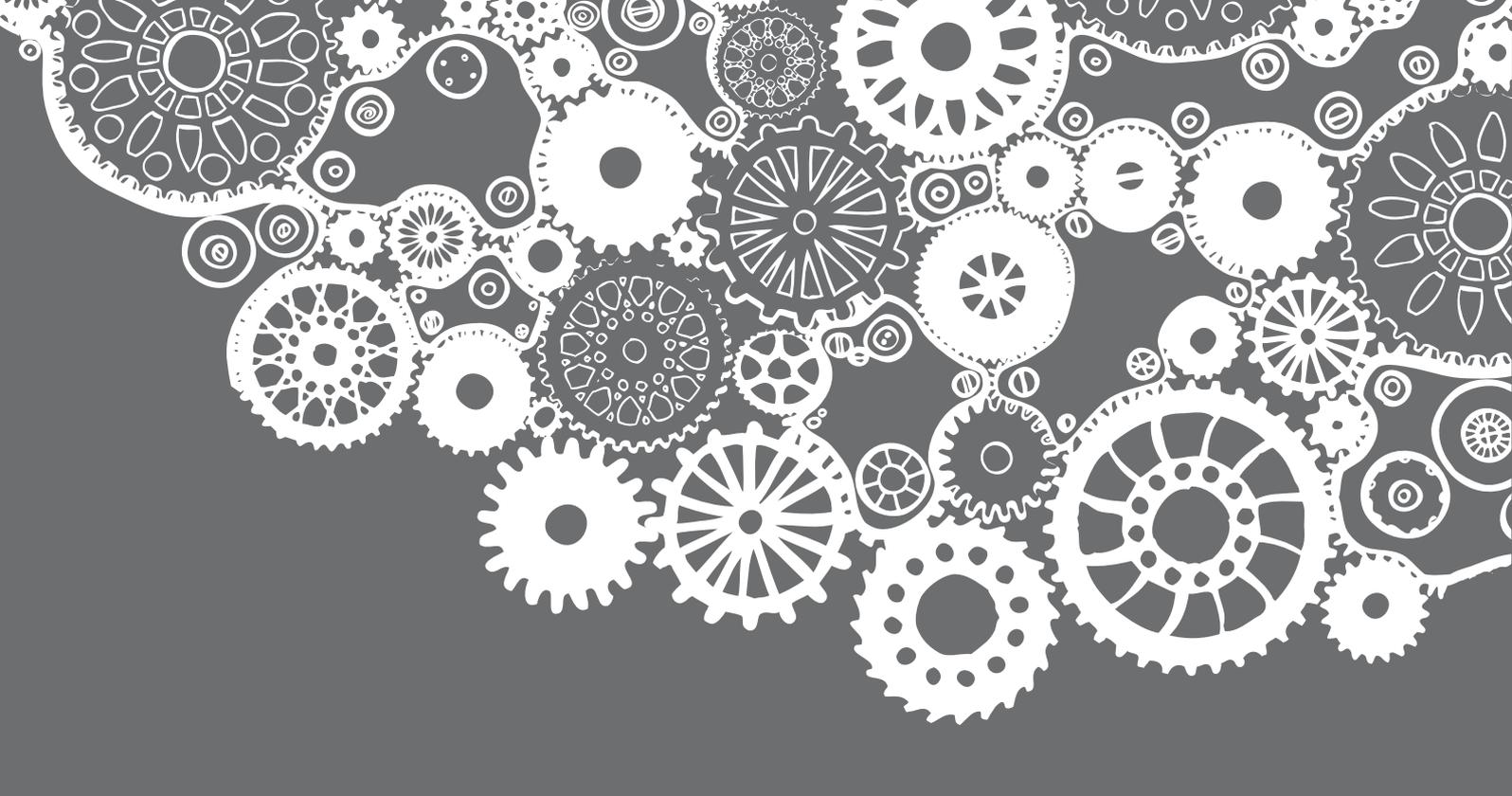
¹⁰ GE Seeks to Drive 3D Printing Future With \$1.4 Billion in Deals, Bloomberg, 2016 by Rick Clough, Niclas Rolander and Andrea Rothman

¹¹ Forecast: 3D Printers, Worldwide, 2015, Gartner, 17 September 2015, G00277739

¹² Siemens Expands Georgia Tech Partnership to Drive Advanced Manufacturing Research, Software and Innovation, 2015 by Brie Sachse

¹³ Gartner, 3D Printer Market Survey Reveals Enterprise Demand Drivers for Technology, Printer and Vendor Decision Making November, 2014, FOUNDATIONAL August 2016

¹⁴ Co-creation and user innovation: The role of online 3D printing platforms, ScienceDirect, 2015 by Thierry Raynaa, Ludmila Striukovab, John Darlingtonc.



provide the 3D print in the selected material. This proximity factor to the consumer has made them successful and increases accessibility of 3DP to anyone¹⁵. Other players include Additer, Kraftwürz, Maker 6, Make XYZ, Materialise and Spark.

- ▶ **Software vendors.** One key differentiator for companies to consider is an open-source platform for crowdsourcing ideas and for providing completed blueprints for spare parts. Companies that have ventured down this avenue have been heralded by hobbyists, who eagerly download upgrades or replacement parts. Companies providing open-source platforms for products can generate brand loyalty and, above all, can guarantee that there is one file amid a slew of counterfeit reverse-engineered replacement parts that is legitimate. C, for example, is the first open 3DP software platform (not including the pioneer Reprap, as it was limited to hardware). C was created by Autodesk and runs with an Ember 3D printer.

- ▶ **Professional services providers.** Bringing together different consulting competencies including strategy, supply chain, design and engineering, product development, IT, analytics as well as tax and legal services helps manage the end-to-end process of 3D printing and accompany organizations on their journey to adoption. In an inventory of thousands, choosing which components may be best suited to 3D printing requires a diagnosis and methodology too. In addition, they can recommend and bring together the right vendors for a 3D printing route.

“It is not just about 3DP technology adoption. For example, inserting a 3D printing sub-process into traditional stamping will likely require process redesign.”

Paul Brody,
US Advisory Technology
Sector Strategy Leader, EY

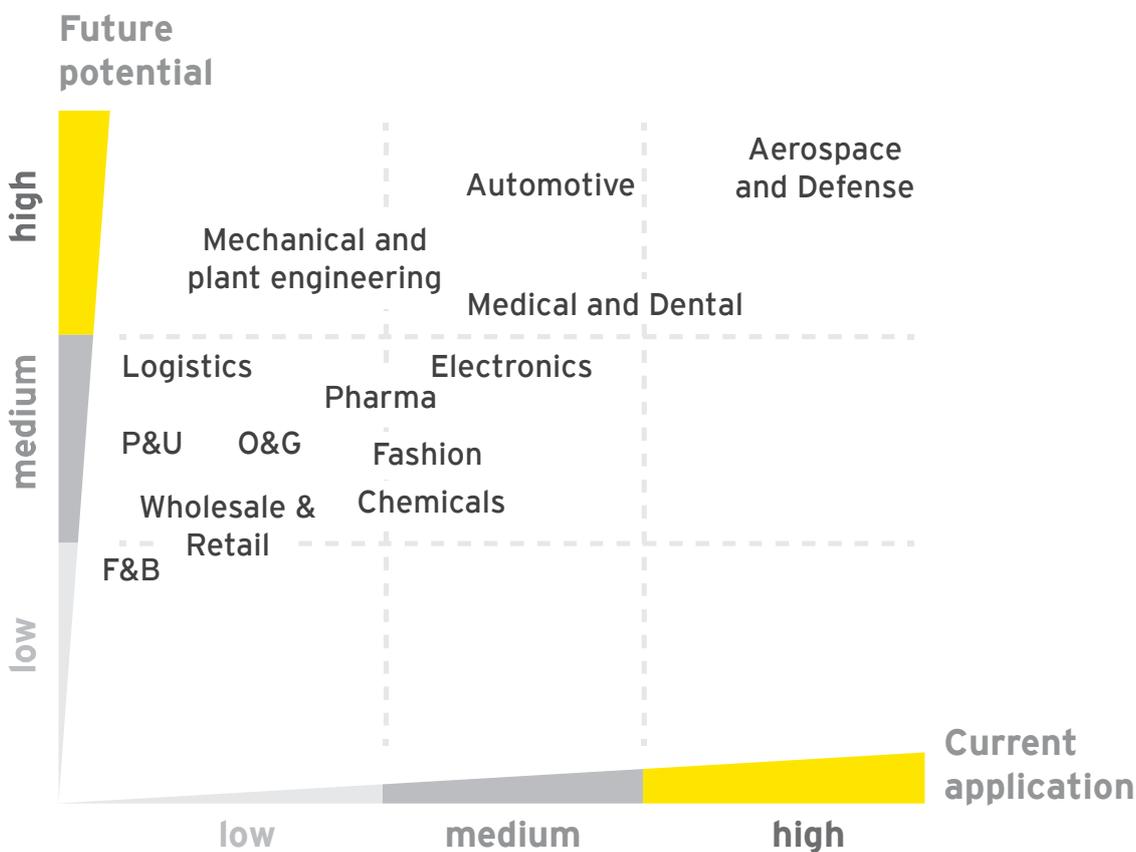
¹⁵ *3D Hubs Proves 3D Printing Is Bankable*, Forbes, 2014 by Jennifer Hicks



Use cases: 3D printing is impacting a variety of industries

3DP has made ripples through various industries. The industries can be mapped based on their current level of applying 3DP, compared to the future potential (Figure 2).

Figure 2: Current application and future potential of 3D printing by industry



Source: EY analysis based on 2016 EY global 3D printing survey.



Example applications of 3D printing across industries

The following provides an overview of different use cases across selected industries:

- ▶ **Aerospace and defense.** This industry is at the forefront of 3DP in the manufacturing industry. Due to the low-volume, high-value production typical of this sector, 3DP is of particular appeal to big conglomerates and small and medium-sized companies alike. Using this technology rather than traditional methods is yielding products that are faster, lighter (better weight to thrust ratio), less wasteful (more fuel efficient) and more financially viable.¹⁶ GE has stated that from 2016, its new Leap aircraft engine will include nineteen 3D-printed fuel nozzles, designed to last five times longer than traditionally made components.¹⁷
- ▶ **Health care.** The medical field is another industry greatly impacted by 3DP. US hearing aid production converted to 100% 3DP in less than 500 days.¹⁸ Key to this transformation was that 3D printers enabled a manual, labor-intensive industry to transform into an automated one.¹⁹ As health care focuses intently on reducing costs, improving quality and becoming more patient-centric, other

sub-sectors are also looking at 3DP. The technology has enabled a more patient-centered approach in medicine by offering customization of prosthetics and dentistry, and by enabling bio-printing, where scientists print human-sized bones, cartilage and muscle.²⁰

- ▶ **Food.** Many people shy away from the thought of 3D-printed food, but there has been a lot of innovation in this area. From crystalized sugar cake toppers and intricate chocolate designs, to cracker-like yeast structures with seeds and spores that sprout over time, to ready-to-bake pizzas and filled ravioli, printed food has the culinary community talking. Early adopters are German retirement homes, which serve a 3D-printed food product called Smoothfoods to elderly residents who have difficulty chewing.²¹ The EU has invested nearly \$3.3 million in this project with the hope of improving quality of life for frail and elderly people living in care facilities.²² For people who have trouble chewing or swallowing, this method produces purees that offer tastier alternatives than traditional meals such as baby food.

¹⁶ *How 3D printing is driving efficiency in aviation*, Euronews, 2015 by.

¹⁷ *3D Printing Creates New Parts for Aircraft Engines*, GE Global Research.

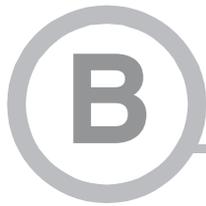
¹⁸ *The 3-D Printing Revolution*, Harvard Business Review, 2015 by Richard D'Aveni.

¹⁹ *The 3D Printing Revolution You Have Not Heard About*, Forbes, 2013 by Rakesh Sharma.

²⁰ *Organs to Order: 3D 'Bioprinter' Makes Replacement Bones, Ears*, Livescience, 2016 by Agata Blaszczyk-Boxe.

²¹ *Why 3D food printing is more than just a novelty – it's the future of food*, Digital Trends, 2015 by Kyle Wiggers.

²² *EU funds 3D-printed 'smoothfood' for care homes*, Wired, 2014 by Katie Collins.



Addressing sector-specific factors will determine 3D printing adoption

In this section, is a detailed review of the status of 3DP in three selected industries, and the factors that could determine the nature of future adoption.

1 | Resource industries (oil and gas and metals and mining)

► **Industry landscape.** The resources industry is characterized by its geographically distributed and often remote operations. This presents operators with significant challenges in managing logistics, making sure key parts are available for maintenance and keeping downtimes to a minimum. Due to the impact of downtime on production targets, operators typically hold large inventory stocks (often as critical spares on multiple projects), much of which may never be used. Similarly, equipment suppliers within the industry have to maintain stocks post-sale for aftercare support, often with little understanding of equipment performance on-site and, therefore, pipeline requirement for spares. The geographical distribution of the industry, with both suppliers and operators often in challenging locations such as the open ocean, means that transportation/logistics costs make up a large portion of replacement parts/maintenance costs. With commodity price volatility continuing to impact the industry and the continued need to minimize downtime, resource companies and suppliers are seeking to reduce costs wherever possible while maintaining or improving quality of products and speed of repair/maintenance activities.

► **Benefits of 3DP.** 3DP is appealing to suppliers as well as operators in this market. For suppliers, there is the potential opportunity for reduced cost to supply aftercare services for major equipment. This is due to a reduced need for storage/production of spare parts (especially for discontinued/older products) and aftersales logistics and client support. The reduction in transportation costs means that product costs can be reduced, fluctuations in transport costs can be avoided and location is no longer a barrier to client service (opening up the market to smaller, currently regional suppliers). There is also the potential to use analytics for the consumption of spare parts (as use of tracking would be possible) to enhance product performance and predictive maintenance/aftercare activities. In addition, 3DP shortens the development and retooling process through design changes and allows parts to be tailored to specific site conditions and requirements. For operators, critical spares and wider inventory storage costs can be minimized and lead time (for shipping of spares) reduced to only the time it takes to print parts. Cost of products can be reduced due to exclusion of transportation costs. Security of supply issues (including bribery and corruption) are negated, allowing remote operations to run independently of outside/local influences, even in geopolitically challenging locations. With fewer welds, quality of components may be higher due to a reduced number of weak points on metal products. 3DP also allows lower cost trials and prototyping of new components in existing plants and operations.

There are several cases where 3DP is already being applied in the field:

► **Sandvik use case.** Sandvik, a global engineering group in tooling, materials technology, mining and construction and a key supplier for many resources companies, is evaluating 3DP through various initiatives to observe how the technology can be used in its production. As part of these initiatives, Sandvik is opening a new 3DP research



²³ Sandvik Pushes 3D Printing to Create Fuel Tubes, Drilling Gear, BloombergBusiness, 2015 by Niclas Rolander.

²⁴ Here's Why 3D Printing Needs More Metal, Fortune, 2015 by Andrew Zaleski

and development center to evaluate benefits across the corporation. “Advantages may include faster production, increased flexibility and being able to create components in shapes impossible to accomplish through standard methods. What is attractive about 3DP is the new way of thinking,” said Mikael Schuisky, Sandvik’s operations manager for additive manufacturing. “We are used to thinking that objects are processed out of a material. We need to start thinking about starting from a blank canvas,”²³ pointing to the fact that traditional manufacturing methods help cut away unwanted material where 3DP makes an object by layering materials in the exact shape of the finished product.

- ▶ **Alcoa use case.** Similarly, Alcoa, a global leader in lightweight metals technology, engineering and manufacturing, is investing US\$60m in building its new additive manufacturing center in an attempt to fill a big need in the market for providing low-cost metal materials specifically made for 3DP. “There are just a few materials available today that are usable within 3D printing of metals,” says Rod Heiple, Alcoa’s director of R&D for engineered products and solutions. “A material developed as a feedstock for one additive process may not be, and in fact is unlikely to be, the optimal material for the next additive manufacturing process.”²⁴
- ▶ **Mine topography.** Another application for 3DP, specifically for the mining sector, is “mine topography.” Mining engineers print a 3D topographic model to aid in the visualization of mining sites and other geological locations using survey data and aerial photographs. This is used for securing the optimal layout of the mine. “It’s not always apparent from looking at a drawing how mine waste facilities integrate with their surrounding environment,” explains MineBridge’s Carlo Cooper. “By using 3D printed models, it’s easier for stakeholders to see the visual impact of these structures.”²⁵

There are obvious opportunities for 3DP in the resources industry; however, there are several factors that can impact the uptake:

- ▶ **Reluctance to collaborate.** Engineering firms and suppliers may be reluctant to provide CAD drawings/input to clients, as they risk losing IP. This perceived lack of product control

and loss of IP/security concerns need to be overcome and surpassed by a benefits case of technology for the platform to be successful. Similarly, the analytics benefit above (for post-sales care) may expose engineering firms to more accurate and uncomplimentary comparisons between them and others.

- ▶ **Technology.** The technology is developing extremely quickly, meaning that selection of providers to partner with could be challenging. It’s key to build flexibility into any agreements. In addition, the industry will likely require major software investment to fabricate intricate designs in 3DP. Resource players could want the original equipment manufacturers (OEMs) to drive this even though it might open doors to cannibalize their own sales.
- ▶ **Quality issues/approvals.** Components on O&G facilities are subject to stringent testing requirements. There is significant work required to facilitate not only that 3D-printed products meet existing requirements, but that testing and approvals can be done on a product range rather than individual printed products. The opportunity in the oil and gas industry is not just in the machinery parts, but also in ancillary products that support O&G operations and have lower critical importance and hence lower quality requirements.
- ▶ **High cost of 3DP.** Parts to build the printer are still very expensive. Actual printing is cheap. In addition, there is a lingering concern about warranty. Resource companies are hesitant to put 3D-printed parts into their machines if they are not covered for damage in case the parts fail.
- ▶ **Success of early adopters.** Timing of investment can be key to uptake, as selecting the time when the technology has become both cheap enough and of sufficiently high quality may provide early adopters with a significant advantage. At that point, adoption could be rapid. Significantly though, the O&G industry is (in many locations) impacted by local content obligations, meaning that 3DP adversely affects a company’s ability to deliver against their obligations.

²⁵ *Whiteclouds Creates Full Color 3D Printed Topography from Aerial Photographs*, 3D Printing Industry (3DPI), 2014 by Scott Grunewald

2 | Automotive

- ▶ **Industry landscape.** The automotive industry is under significant price and cost pressure. Tier 1 and tier 2 suppliers, which provide car manufacturers with auto parts, are chasing operational excellence to remain competitive. Margins for component parts are tight. In addition, the service agreements between component suppliers and OEMs require spare parts to be on inventory for several decades. On the flip side, consumers demand customization. This adds complexity into the production, as low-volume and high-variation parts can bring inefficiencies into the system.
- ▶ **Benefits of 3DP.** 3DP is especially attractive to the automotive industry, because in some cases it can produce what traditional manufacturing methods cannot. 3DP can thereby add most value in the realization of product concepts. With 3DP, lightweight car components can be produced, which could lead to car weight reduction, improvement of car performance and better fuel economy. In addition, direct manufacturing applications, where 3DP can be applied in the production of low-volume and high-customization parts, can effect significant efficiency gains in production, operations and supply chain. Furthermore, 3DP can improve efficiency in manufacturing by direct manufacturing of tools for injection moulding. This method, which helps to produce car interior plastic parts, usually requires significant cooling time. 3DP can improve production cycle times, improve the quality of the tools and lower maintenance costs by applying internal cooling channels to the injection moulding method. In addition, automotive OEMs use 3DP for cost-effective and fast production of manufacturing aids, jigs and fixtures. 3DP

can also be used to produce spare parts, as well as tools for spare parts. The parts and tools can be printed on demand from digitally stored blueprints rather than maintained in large inventories. Several cases of 3DP are already applied in the field:

- ▶ **Local Motors use case.** Local Motors is the first company able to 3D print most of a car. About 75% of the current car model is 3D printed, with a goal to consolidate the traditional bill of materials to get to 90%.²⁶ This is especially significant, because traditionally it takes thousands of components to make a car, while in this example it takes dozens, reducing the complexity of the car and hence its longevity.²⁷
- ▶ **Toyota use case.** Toyota Central R&D Labs Inc. and Materialise have developed 3D-printed car seat designs as well as processes for production. The bionic structure and the softer core material, which does not include the foam used in traditional seats, is lighter and more comfortable. Additionally, it has improved the heating functionality as the surface material absorbs less than half of the energy when sitting in the sun.²⁸
- ▶ **BMW use case.** BMW developed a one-piece, light-metal, 3D-printed water pump wheel to replace the previously applied model composed of plastic parts. The high-precision component, which is subject to high stresses, consists of an aluminium alloy. It has turned out to be the ideal product for the small batch. The key reason is that 3DP allows for the inclusion of design refinements, achieves ideal aerodynamics of the component and confirms the dimensional accuracy of the water pump wheel during the entire production process. There are already 500 water pump wheels in use in both German Touring Car Masters (DTM) cars and Z4 GT3 customer vehicles.²⁹

²⁶ Local Motors FAQ, How much of the LM3D is 3D printed?, 2016

²⁷ This drivable car was 3D printed in 44 hours, Business Insider Tech, 2015

²⁸ Print Your Next Car Seat for Improved Fuel Efficiency, PSFK, 2015 by Jason Brick

²⁹ Racing technology right from the 3D printer: BMW makes water pump wheel for DTM racecars using additive production method, BMW Group, 2015

³⁰ Peugeot's Fractal concept uses 3D-printed damping chambers to trap sound, Digital Trends, 2015 by Andrew Hard

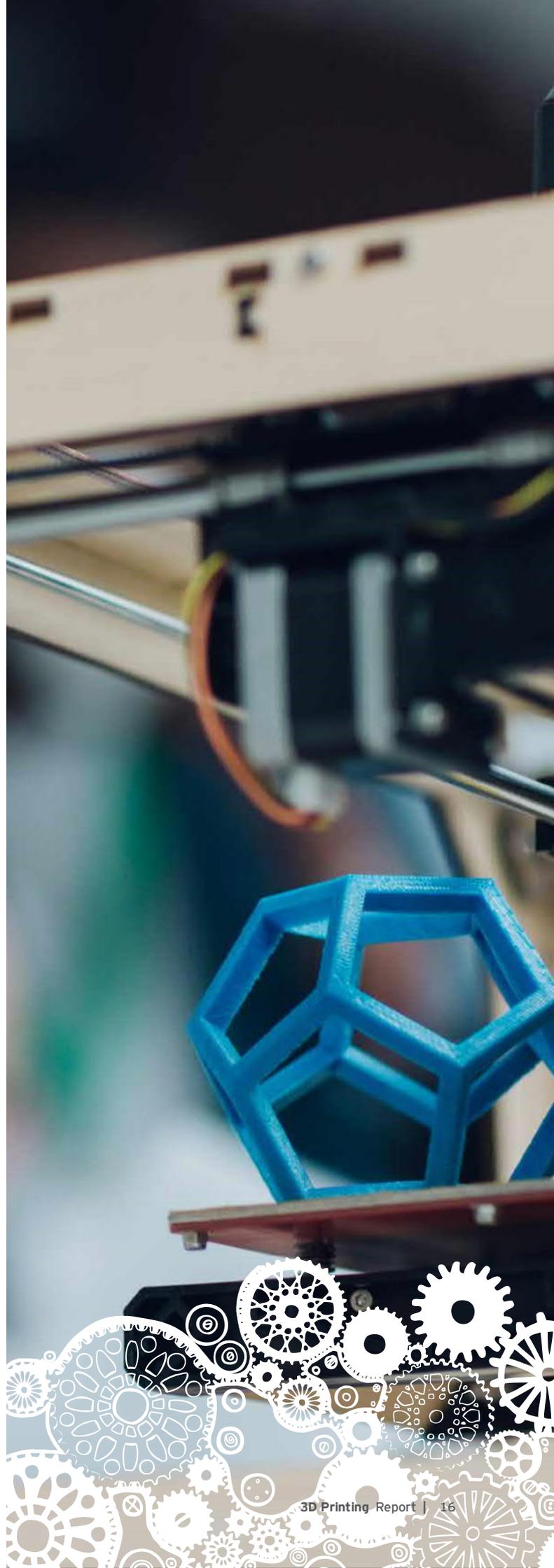
³¹ Ideas Incubator video, Peugeot, 2016

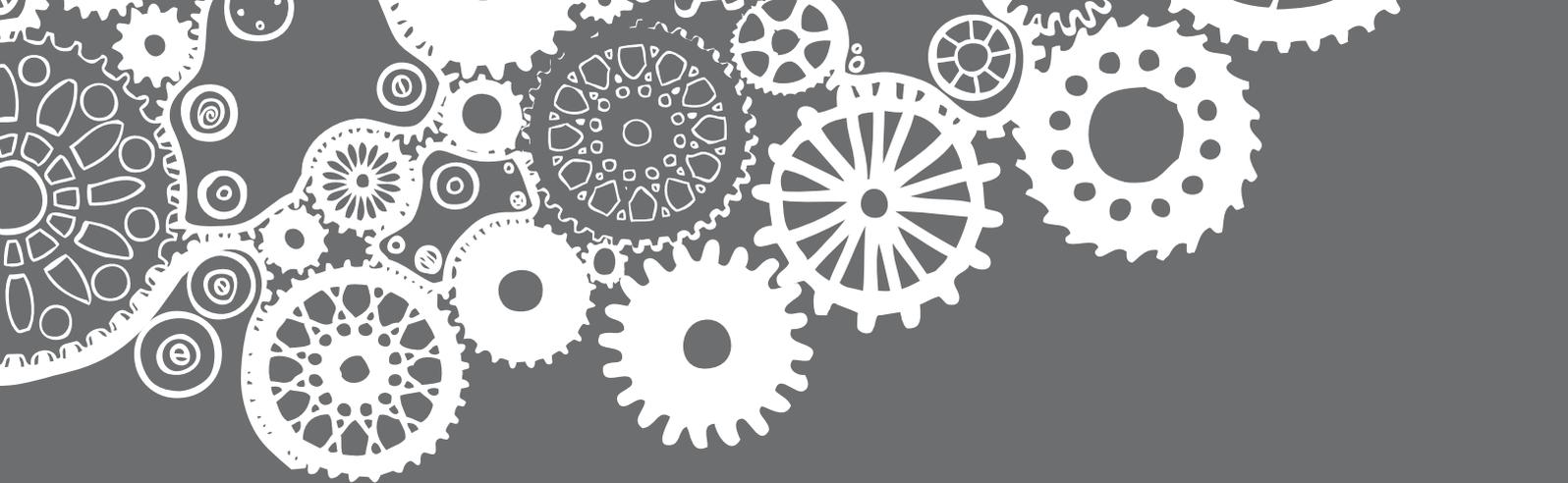
- ▶ **Peugeot use case.** Peugeot's sound-inspired Fractal concept car has an interior, called i-Cabin, with 3D-printed panels, which are both visually stimulating and acoustically functional.³⁰ The "Fractal" name is a reference to the 3D print models shaped as anechoic chambers and repeating patterns. To generate the sound-trapping textures, they needed to use 3DP, which was the only way to produce these parts with very complex shapes. Eighty-two percent of Fractal's interior surfaces were made with 3DP, which is something pretty spectacular for the automotive world. It allows achieving style that's finer, more efficient and lighter than would be possible through traditional processes.³¹

Opportunities for 3DP in the automotive sector are vast, but there are still some factors restraining the adoption of this technology:

- ▶ **Costs.** Material and system costs for 3DP are still high. For a cost-sensitive industry like automotive, can slow adoption. Manufacturers and suppliers need to find the real value-add applications of this technology in their value and supply chains. Business cases are often obvious once supply chain operations costs for specialty part production are compared to 3DP costs over time.
- ▶ **Production speed.** In the last decade, additive manufacturing technologies have drastically advanced in speed and quality and, as a result, are increasingly applied in direct manufacturing of components and end parts. Nevertheless, in many of these cases, application is at or near lot size one production. The production speed of the current 3DP technologies is still a limitation, and if the product design is not exclusively 3DP producible, then application of 3DP for high-volume products is not economically feasible.
- ▶ **Mind-set.** 3DP has been used in automotive for prototypes since the 1990s. A mental shift in the industry could help 3DP be viewed as a technology for production of end components – not as a substitute for traditional production, but rather as a means of creating unique value-adding products only producible with additive manufacturing.

³¹ Ideas Incubator video, Peugeot, 2016





3 | Consumer products and retail

- ▶ **Industry landscape.** The consumer products and retail (CPR) sector is represented by large multinational companies, which own some of the world's best-known brands, operate extensive manufacturing networks and manage complex global supply chains/routes-to-market. The balance of the sector has been disrupted by three fundamental shifts:
 1. **Consumers are changing.** The rise of digital has changed the game from B2C to C2B. Demographic changes are shifting the control further toward consumers. In CPR as in health, this trend appears to have reached a tipping point and consumers are demanding LATTE (local, authentic, traceable, transparent and ethical) products.
 2. **Growth is challenging.** Political, macroeconomic and regulatory volatility in emerging markets coupled with fragile mature markets is increasing complexity and ambiguity. New players are taking share, current product portfolios and supply chains are found wanting, and rules of marketing are being redefined by analytics.
 3. **Costs are harder to control.** External cost pressures related to commodities, currency and talent are growing. Internal cost structures are under stress due to an imbalance in mature and emerging market production capacities, the impact of omnichannel on supply chain and the impact of digital on SG&A.
- ▶ **Benefits of 3D printing**
 - ▶ **Mass customization.** 3DP addresses emerging consumer trends of personalization, connectedness and convenience by letting users ideate, design and manufacture individualized products. Products designed for their own ergonomic needs can enhance utility and maximize return on each design for companies.³²
 - ▶ **Time-to-market.** Rapid prototyping makes R&D cycles shorter while providing the flexibility of creating and testing multiple design iterations. From a retail perspective, 3DP can be used to modify, rather than create, existing products. This can incentivize store visits to personalize the fit of the item via point-of-sale production and could have transformational impact on manufacturer-retailer relationships.
 - ▶ **Manufacturing and supply chain efficiency.** 3DP enables on-site production, thereby helping companies reimagine their manufacturing and supply networks. It can slash development time, eliminate tooling costs, limit inventory/storage spaces, reduce logistics/transportation costs and help contain labor requirements.³³
 - ▶ **Waste reduction and lower taxes.** 3DP can improve the productivity of materials by eliminating waste. Nike indicates that reducing waste through 3DP alone could produce US\$1 billion in cost savings. The electronic transmission of design plans for local production can potentially eliminate custom duties.³⁴

³² What could 3D printing mean for consumer products?, Taylor Wessing LLP Article, 2013 by Lorna Caddy, Randeep Grewal.

³³ 3D Printing and Its Disruptive Impacts on Supply Chains of the Future, Technology Innovation Management Review, 2015 by Sebastian Mohr, Omera Khan.

³⁴ What Happens When 3D Printing Turns Consumer Products Into Digital Content?, Forbes, 2014 by Jonathan Salem Baskin.

- ▶ **Consumer engagement.** CPR companies leverage 3DP to garner valuable consumer insights and develop innovative marketing campaigns. Co-designing/co-creating with consumers and crowdsourcing via open platforms provides these companies a unique opportunity to connect with consumers and drive brand loyalty.

There are several cases where 3DP is already being applied in the field:

- ▶ **Nike use case.** Already using 3DP in its automatically knitted Flyknit shoe fabric, Nike is pushing 3DP further through a new design and manufacturing center in partnership with DreamWorks Animation. It could be capable of nearly instantaneous digital print applications, photo-real 3D visualizations and ultra-rapid prototyping.³⁵
- ▶ **Fashion use case.** Haute couture specifically has been in the media for 3D-printed dresses on the cat walk. “You can now print 3D surfaces without seams or without parts and there are just gradients ... of material that vary in property, size, and flexibility, and complexity,” says Neri Oxman, Professor of Media Arts and Sciences MIT Media Labs. “The options to vary material properties, but also to use highly complex geometries in relatively short periods of time, is completely transforming the fashion industry as we know it.”³⁶
- ▶ **Unilever use case.** Unilever leverages 3DP injection moulds for its household care and laundry goods divisions, slashing lead time for prototype parts by up to 40%. It 3D prints injection mould tools to create prototype parts in final material, for full functional and consumer testing.³⁷

- ▶ **Hershey use case.** Hershey engaged consumers to create unique designs through a 3DP candy machine. Consumers interacted with a library of 3D graphics on an iPad to get the machine to form a number of chocolate designs, providing Hershey valuable insights on preferences.³⁸
- ▶ **Mattel use case.** Mattel showcased ThingMaker 3DP to create customizable toys at the New York Toy Fair. Developed in collaboration with AutoDesk, it comes with an app that lets users select from dozens of 3D design blueprints, so they can print out parts that can be easily connected.³⁹

There are obvious opportunities for 3DP in CPR; however, a couple of factors could determine the uptake:

- ▶ **Cost effectiveness.** To penetrate the CPR sector beyond prototyping and novelty applications, 3D-printed products needs to be more acceptable to a larger number of consumers so that it can compete with the speed and scale of traditional manufacturing. Companies could need to strike the right balance of using 3DP and complementing it with traditional manufacturing techniques.⁴⁰
- ▶ **Innovation.** Next-gen devices and network connectivity could broaden the space for 3DP in CPR. There can be huge benefits with the rapid advancements in these technologies – for example, consumers designing products on their smartphones and iterating prototypes.

³⁵ 3D Printing In Manufacturing Revolution, Investor’s Business Daily, 2015 by Elaine Low, Nike Eyes.

³⁶ 3D Printed Dress on the Catwalk at Paris Fashion Week, Stratasys, 2013 by Neri Oxman

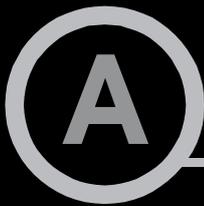
³⁷ Unilever Leverages 3D Printing Injection Molds, Slashing Lead Times for Prototype Parts by 40%, PR Newswire, 2015

³⁸ Hershey’s Chocolate 3D Printer Whips Up Any Sweet Design You Want, TechCrunch, 2015 by Sarah Buhr

³⁹ This \$300 3D printer lets kids create their own toys, Techspot, 2016 by Rob Thubron

⁴⁰ The Future of Retail, Chain Store Age, 2015 by Andrew Levy

IV Accelerating the 3D printing journey



Organizations need to overcome their lingering concerns to drive faster adoption

There are three key concerns that companies can address to accelerate their 3DP journey:

- ▶ **Quality.** With current laws clearly out of sync with this rapidly emerging technology, 3DP leads to many unanswered questions around liability. If manufacturing moves to users, who will be accountable for product functionality or potential hazards? How will regulations change in a 3D-printed world? In industrial applications specifically, quality of the prints is very important. As an example, some 3D-printed techniques like direct metal laser sintering and electron beam melting, although made to the specifications of the CAD model, can have very rough finished surfaces. 3DP has received criticism for poor surface quality. However, a study by the Uppsala Universitet⁴¹ proved that in controlled testing with an Arcam A1, the use of a finer powder and a smaller build-layer thickness can improve the surface resolution of end products. Companies that have know-how in materials science coupled with the discipline of regimented trial and error to learn the material compositions and the melting properties of powder could do well with additive manufacturing.
- ▶ **IP protection.** Public access to blueprints online raises copyright and intellectual property (IP) right concerns. If anyone can print anything, who is the creator of the object? For example, if a spare part is required and a company doesn't need to go to the OEM, there is a potential cost savings opportunity by using "aftermarket" parts, and 3D scanners and printers may make this easier. The process would entail reverse engineering⁴² a part with the

assistance of 3D scanners, thereby generating 3DP files for use or resale. This would be an IP infringement. It has been predicted that by 2018, theft of 3DP intellectual property could total roughly US\$100 billion in losses per year.⁴³ In its most basic sense, patent infringement occurs when every element of a claimed invention or process exists in the infringing "physical embodiment" of the product or process.⁴⁴ So what does this mean for possessing and creating digital copies of the OEM's spare parts or other products? While it remains unclear how lawmakers will balance the scope of the law to prevent it from becoming either too narrow or overreaching, it seems that affording protection to the patent holder against the sale of the CAD file could strike the appropriate balance, essentially preventing infringers from "extract[ing] the commercial value of the invention."⁴⁵

- ▶ **Taxation.** One of the key areas of consideration for 3DP is the intersection of IP and taxation. IP is expected to "account for an increasing share of a product's value, as digital printing reduces costs" for both individuals and organizations.⁴⁶ When 3DP becomes commonplace, warehouses and manufacturing operations may no longer be the norm. Current multinational tax profiles based on minimizing IP profit rely on non-IP related substance. There is likely to be a major question as to the point of production of an object, since 3DP does not necessarily align profits to people and their functions for taxing purposes.⁴⁷ This is important, as there are tax inefficiencies within the current supply chain model. It could therefore be necessary for a company transitioning from the current supply chain model to a 3DP warehouse to structure its tax planning in an efficient manner.⁴⁸

⁴¹ *Optimization of Electron Beam Melting for Production of Small Components in Biocompatible Titanium Grades*, Uppsala Universitet, 2015 by Joakim Karlsson

⁴² *The 3D printing revolution*, Harvard Business review, 2015 by Richard D'Aveni

^{43, 44, 45} *Digital Patent Infringement in an Era of 3D Printing*, University of California, Davis, 2015, Vol. 48:1319, pg. 1322 by T. Holbrook, L. Osborn

^{46, 47, 48} *3D Printing Taxation Issues and Impacts*, EY, 2015 by Channing Flynn



Steps companies need to take to accelerate their 3D printing journey now

Starting the journey of 3DP is an ambitious task for many companies, since they need to understand to address some general challenges:

- ▶ **VUCA (volatility, uncertainty, complexity and ambiguity).** Companies face both macro and industry-specific needs and business challenges such as economic uncertainty, cost volatility, pricing pressure, increasing customer requirements and operational challenges for assuring fast response to these customer needs. A 3DP journey may not make life simpler, at least not right away – the 3DP industry is rapidly evolving and offers a variety of systems, different materials, diverse applications and several different suppliers of systems and services. For many companies, the prospect of exacerbating VUCA is unappealing.
- ▶ **Lack of awareness.** The level of awareness of the state of the art of 3DP and its application is very low in many companies. There is a common path that most of the first movers in the 3DP industry take. To gain the needed information, companies often start collaborations with universities, system manufacturers, research institutes and service providers.
- ▶ **Inexperience.** Organizations start gaining experience with the technology by testing it in different areas and applying it to certain sectors like product development or engineering. This can be a very long and time-consuming path to follow. And there is no guarantee it will lead to

identification of the optimal value-adding application of 3DP for the company.

For most companies, 3DP is very new and a potentially dramatic change for both operations and the business. Many organizations need help understanding how the technology can transform them and how they could optimally lead this transformation. Generally, 3DP could help companies gain competitive advantage, improve their positions in the value chain, achieve growth and increase the efficiency of their supply chains and operations. As for the application of 3DP, it is possible to distinguish between 3DP as an efficiency strategy and a growth strategy:

- ▶ **Efficiency strategy.** For the efficiency strategy, there is a targeted application of 3DP in the current supply chain and operations, aiming to improve the performance in that particular area. The efficiency strategy could cover, for instance, prototypes in product development for reduced time-to-market and development costs or direct manufacturing of tools with conformal cooling for reduced cycle times and a higher utilization of manufacturing. Following this strategy is the less risky opportunity since it requires no changes in the end product, just in the way it is created.
- ▶ **Growth strategy.** Unlike the efficiency strategy, the growth strategy comes by introduction of new or redesigned 3DP products. The biggest benefit can be achieved when 3DP is applied as a direct manufacturing technology for

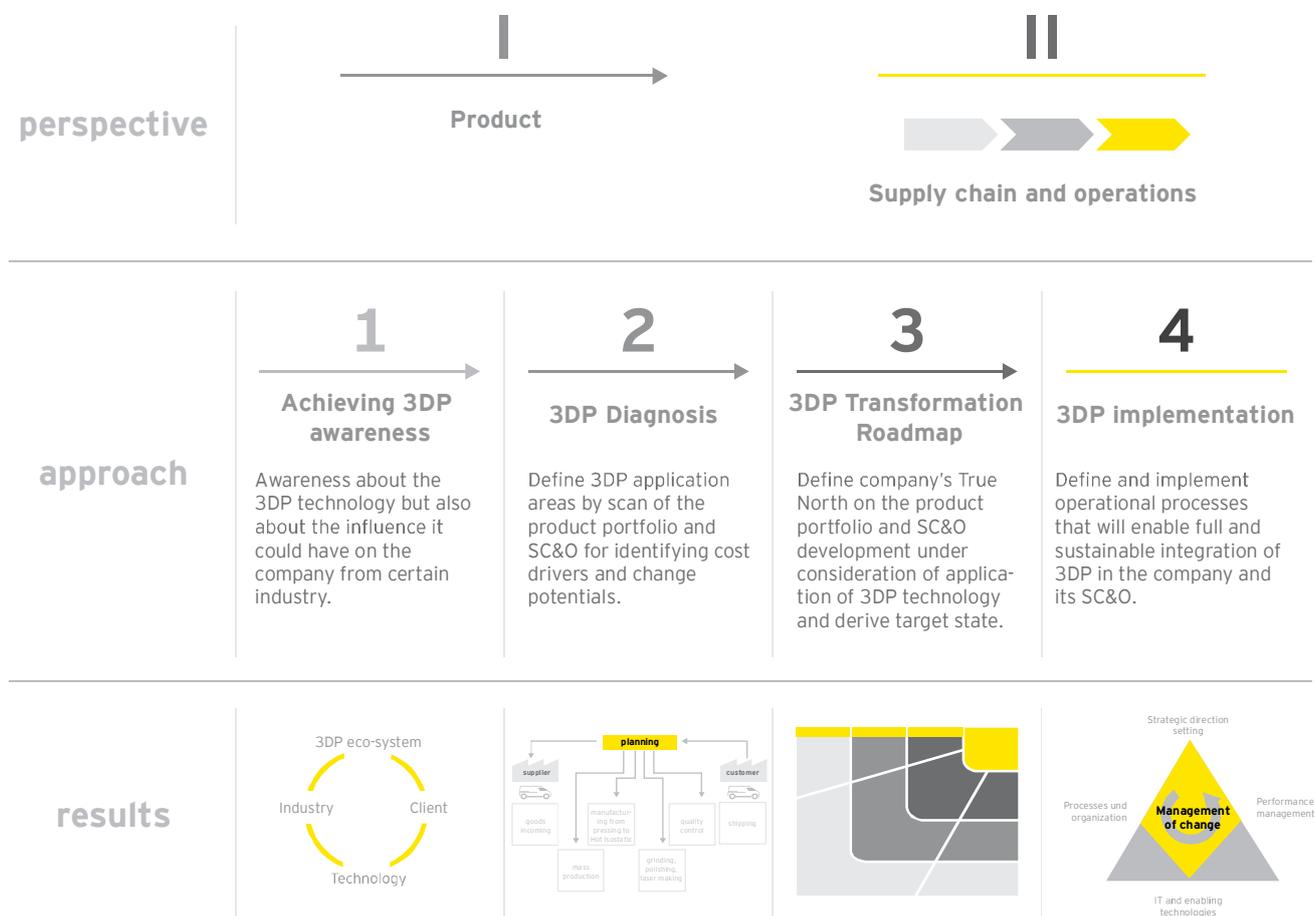
production of end products and components. This can enable companies to potentially optimize product design, gain additional customer value, create new products or improve existing ones. These enhancements can open new revenue sources and markets, and are therefore referred to as a growth strategy. 3DP for direct manufacturing of customized and personalized products and components could therefore be recommended. Additionally, 3DP can be considered for parts and products of a certain level of complexity, with new geometries, internal or bionic structures, in particular when additional value for the customer is created by a new product design, improved quality and functionality. Changing the design of the end product will then trigger changes and improvements in the supply chain and operations. With a 3DP-feasible design, companies can achieve the freedom to produce even closer to the point of demand, which helps increase their responsiveness and deliverability by decreasing the cost or inventory, the transportation efforts and logistics handling. Companies can also obtain the flexibility to produce lot size one products without tools and changeovers while maintaining production capacity. The engineering departments benefit from new possibilities for designing and producing special and customizable machine parts

independent from suppliers. Last but not least, 3DP supports companies to rethink their aftermarket and spare parts strategies and to establish new approaches with increased responsiveness and reduced costs.

The first movers that successfully adopted 3DP viewed it as a strategic move and had a clear vision of what 3DP presented to their business. EY can help companies understand the biggest value of the 3DP application for the business and help them trace a path to it. This follows a four-phased approach (see Figure 3):

- ▶ **Creating organizational awareness.** The aim of the first phase is to raise the level of the client's awareness, enabling joint working to identify 3DP potential.
- ▶ **Performing a 3DP diagnostic.** During the second phase, the focus is on identifying the areas of application and use cases that would bring the highest added value. To begin with, we work together with clients to understand the company's strategy, business model, product portfolio and efficiency challenges in the supply chain and operations. Based on the current operations performance and vision of future development, we help the client select the relevant product groups and operational areas within which to

Figure 3: 3D printing four-phased approach

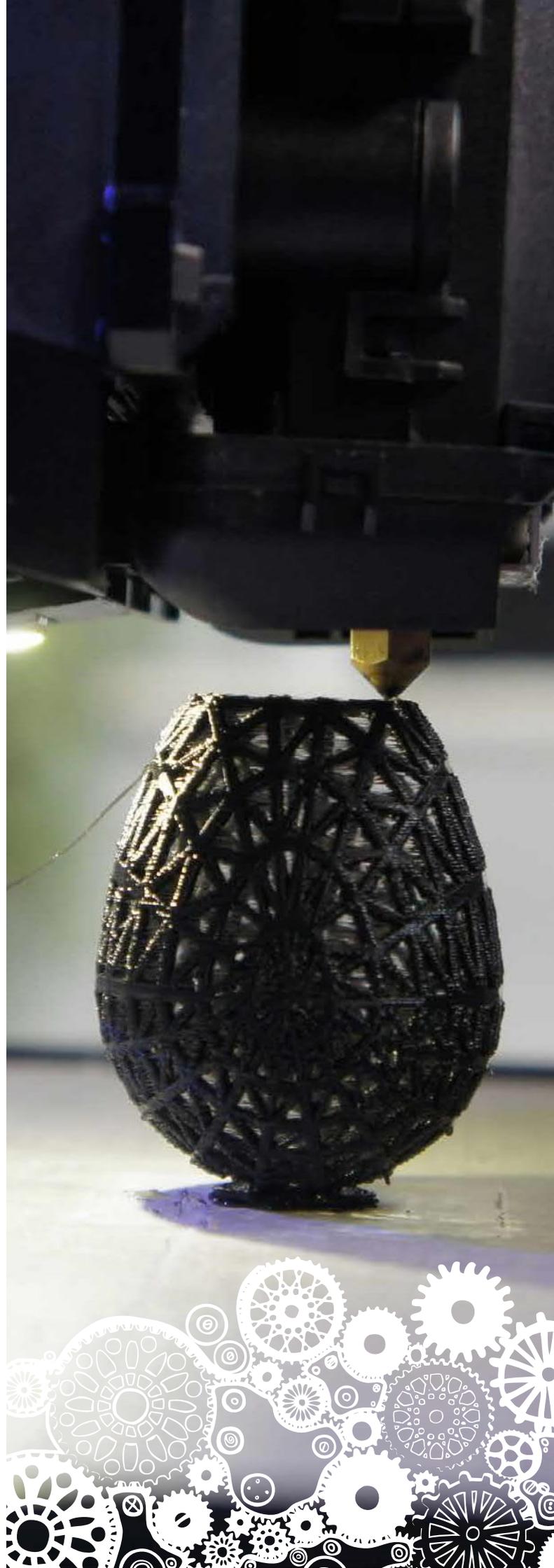


conduct deeper analysis. We help analyse further for printability and identify the added value from the redesign for 3DP. We then support estimates as to the impact of 3DP applications and the business cases for areas with the highest potential. Quantification of the impact is particularly important, since this can not only justifies the comparatively high investment but also demonstrates the impact the use of 3DP could have on customer value and on the value chain.

- ▶ **Developing a transformation road map.** In the third phase, we help consolidate, prioritize and build a three- to five-year transformational road map. Within this road map, we work with the client to define the aspects necessary for transforming the business and operations to support successful integration of 3DP. This also includes helping the client identify partners and providers, skills, organizational design and the specific type of 3DP application. Capturing the potential value of 3DP is not isolated to identifying the right use cases. Companies also need to build capabilities and redesign the organization in a way that can support the sustainable embedding of the 3DP technology into the company.
- ▶ **Supporting implementation.** In this phase, we support the client with the definition and implementation of operational processes that are required for the full and sustainable integration of 3DP in the organization and its supply chain. Creating early success in the implementation phase is critical to delivering sustainable value.

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