Hype Cycle for 3D Printing Technology in Manufacturing, 2023

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Initiatives: Manufacturing General IT Initiatives

3D printing is providing business advantages to manufacturers as its technologies continue to grow across many verticals. Business leaders and CIOs should use this Hype Cycle to identify capabilities of 3DP-related innovations and use cases with their potential opportunities and risks.

More on This Topic

This is part of an in-depth collection of research. See the collection:

- 2023 Hype Cycles: Deglobalization, AI at the Cusp and Operational Sustainability

Analysis

What You Need to Know

This Hype Cycle profiles a wide variety of 3D printing (3DP) use cases, technologies, processes, techniques and services meant to aid in the decentralized production of mainly low-volume parts and supplement existing manufacturing setups. CIOs, CTOs and other business and technology leaders should use this Hype Cycle to assess the hype and maturity of the innovations described, and understand the implied risks to adopt them.

3DP, an additive manufacturing technology, uses devices to create physical objects from digital models. The 3DP technology has different levels of maturity across various manufacturing industry verticals. With the evolution of the technology and increasing availability of cheaper printers, manufacturers are producing items, such as prototypes; tools, jigs and fixtures; finished goods; and spare parts utilizing various material types. This has helped users save costs, promote innovation, unlock or contribute to unlocking new revenue opportunities, and establish a more customizable, flexible and resilient manufacturing capability.

However, the implementation of 3DP can be resource-intensive and sometimes involves lengthy testing and developmental efforts. Hence, leaders throughout the organization must carefully assess the position of each 3DP innovation on the Hype Cycle, and recognize the associated risks and opportunities of adoption to better align 3DP adoption with their organization's strategic objectives and capabilities.

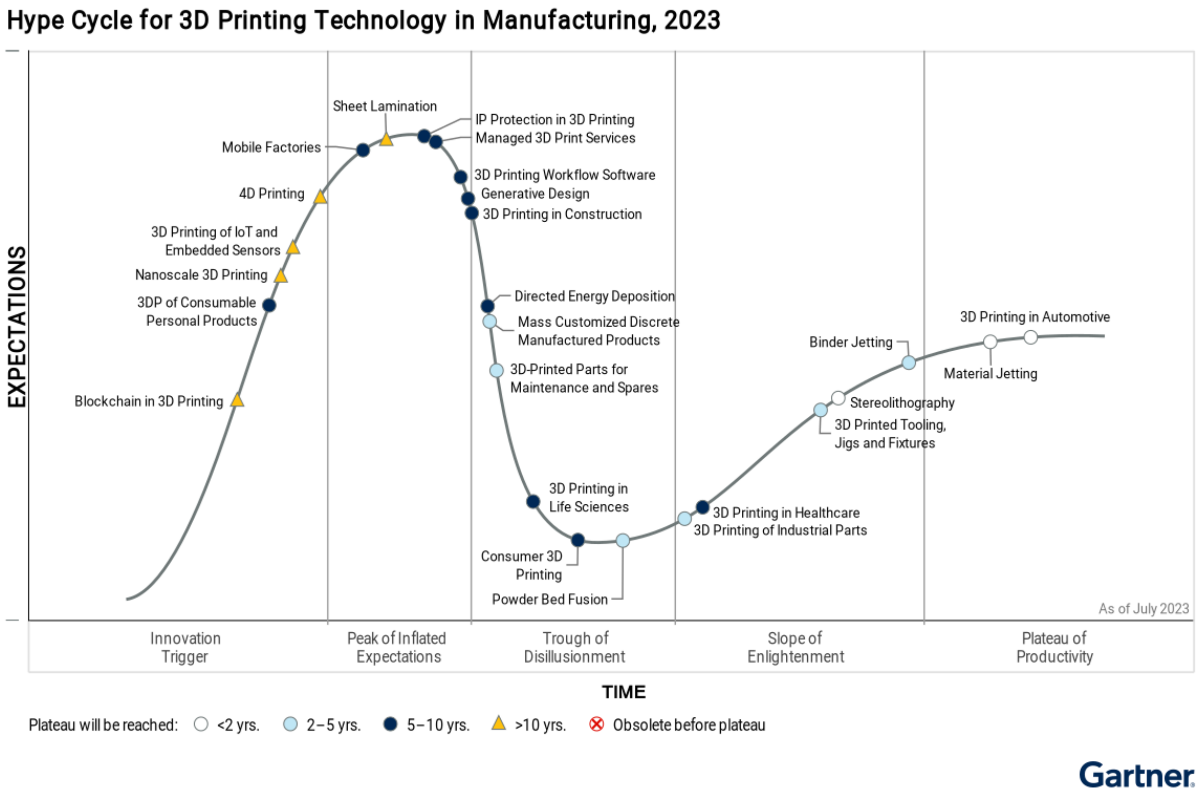
The Hype Cycle

The 3DP ecosystem comprises hardware, material and software providers, service bureaus and end users. 3DP technology adoption goes beyond the usage of hardware, such as printers and material, and includes software and services. This trend of collaboration has led vendors to partner with each other to innovate and optimize 3DP technologies and services, thereby resulting in the increasing maturity of 3DP profiles. CIOs and business leaders must prepare for the impact of innovations critical to their organization that are fewer than five years away from reaching mainstream adoption and should include the innovations in their plans for technology assessment. The major themes that emerged through this Hype Cycle are:

- 3DP techniques, such as powder bed fusion, material jetting, stereolithography and binder jetting are maturing and moving out of the Trough of Disillusionment and up the Slope of Enlightenment, due to increased development of the techniques and higher adoption by end users. However, limited applications of sheet lamination and directed energy deposition techniques in manufacturing keep them from maturing.
- Various 3DP use cases, such as 3D-printed tooling, jigs, fixtures and industrial parts, have gone beyond the Trough of Disillusionment as manufacturers start to attain a better understanding of their applicability, risks and benefits.
- Emerging technologies that are behind the Peak of Inflated Expectations (such as 4D printing, nanoscale 3D printing and blockchain in 3D printing) will take more than 10 years to mature, indicating the need for considerable efforts to bring about efficiencies across these technologies.

See the Hype Cycle Phases section to learn more about each phase.

Figure 1: Hype Cycle for 3D Printing Technology in Manufacturing, 2023



The Priority Matrix

The Priority Matrix illustrates when 3D printing will enable organizations to achieve some degree of benefit. Nine innovations encompassing technologies and services — primarily focused on 3DP manufacturing techniques and use cases — will reach mainstream adoption in fewer than five years. Five technologies will not see mainstream adoption for more than 10 years. Two of these, 3D printing of Internet of Things (IoT) and embedded sensors and 4D printing, however, will have a transformative impact on manufacturing industries. While there are no transformational innovations in the next two years, the short-term focus should be on the innovations with a high degree of benefit.

Organizations aiming to gain a competitive advantage and improve ROI on 3D printing must consider the dependencies and correlations between individual trends, technologies and services. For example, 3D printing of industrial parts and 3D printed tooling, jigs and fixtures are impacted by trends in powder bed fusion, material jetting printing techniques and the focus on mass customization and decentralized production. These and similar 3DP technology combinations benefit a wide range of industries — from industrial manufacturing, to automotive, to consumer goods, to life sciences and healthcare.

Another competitive differentiator arises as staff begin using generative design technology to create unique items and leverage workflow software to optimize the 3DP value chain. Equipped with their new expertise, personnel can advise senior management on whether to invest in 3D printers or to engage 3D printing service bureaus when appropriate.

Table 1: Priority Matrix for 3D Printing Technology in Manufacturing, 2023

(Enlarged table in Appendix)

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Transformational		Mass Customized Discrete Manufactured Products Powder Bed Fusion	Generative Design Mobile Factories	3D Printing of IoT and Embedded Sensors 4D Printing
High	3D Printing in Automotive Material Jetting Stereolithography	3D-Printed Parts for Maintenance and Spares 3D Printed Tooling, Jigs and Fixtures	3D Printing in Construction 3D Printing in Life Sciences Directed Energy Deposition IP Protection in 3D Printing	Nanoscale 3D Printing
Moderate		3D Printing of Industrial Parts Binder Jetting	3DP of Consumable Personal Products 3D Printing in Healthcare 3D Printing Workflow Software Consumer 3D Printing Managed 3D Print Services	Blockchain in 3D Printing Sheet Lamination
Low				

Source: Gartner (July 2023)

Off the Hype Cycle

- Material Extrusion: It is the simplest 3D printing technology and has witnessed wide-scale adoption across manufacturing verticals. Most organizations have a considerable understanding of the technology. Thus, it has matured off the Hype Cycle. Material extrusion is particularly compelling for prototyping because of the low cost of the 3D printers and plastic materials.

- 3D Print Creation Software: Commercial 3D model creation software (i.e., 3D computer-aided design [CAD]) has been available since the late 1970s, and 3D printers that interpret those models for printing have been available since the 1980s. High maturity has led to this technology's movement off the Hype Cycle. This type of software continues to be rapidly adopted for 3D printing, while online libraries facilitate the use of 3D model-creation software by experienced and novice users alike.

- 3D Scanners: Given the broad adoption of 3D scanners, this technology has gone beyond hype and into reality, with low-end 3D scanners now available for less than $150. Scanner capabilities prove to be increasingly well-suited for consumers, as well as larger enterprises as continued technological advancements include improved ease of use, increased functionality and lower 3D scanner prices.

- 3D Printing Service Bureaus: Organizations considering additive manufacturing engage print service bureaus to mitigate their investment risk, fill gaps in 3D printing expertise, provide test/pilot access to technology and accelerate the pilot process. Due to the wide-scale adoption and exposure of manufacturers to 3DP service bureaus, this has gone beyond the hype and has been moved off the Hype Cycle.

- Enterprise 3D Printing: Enterprise 3DP is a mainstream market with applications crossing many industries, whether the parts are produced with an in-house printer or through a 3D print service bureau. It has moved beyond the Plateau of Productivity and is considered normal, unhyped technology.

- 3DP in Oil and Gas: The priorities and roadmap for 3D printing in oil and gas have consolidated and strengthened, making this a mature use case. Since there are similarities in applications, this profile has been combined with others, such as 3DP of Industrial Parts, 3D Printed Tooling, Jigs and Fixtures, and 3D Printed Parts for Maintenance and Spares.

- 3D Printing in Retail: Major hardware technology advances, anti-counterfeiting software to protect a company's intellectual property and testing of the viability of 3D-printable materials are signs that the 3DP in the retail market is growing. Due to considerable similarities between this innovation profile and the consumer 3DP innovation profile, they have been merged in this version.

- 3D Printing in Supply Chain: Advances in hardware, software and materials have made 3D printing a more viable process across the supply chain. The technology has impacted supply chain strategies by enhancing existing supply chains and defining new ones. This innovation profile has been split up and included with other innovation profiles, such as 3DP of Industrial Parts, 3D Printed Tooling, Jigs and Fixtures and 3D Printed Parts for Maintenance and Spares.

- 3D Printing in Aerospace and Defense: Aerospace and defense manufacturers are exploring ways that the technology can simplify production processes and reduce the lead time for production of finished goods. As the material science behind 3D printing industrial parts continues to improve, use of 3D parts in aircraft and weaponry is maturing from prototyping to other use cases. Hence, this innovation profile has been split up and included with other innovation profiles, such as 3DP of Industrial Parts, 3D Printed Tooling, Jigs and Fixtures and 3D Printed Parts for Maintenance and Spares.

- 3D Printed Wearables: The profile on 3D printing for wearables, focused on production of customizable, unique and fashionable wearable devices through 3DP, has been added to the profile of 3D Printing of IoT Devices and Embedded Sensors.

- Printed Electronics: 3DP of electronics is beneficial due to the capability of printing on uneven surfaces, mass customization, material wastage, simplified assembly, absence of harmful chemicals and protection from external damage. As 3DP helps create small-sized parts, this use case has been split up and combined with the Nanoscale 3DP and 3D Printing of IoT Devices and Embedded Sensors innovation profiles.

- Classroom 3D Printing: 3D printing has practical and pedagogical benefits that make it a good tool to use in education and research. Due to falling costs and specific applications, we see widespread use of 3DP across education and dropped due to decreased client interest.

- 3D Bioprinted Organ Transplants, 3D Printed Surgical Implants, 3D Bioprinted Human Tissue, 3D Printed Presurgery Anatomical Models, 3D Printing of Dental Devices and 3D Printing in Healthcare: These innovation profiles have been combined into the new 3D Printing in Healthcare profile.

- 3D Printed Drugs, 3D Printing of Medical Devices and 3DP Bioprinting for Life Science R&D: These innovation profiles have been combined into the new 3D Printing in Life Sciences profile.

On the Rise

Blockchain in 3D Printing

Analysis By: Sohard Aggarwal, Ivar Berntz

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Blockchain in 3D printing (3DP) is an expanding list of cryptographically signed, irrevocable transactional records shared by all participants in a 3DP network. With collaborative manufacturing demands for improving the speed of delivery for 3DP-related assets, blockchain has potential impact across manufacturing phases: designing, developing, validating and executing 3D-printed transactions.

Why This Is Important

Blockchain technology has the potential to enable new business models and even improve trust in manufacturing ecosystems. Manufacturers look to utilize distributed manufacturing networks or engage in co-developing products and designs. So trust, cybersecurity, intellectual property (IP) theft and protection or even malicious data could be sources of vulnerability. Blockchain encryption can facilitate secure and traceable interorganizational or intraorganizational data exchanges.

Business Impact

Besides the potential for embedding trust and control among the participants in the 3DP value chain, blockchain will:

- Enable better protection of IP and higher level of cybersecurity.
- Generate greater operational savings and lower costs by eliminating the intermediaries involved with brokering transactions.
- Allow better usage of distributed innovation and supply chain models and faster connections between independent or smaller 3DP stakeholders in a product development or fulfillment process.

Drivers

Blockchain in 3DP is early in the Innovation Trigger phase and has embryonic maturity. The following factors can accelerate adoption:

- The 3DP value chain has multiple stages: concept, computer-aided design (CAD), bill of materials, actual printing process and quality checks. Each of these steps represents a vulnerability in the system. Applying blockchain in 3DP printing can provide security as well as traceability of the movement across this value chain.
- Enterprises can explore blockchain for IP protection, preventing counterfeiting and adding compliance into service-oriented printing runs. Manufacturing organizations evaluating distributed production or contract manufacturing need higher levels of governance and cybersecurity to combat the threat of data, design and IP theft. Blockchain deployment can facilitate these requirements.
- The existing 3DP service bureau ecosystem is rapidly expanding, with new firms, as well as existing legacy 3DP instrument vendors. They will likely have some involvement and could see blockchain in 3DP, as the companies that don't evolve will ultimately be threatened by competing business models.
- Blockchain can be utilized to certify and validate production output based on original parameters and designs. It ensures that products are produced with the correct production output to prevent other parties from reselling. In doing so, it ensures IP is not being replicated for other purposes.
- The convergence of 3DP, AI and blockchain can help product designers and manufacturers to analyze, evaluate and optimize 3D products at the design stage to secure the design files to prevent counterfeiting.
- 3DP has the potential to enable microfactories or rapid prototyping and product development, or new business models, including product personalization. So blockchain in 3DP can be used to improve trust and traceability among participants.

Obstacles

- Applying blockchain into 3DP transactions, especially in distributed co-collaboration environments with multiple parties, appears to be an attractive avenue for securing a series of events. However, quantifying and measuring real value such as ROI will be extremely difficult.

- Storage of large CAD files in perpetuity across a network with any semblance of performance will be difficult to engineer. However, it remains unclear which data can and should be transacted over blockchain, and what value blockchain provides against conventional technologies like cloud- and SOA-based applications. Additionally, security and transaction formats dealing in file transfer protocols with the printing services need to be standardized before implementation.
- Numerous vendors selling blockchain are struggling with how to assemble the right technology stacks. In most cases, clients are still not convinced that the business cases justify the risk.

User Recommendations

- Start by mapping the technical, operational, logistic and partnering details before implementing a proof of concept (POC). Building the business justification for "Why blockchain?" is essential. In most cases, other cloud-based technologies and workflow process applications that are more centrally manageable and secured are more viable.
- Factor both the scalability and suitability into the economics of the decision-making process. Several options can implement a blockchain-based system and a spectrum of permissions, algorithms and environments.
- Manufacturers with high digital maturity and appetite for risk: Look to build or invest in a blockchain platform with a larger partnering entity, such as IT and contract services firms that have an industry-based or functional specialty.

Sample Vendors

Assembrix; CoreLedger; Data Gumbo; General Electric; SIMBA Chain; Vistory; Wipro

Gartner Recommended Reading

Guidance for Blockchain Assessments

Emerging Tech Impact Radar: 2023

Quick Answer: Emerging Product Quality Technologies in Quality

Use Digital to Achieve Sustainability Goals

Supply Chain Executive Report: Fostering a Digital Supply Chain Ecosystem

3DP of Consumable Personal Products

Analysis By: Ivar Berntz

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

3D printing (3DP) of consumable personal products uses a 3D printer to create custom products that are edible or can be applied on the body.

Why This Is Important

While the concept of personalized and consumable 3D-printed products has been around for decades, Gartner has recently witnessed a rise in the commercialization of 3DP for food and personal care products. Though the number of 3D food printer manufacturers is low, research is taking place in academic institutions. Further, 3DP is being used to produce personal care products, which are augmented by the technology's capability of rapid prototyping and innovative product development.

Business Impact

Consumers want more-personalized choices, faster. 3DP and other customization technologies create the expectation that food and other consumable products can be personalized. We expect this technology and its applications to continue to develop and climb the Hype Cycle toward the Peak of Inflated Expectations. In select cases, consumers are already able to customize products through printers owned by them or by stores — for example, accessories for Ford cars or mobile phone cases and screen protectors.

Drivers

- **Personalization:** Consumers' demand for personalized products is increasing, which can be delivered more rapidly through 3DP. In use cases like customization of food products, such as cakes catered to a particular event, 3DP provides the opportunity to be creative and produce intricate food designs, saving both time and resources. Additionally, the use of 3DP to produce personalized medicine and cosmetics has surged, as the precision of 3DP helps in delivering treatments to better serve each unique consumer.

- **New product development:** 3DP offers design and structural freedom, leading to development of in-house capabilities, such as prototyping, design verification and consumer testing. The freedom to design products has also led to the use of technology in personal care product packaging, such as cosmetics and perfumes. Since it is an additive procedure, expensive raw materials and resources are not wasted.

- **Functional food and nutrition:** Due to the precise design process, the technology also helps create edible products with precise amounts of nutrients required by a particular consumer's health. Tracking the quantity of vitamins and carbohydrates in food products also helps meet quality and safety standards.

- **Sustainable sourcing:** With a growing population, there is an increased chance of food shortages around the world. 3DP can produce food products with fewer ingredients used, such as algae, insects and seaweed. Additionally, the technology helps reduce waste by converting imperfect or unsellable food into visually appealing food that individuals with digestive issues can consume.

- **Technology evolution:** Advancements across printing technologies, such as materials extrusion, powder-based printing technologies, selective laser sintering and binder jetting, are driving growth in use cases of consumable products.

Obstacles

- In line with 3DP adoption challenges across industries, the investment cost of equipment and limited materials options remain major challenges for the technology in the retail industry as well. The cost is further increased by the need for skilled labor to design consumable products.
- There is a high dependency on properly preparing edible materials to ensure consumers' safety and palatability. The ingredients required to produce 3D-printed food products need to be precooked or preprocessed to achieve the consistency necessary for extrusion.
- Additionally, fluctuating temperatures during the 3DP process of food products may result in the growth of microbes and contamination of the food.
- Technology adoption should meet regulatory and policy guidelines set by regulatory bodies, such as the U.S. Food and Drug Administration (FDA), which may be a challenge for some use cases.
- Further, there is a need to safeguard intellectual property related to personal products' design and ingredients.

User Recommendations

- Partner with the finance, marketing, engineering, operations and legal teams to validate the viability of 3DP technologies.
- Develop internal guidelines for policy, quality, practice and regulation to ensure consumers' safety, and apply them with the same rigor as for traditional modes of production.
- Hospitality and food service and processing industries: Explore unique benefit areas of 3DP, and offer high-value, high-price, custom-printed foods at weddings, social events and business meetings. Reconstitute imperfect or unsellable food to manage waste and create new, more visually appealing foods that individuals with digestive issues can consume.
- Cosmetics and consumer health product companies: Follow market development and government guidelines related to 3D printers and materials that could be leveraged to print topical products and medications, with an aim to ensure consumer safety.

Sample Vendors

3D Systems; byFlow; The Digital Patisserie; Mink; Natural Machines; PancakeBot; Print2Taste; SavorEat

Gartner Recommended Reading

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Guide for 3D Printer Manufacturers

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

The Manufacturing CIO's Role in Adopting and Scaling 3D Printing

Nanoscale 3D Printing

Analysis By: Michael Shanler

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Nanoscale 3D printing (3DP) is the use of specialized additive manufacturing technology and related processes to create minute, intricate structures and/or features with high aspect ratios. Nanoscale objects are measured in micrometers.

Why This Is Important

Nanoscale 3DP could be leveraged for miniaturization efforts, developing new medicines, in vivo medical devices, espionage tools, microsensors, artwork, microrobotics and printable electronics. The use of 3DP technology for micromanufacturing and nanomanufacturing is still in the R&D phase, with close collaboration between corporate development engineers and university researchers.

Business Impact

Nanoscale 3DP represents the intersection of 3DP, engineering design, science, physics and chemistry. Nanoscale 3DP has a strong potential relationship with 4D printing, where the fourth dimension represents an activity such as movement or a dynamic response of the printed item over time. Interest in technical partnerships and co-development efforts, and internal R&D projects by 3DP hardware providers, are beginning and could affect medicine, information security, art and electronics.

Drivers

- General trends for miniaturization of technology, and reductions in costs for optics, sensors and automation, are major drivers creating opportunities for nanoscale design, inspection and production systems.
- A variety of research and technical universities are driving nanoscale 3DP laboratory and experimental activities, including Jilin University (China), Rutgers, University of California-Irvine, University of Southern California, Penn State University and Ohio University. Research institutes working on nanoscale 3DP include HRL Laboratories and The National Centre for Metallurgical Research (CENIM) (Spain). Application areas include chemical sensors, biosensors, actuators and microfluidic circuitry.
- Today, nanoscale requires not only specialized 3DP equipment and optics but also additional postprinting processing steps — both mechanical and chemical. R&D investigators are reporting that operating at this scale requires specialized approaches and new procedures for printing, processing and inspection.
- Costs in R&D are escalating across all industries, putting extra pressure on R&D groups to speed up previously lengthy tasks, produce less waste and automate processes wherever possible.

Obstacles

- Commercializing and scaling 3DP in a robust process is still a risky and likely resource-intensive endeavor, which cannot be ignored until there is more progress with proofs of concepts (POCs) and R&D efforts.
- Major technical challenges persist, involving the liquid materials used to create prints. This is due to the grain size of premixed slurry or powdered material that can impact the resolution of the end part. There are also some concerns about toxicity of nanosized particles, which will require further safety testing.
- As of 2022, there are only a handful of companies selling 3DP software or equipment for manufacturing at the nanoscale level. For this reason, the technology is positioned very early in the Hype Cycle, in the Innovation Trigger phase, and will still take more than 10 years to reach mainstream.

User Recommendations

- R&D engineers, technologists and new product development stakeholders should keep nanoscale 3DP on the watch list, as the technology could lead to new product innovations. This technology is currently buried deeply in university and corporate R&D.
- Form partnerships to explore new areas such as nanodeposition, micro-electromechanical systems (MEMS) and focused electron beam-induced deposition (FEBID).
- Support engineering, design and inspection platforms that have the suitable CAD or product life cycle management (PLM) plug-ins.
- Plan POCs for IT data models and inspection techniques for advanced imaging and image analysis.
- Engineering and scientific leads interested in mitigating risks for nanoscale 3DP should seek out academic partners and collaborators to help refine the technology and run proofs of concept. PLM, computer-aided design (CAD) and 3DP process leaders should work with vendors to ensure realistic roadmaps can support internal workflows.

Sample Vendors

3D Systems; Boston Micro Fabrication; Fraunhofer IMM; Heidelberg Instruments; Nano Dimension; NanoScale Systems; Nanoscribe; Nanowerk; Stratasys; UpNano

Gartner Recommended Reading

Emerging Tech: 2D Materials Will Propel the Semiconductor Industry Into a New Era

Emerging Technologies: Emergence Cycle for Alternatives to EUV Lithography Technology

Healthcare and Life Science Business Driver: Medical Technology Innovation

3D Printing of IoT and Embedded Sensors

Analysis By: Ivar Berntz

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

3D printing of Internet of Things (IoT) and embedded sensors entails the creation of parts and products with embedded electronics. This allows the development and production of smart devices and products with software configurable functionalities for recreational and professional purposes.

Why This Is Important

3D-printed smart devices have the potential to revolutionize the way we interact with IoT and increase the scope of IT significantly. By embedding sensors, actuators, logic circuits and connectivity directly into 3D-printed objects, it is possible to create an interactive and responsive environment. Examples range from remote-controlled 3D printer parks, home-printed objects with Wi-Fi and edge computing, or entire smart factories, able to operate autonomously.

Business Impact

Embedding sensors in the process is supportive to more widespread use of 3D printing, in general. 3D printing could enable more affordable mass customization of products and devices. This could allow for a much more personalized user experience, to create internet-connected smart devices that can communicate with one another as well as reduce waste or increase efficiency in manufacturing, logistics, etc.

Drivers

- 3D printing of embedded sensors and IoT devices is well suited for prototyping, as design changes can quickly be printed out and tested, accelerating new product development.
- 3D printing of IoT devices can also reduce costs by replacing traditional silicon circuits with 3D-printed plastic circuits.
- Wireless sensors are already responsible for many IoT functions. In the future, as we see the development of applications ranging from smart cities to better connected healthcare implants, these sensors are possibly going to be even more important.
- 3D printing is sometimes the best option to print intricate designs and geometries. It can be used to create precise custom-shaped or custom-sized objects with sensors or IoT capabilities for a variety of purposes.
- 3D printing promises to do to physical objects what the internet did for information — make almost everything accessible from almost anywhere with a printable, eventually wearable, plastic device that almost anybody can use. Yet, IoT devices are typically fragile electronic circuits used in environments that were never designed for them (for example, Circuit Digest's IoT Based Smart Agriculture Monitoring System). With a 3D printer, one can also custom print a container for an IoT device.
- It's attractive for construction, machinery, jewelry, wearables, etc., because of the concept of being able to integrate an IoT sensor into everything that is built, e.g., 3D-printed bridges (as is the case of a pedestrian steel bridge in Amsterdam (IET), but also in concrete in remote places) or buildings, to sense concrete cure, traffic load or general condition.

Obstacles

- No standardization. There are a multitude of different 3D printing technologies and materials available, which makes it difficult for companies to invest in the technology.
- R&D efforts are still in the basic research phase, not the applied phase. For 3D printing to reach its full potential in the IoT era, there needs to be more standardization among different technologies, materials and system integration.
- Cost of printers and materials are still expensive when compared to alternative manufacturing technologies. Also, the cost of materials can be quite high.
- There are no high quality proof of concepts (POCs), meaning that this innovation will need to mature a bit more before there's a clear path to value.
- Material combinations are difficult. This may require new technologies and close collaboration between engineering, material scientists and marketers to create the right use cases and achieve necessary physical characteristics.

User Recommendations

When involved in deciding which categories of IoT products are good candidates for 3D printing, consider that you may:

- Design without typical manufacturability constraints as IoT device miniaturization requires tiny and delicate parts that are difficult to manufacture using traditional methods anyway.
- Create fully functional prototypes as 3D printing makes the prototypes easier and quicker to deploy.
- Prototypes can be made attractive from the onset so they sell. The customers want to feel the products with their own hands. 3D printing allows the design of a good-looking product.
- Include functions for monitoring and maintenance of assets. This could include the 3D printers themselves, the printed products and also their changes over time. As 4D printing matures, there will be a potential opportunity for IoT to be involved in monitoring the response of printed parts to external stimuli.

Sample Vendors

Anycubic; Elegoo; Fictiv; Peopoly; Protolabs

Gartner Recommended Reading

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Important and Compelling Innovations for Commercial IoT Use Cases

4D Printing

Analysis By: Michael Shanler, Mim Burt

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Four-dimensional printing (4DP) is a technique whereby the materials are encoded with a dynamic capability — either function, confirmation or properties — that can change via the application of chemicals, electronics, particulates or nanomaterials. The printing technology includes added functionality to sequence, mix and place specific materials that will have a calculated effect.

Why This Is Important

- 4DP is an emerging technology in the emergent stage. This technology adds another dimension to the 3D printing (3DP) process by creating an object designed to change shape after it leaves the print bed.
- The concept of this “shape-shifting” technology is being developed through collaborative efforts between academia and technology firms.
- This technology will drive next-generation materials and innovations making it possible to create technology-based products that could disrupt the life science industry.

Business Impact

4DP will have significant impacts on design. While smart materials, which represent the "fourth dimension" for materials, have actually been around for several decades, usage of 3DP technology to drive 4DP is a rather new development and has a lot of interest from R&D teams. It could be used to make complex devices without the need for assembly.

Drivers

- This technology will soon reach the Peak of Inflated Expectations as scientific advancements in biology, chemistry, electronics and 3DP will accelerate 4D printing beyond proof of concept testing.
- Over the next two years, 4DP research will generate interest and hype, especially as traditional 3DP technologies, which operate as a platform for 4DP, become widely adopted.
- Shape-shifting materials have already been leveraged in the automotive, aerospace, defense and medical industries. Dynamic and self-assembling materials have already begun to disrupt the way engineers think. These possibilities are all innovation drivers that will accelerate this technology.
- R&D teams are seeing advances in material science and are looking to include new technologies to innovate product designs and functions.
- Shape-shifted materials that can reduce the drag coefficient of an airplane or vehicle during different environments might help optimize efficiency.
- 4DP designed medical devices such as stents and heart valves can adapt to the volumetric space with biorheology-based precision.
- The sole of an adaptive running shoe can adjust to wet versus dry pavements and improve grip.
- A self-assembling medical stent can reduce surgery times and improve patient outcomes.
- Implants can change shape once they come into contact with body heat to conform with wound areas and lead to better surgical outcomes.
- A dynamic valve in an irrigation system can improve irrigation on a farm. A roof on a house could change form to facilitate draining, and walls could increase or decrease in thickness during the winter or summer to improve insulation values.

Obstacles

- Material science research for 3DP is still an underserved market. Software is still at a niche stage for programmable materials with self-assembly characteristics. Modeling the geometries, determining interactions for changing states and calculating the energy (such as those from heat, shaking, pneumatics, gravity and magnetics) is not an easy task.
- Scientists, engineers, and product designers haven't put as much effort into dynamic materials, as there are fewer options to be trained on disciplines. The technical risks and potentials for technology use to enhance product experiences is still more nascent within the industry.
- An immense number of scientific and formulation-based patents may impact business cases for new materials, applications, and scientific and engineering areas.

User Recommendations

- Determine how 4DP can drive product innovation with engineering and product teams. Ask those teams about requirements for infrastructure, data and informatics.
- Evaluate, with business leads, the best approach for bringing in the technology. Do quick scenario planning with a focus on skills, technology, governance and data to play out "build, buy or rent" scenarios.
- Investigate partnerships as the primary method for getting into the game with either current 3DP vendors or academics with materials expertise and capabilities.
- Improve 4DP processes through R&D partnerships with material companies to develop and enhance specifications for 4D-suitable materials.

Sample Vendors

3D Systems; Autodesk; ExOne; Geosyntec; HP Inc.; Materialise; MIT; Organovo; Stratasys

Gartner Recommended Reading

Market Trend: 3D Printing Increases Production Flexibility for Manufacturers

Quick Answer: How 3D Printing Helps Manufacturing CIOs Contribute to Sustainability and Circular Economy

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Trend: Emergence of Design and Manufacturing Marketplaces

At the Peak

Mobile Factories

Analysis By: Simon Jacobson, Ronak Gohel

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Mobile factories are self-contained production units constructed of ready-for-use modules that can be deployed into markets and assembled at a fraction of the traditional time, cost and risk of conventional capacity.

Why This Is Important

Localizing manufacturing operations raises the importance of operational resilience even as cost efficiencies pressure organizations. Mobile factories are an innovative way to develop highly flexible, fit-for-purpose capacity at less cost and lead time than to stand up a traditional site. Early adopters that have operationalized this strategy often aim to provide greater options to customers and explore demand in uncertain new markets with the intent to scale up, should the market be profitable.

Business Impact

Mobile factories are an innovative approach to leveraging technology and creating resiliency in the network. They offer simplified production setups, improved resource utilization, and significantly lower capital investment and scale-up time — all without risk to competitiveness, flexibility or compliance.

Drivers

- Localizing manufacturing networks and activities to meet personalized demand with minimal risk

- Leverage of competitive ambition, innovation capability and standard processes for deploying modular, flexible and cost-efficient production capacity at a fraction of capital expenditure

- Surging interest in smart factories. Specifically, capacity that utilizes interoperable plug-and-play combinations of new manufacturing techniques and automated systems
- Capitalizing on technologies supporting distributed and localized production, including edge/cloud architectures, digital twins for modeling, simulation and virtual commissioning, and remote monitoring of production assets

Obstacles

- Supply chain as a service (SCaaS) and varied external manufacturing options might be more viable options to lower costs and risk in certain geographies and industries. Current adoption and investigation is from life sciences and consumer products manufacturers.
- Capital planning processes and collaboration are misaligned across supply chain, manufacturing, and engineering.
- Growing product volumes and mixes stretch the limits of fit-for-purpose capacity.
- There is a need for access to infrastructure and resources on a local scale (includes raw materials, skills, and technology).
- Local compliance and environmental regulations are dynamic and uncertain.
- Realizing mobile factories is broader than 3D printing. Coordinating an ecosystem of technology suppliers and OEMs requires significant internal collaboration.

User Recommendations

- Focus on portions of the business where the customer and business requirements are fluid to define design agility for changing the operating model.
- Examine the up-and-downstream network designs during long-term planning. Raw materials order patterns and distribution networks might have to be reconfigured.
- Collaborate with machine builders and technology partners to develop standard configurations for accelerated ramp-up and cost-effective ongoing maintenance.
- Investigate local infrastructure, tax laws and government subsidies, and labor availability to ensure feasibility.
- Embed mobile factories as one kind of capacity orientation within a broader smart factory portfolio.

- Define the sustainability impact of mobile factories, including greenhouse gas and circularity advantages, versus other network solutions.
- Develop a transfer or wind-down strategy. Not all mobile factory deployments will be successful. This requires firm time frames on when to see results by running cost models to evaluate total costs to serve against commercial price points.

Gartner Recommended Reading

Global vs. Regional Supply Chains — Identifying the Right Approach for Your Network

3 Types of Process Agility Enable Supply Chains to Thrive During Change and Uncertainty

Build Segmentation Into Your Manufacturing Strategy to Deliver Business Outcomes

Tool: Evaluating Countries for Manufacturing Site Selection

Sheet Lamination

Analysis By: Ivar Berntz

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Sheet lamination is a 3D printing (3DP) technology in which material is bonded to form an object. Sheet lamination involves impregnating thin sheets of paper with an adhesive, ultrasonic welding of metal sheets or jetted adhesives that bond sheets of composite materials. Unlike any other additive manufacturing technology, sheet lamination enables 3D printing of polymers, metals or paper, albeit with totally different devices.

Why This Is Important

Sheet lamination is climbing to Peak of Inflated Expectations very slowly. It is the 3D printing technology with the fewest number of printer hardware providers. A few of the technology's hardware providers no longer offer this solution. However, the technology is well-suited for certain subindustries such as consumer packaged goods (CPG) and retail. This checkered performance is affecting the position that sheet lamination technology has on the Hype Cycle.

Business Impact

The sheet lamination process can be used in laminated-object manufacturing to quickly produce prototypes for CPG and retail industries. One interesting application is in the development of product packaging, with an opportunity of using carbon fiber lamination to achieve high structural strength. Marketers find that office paper closely simulates paper-packaging substrates, and that, when inkjet-printed, looks very close to the finished package.

Drivers

- With easily accessible raw materials, large build areas and no need for support structures, sheet lamination printers result in faster production time compared to other technologies.
- Additionally, the total cost of ownership, including the printer and raw materials, is low compared to other technologies capable of printing larger products.
- While this technology is not generally suitable for the production of functional parts, it is well-suited for producing models. This makes it suitable for research and development of prototypes. However, carbon fiber is now being used to create parts with structural strength.
- A wide range of vertical markets could benefit from the woven-fiber parts that can be created by Impossible Objects. Its fiber fabrics include carbon, glass and Kevlar, as well as polymers, including polyamides and polyether ether ketone (PEEK).

Obstacles

- One of the major challenges for sheet metal technology continues to be the limited number of materials that can be printed. It can print parts with sheets of paper, plastic, fiber and some metals.
- As opposed to other 3DP technologies, the resolution of the layer that is printed cannot be changed and will be based on the thickness of the sheet.
- Production of parts smaller than the size of the sheet leads to wastage of raw materials impacting the sustainability parameters. Additionally, postprocessing for this technology varies with the type of raw materials used.
- A few companies that used to offer this technology are either shut down or have changed their products due to limited application and higher adoption of other 3DP technologies. For example, Solido and Mcor Technologies are no longer operational and ETEC does not offer the lamination systems.

User Recommendations

- Work with engineers and marketing personnel to adopt the sheet lamination's paper-based technology for new product prototypes, mechanisms, figurines, medical models, decorative finished goods and packaging material.
- Prepare to make a trade-off between material performance and bond strength, especially when engineers look at this technology to deliver parts with complex internal structures, strong materials and physical properties such as electrical conductivity.
- Review the lamination of woven materials for CPG, aerospace, automotive, industrial, medical device, sporting goods and other large-format applications.
- Assess the sheet lamination technology while printing parts from either paper, metal or composites.
- Leverage sheet lamination technology to create educational models as per school curriculums at all levels, as this technology has one of the lowest raw material costs out of the 3DP technologies.

Sample Vendors

Fabrisonic; Impossible Objects

Gartner Recommended Reading

Market Trend: 3D Printing Increases Production Flexibility for Manufacturers

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Guide for 3D Printer Manufacturers

IT/OT/ET Alignment With 3D Printing Enhances Scalability

IP Protection in 3D Printing

Analysis By: Ivar Berntz, Marc Halpern

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Intellectual property (IP) protection in 3D printing refers to practices and supporting technologies that protect creations from anyone attempting to illegally use, license or distribute that innovation. Such creations include inventions, literary and artistic works, product designs and symbols, and names and images used in commerce.

Why This Is Important

Technologies to prevent IP theft using 3D printers continue to climb from the technology Innovation Trigger to the Peak of Inflated Expectations. Since IP protection remains a joint legal and research and development (R&D) activity, organizations are scrambling to put controls in place. While some of the more established commercial IP-tracking solutions are proving to be only partially capable of safeguarding a company's ideas and design properly, new 3DP-centric services are becoming more important.

Business Impact

Numerous parties are involved in the process of producing 3D-printed goods due to multiple business models for 3D printing (3DP) adoption, such as company-owned printing hardware and software, assistance of a 3DP service bureau or a hybrid setup. This increases the need to safeguard a company's IP. Enterprises that do not protect their IP lose competitive advantage, resulting in financial losses and lost growth opportunities.

Drivers

- The cost of 3D printers and 3D printing services continues to decline, while the quality of printed parts they can produce improves, resulting in an increased uptake of the technology across the companies' value chains. These high-quality product designs are often of a proprietary nature and hence need to be safeguarded, especially when engaging with a 3D printing service bureau.
- The declining cost of 3D scanners, which can be used to easily steal shapes and designs to 3D print, further increases the likelihood of IP theft. Therefore, such IP protection technology will continue to gain importance as manufacturers increasingly adopt 3D printing to produce parts and products from a growing number of material types.
- Some organizations may redefine their value propositions and business strategies to emphasize value-added services and their ecosystems that serve customers, such as offering proprietary designs as digital products, rather than prioritizing the physical content of products as the key value proposition.
- Implementation of IP protection practices will lengthen design, R&D and manufacturing processes. Yet these practices supported by technology will also make engineer-to-order businesses more scalable. Nevertheless, such IP protection technology and practices will increasingly become an integral part of 3D print creative and production processes.
- Initiatives such as the Registered Community Designs in the EU promote the protection of designs in the region, as it offers the company the exclusive right to use the design under one application.

Obstacles

- Search engines that compare 3D objects are in the early adoption phases for sourcing parts and creating an extension to IP protection. They show promise, but are immature.
- 3D design marketplaces are highly susceptible to IP theft and fraudulent activities for the owners/designers of the assets.
- Concerned parties will need to tighten governance of sourced parts to ensure that the parts and materials they purchase are from the original sources that own the IP. Blockchain technologies can support this traceability. Enterprises knowingly using, or suspected of using, counterfeit parts will be vulnerable to lawsuits or charges of criminal activity. In order to protect them from this liability, they will need to invest in proper processes and their governance.
- Traditional manufacturing IP has predominantly been sought in a company's primary geography, with risks of infringement in other regions. However, 3DP offers decentralized operations, making it necessary for companies to opt for both idea and design protection globally.

User Recommendations

CIOs and IT leaders should:

- Invest to secure the digital thread that connects the flow of data from conception of design to production. This can take multiple IP protection perspectives, including securing content such as 3D models used to create 3D prints. For example, 3D Control Systems advertises a specialized console to protect content and print 3D parts that is compliant with COBIT and Health Insurance Portability and Accountability Act (HIPAA) regulations, with audit logs and complete accountability of IP.
- Leverage tools such as digital asset management software and product data management software to control access to digital content.
- Work with teams to create markers that authenticate objects.
- Work with their peers to redefine business strategies to reduce the potential impact of IP theft or introduce steps into manufacturing, service and sourcing to ensure that original and replacement parts are not counterfeit.

Sample Vendors

3D Control Systems; Applied DNA Sciences; Authentise; Identify3D; InfraTrac; Leo Lane

Gartner Recommended Reading

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Quick Answer: Mapping Design for Additive Manufacturing Tools to 3D Printing Use Cases

Market Trend: Emergence of Design and Manufacturing Marketplaces

IT/OT/ET Alignment With 3D Printing Enhances Scalability

How to Protect Your Innovation’s Intellectual Property

Managed 3D Print Services

Analysis By: Ivar Berntz

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Managed 3D print services (M3DPS) are offered by an external provider to manage a 3D printing (3DP) environment. An M3DPS provider takes primary responsibility for the provisioning of 3DP devices, materials and operations, and maintenance support either on-site, off-site or both. M3DPS may also include software to manage workflows, chargebacks for 3D technology use and solutions to secure 3D printers.

Why This Is Important

M3DPS encompasses services offered by external providers to optimize or manage a company's 3DP initiatives to achieve objectives such as faster new product introduction, monitoring and maintenance of 3D devices and workflow, productivity or efficiency improvements, securely. It is at peak hype, with many entrants claiming it avoids the costs and risks associated with the introduction of leading-edge technology while providing predictable quality with instant global reach.

Business Impact

M3DPS is particularly valuable for CIOs looking to:

- Maintain and improve system availability, service levels and quality of 3D printing.
- Improve the management of material usage and reduce costs across large fleets of 3D printing devices.
- Scale beyond internal 3DP services with distributed 3D print labs.
- Accelerate 3DP technology use and experiments in all areas between prototyping to production.

Drivers

- Procuring M3DPS ensures service levels are maintained and 3D printers are functioning optimally for enterprises with 3DP business dependencies. Also, M3DPS will be well-suited for the commercialization of 3DP, helping commercial printers contain the costs and risks associated with this emerging printing technology.
- Enterprises that invest in 3DP technology, yet do not wish to maintain specialized expertise to support such infrastructures, are primed for M3DPS.
- M3DPS can enable customers to experiment with new business models, for example, supporting fleets of print-on-demand devices for consumer goods. M3DPS can reduce the risks of incorporating 3DP into a customer's business model. The M3DPS provider may offer options to finance the 3D hardware bundled with a multiyear service contract that includes a variety of materials and technical expertise. In this way, enterprises are better able to predict and manage 3DP costs, reduce material wastage and align printing costs and profitability to manufactured products and business risk.
- M3DPS could augment the adoption and scalability of newer production setups.

Obstacles

- Most M3DPS providers specialize in their domain of 3DP technology and are not ready to manage across different 3DP technologies.
- As 3DP is still an emerging market with a low penetration rate, there remains plenty of market opportunity for providers to drive demand for 3D devices, which is easier than selling managed services.
- Software solutions are available to service fleets of 3D printers, managed 3D workflows and device security, but options remain limited without established fleets of managed devices to drive demand. M3DPS development remains slow due to a lack of an established market to drive customer awareness and competition.
- IP protection and other security concerns will hinder the sharing of sensitive data and knowledge with a third-party service provider.

User Recommendations

- Raise senior management's awareness of M3DPS. The potential investment and changes associated with M3DPS are substantial, so businesses need senior management support to ensure commitment from the lower levels of management and communication of the benefit.
- Select providers that exhibit domain expertise to maximize the value of M3DPS investments.
- Start planning and developing your M3DPS objective and strategy. In many outsourcing agreements, the promise of long-term cost reductions can be realized only when continuous process improvement is the goal of the relationship.
- Assure that the selected M3DPS provider's solution can support multivendor integration or various 3DP technologies. Pay attention to the underlying requirements and challenges, and work closely with vendors for efficient deployment and operations.
- Seek 3D printing services bureaus if your enterprise requires highly customized project-based work as M3DPS is positioned to efficiently deliver standardized services at scale.

Sample Vendors

3D Systems; Additive-X; Fathom; Fictiv; HP Inc.; Materialise; Ricoh

Gartner Recommended Reading

Market Trend: Emergence of Design and Manufacturing Marketplaces

3D Printing Workflow Software

Analysis By: Ivar Berntz, Marc Halpern

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

3D printing (3DP) workflow software enables organizations to manage the estimating, pricing, scheduling, capacity planning, costing, order entry, job tracking and billing of 3D-printed items. Organizations use 3D print workflow software to manage their internal operations or to facilitate customer orders.

Why This Is Important

Organizations employ multiple 3D printers across sites, incurring untold costs and experiencing capacity issues. The lack of 3DP workflow software to manage the order fulfillment inhibits rapid deployment, especially for industrial-scale applications. Only a few workflow software providers offer off-the-shelf tools. This forces organizations to build specific systems to support their own processes; however, we expect the number of commercial off-the-shelf (COTS) tools to grow.

Business Impact

Organizations with more than five 3D printers, whether centralized or dispersed, would need this software to integrate with their manufacturing execution systems (MES), ERP and content management systems to provide insight into:

- Costing and pricing of new 3D print orders
- The status of 3DP activities
- Available 3DP capacity with visibility for planning to avoid 3DP bottlenecks
- Increasing part availability
- Improving customer service, and thus increasing revenue and customer satisfaction

Drivers

- 3D print operations, both in-house and for-pay, which utilize multiple connected devices, will benefit from 3D print workflow software. The software enables management to understand the true costs and capacity of installations, address bottlenecks, and improve customer service, thus increasing revenue and customer satisfaction.
- The capability of organizing and tracking each stage of the manufacturing process helps the organization in reducing duplicate or redundant tasks, and reduces the lead time for production and the time to market.
- 3DP workflow software helps manufacturers in monitoring the print orders, work assignments and machine performance, resulting in better visibility, load distribution, employee satisfaction and traceability. It also increases the efficiency of processes such as production planning and offers high-quality assurance.
- Manufacturers can integrate 3D print workflow software into supply chain processes to assist in optimized planning decisions and increase operational efficiency. The software can be incorporated into installation planning processes where multiple 3D printers are required or when 3D printers are used in manufacturing operations alongside traditional machinery.
- Through the automation of processes, manufacturers can also reduce the number of human errors and the cost of integration throughout the entire 3DP process, when done right.

Obstacles

- Potential buyers exploring the 3D print workflow software market should approach with caution. All new technologies come with risks and possible drawbacks, such as incomplete tools, limited integration capabilities, long implementation time and high cost. The 3D print workflow software market is no different.
- Not all workflow solution providers offer a holistic set of capabilities. An incomplete set of 3D print workflow tools can lead to the inability to complete certain tasks, thereby defeating the purpose of leveraging the tool.
- Some 3D print workflow software have limited integration capabilities, making it a challenge for many organizations to integrate their existing production environment with the 3D print workflow software.
- Not all software providers incorporate a particular industry's compliance standards, such as ISO standards, so quality control could be difficult to manage.

User Recommendations

- Establish which type of 3D workflow is needed to adopt as a prerequisite to implementation. There are two main types: software designed for production environments that only use 3D printers, and modifications to MES to support 3D printers in a traditional production environment.
- Anticipate when the complexity of your 3DP workflow becomes too great for a proprietary tool.
- Create a strategic implementation plan, including creating a budget, as costs may quickly rise above expected levels.
- Plan for temporary use of custom software until you become more confident in the viability of commercial software — a recommendation for operations and facilities managers. They must remember that 3DP workflow software monitors and governs 3DP-specific activities.
- Request the IT organization to implement robust, commercially available software that will be the best long-term solution for their organization — recommended for production managers.

Sample Vendors

3D Control Systems; 3D Systems (Oqton); 3YOURMIND; AMFG; AM-Flow; Authentise; Materialise; Shapeways Holdings (MakerOS)

Gartner Recommended Reading

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Guide for 3D Printer Manufacturers

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing in Construction

Analysis By: Ivar Berntz

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Definition:

3D printing (3DP) in construction can either involve using a 3D printer attached to an arm that actively builds a project on-site or the use of printers in a factory that prefabricate components of a building project assembled later. 3DP is enabled and accelerated by the increased use of a building information modeling (BIM) framework containing design information, making the industry more automated and efficient, and greener.

Why This Is Important

There is now solid evidence that 3D printing is credible and applicable in the architecture, engineering and construction sector. The 3DP method of construction is very versatile and can help create specific components of a project and even various types of complex structures in their entirety, merely by getting CAD and BIM information. That includes houses or living spaces, offices, bridges, walls, modular structures, reinforcement molds, columns, urban furniture and even decorative elements.

Business Impact

3DP brings great benefits to the construction industry, as it touches almost all areas of the construction value chain. From contributions to sustainability, increased productivity, higher quality or inventory/logistics optimization, this innovation is capable of changing the way we build. It is likely that the technology will start to be seen more and more in the industry in the coming years.

Drivers

- **Time reduction:** With traditional construction methods, a project can take many months to complete. 3DP can reduce the time to complete certain projects while providing equal or better quality.
- **Cost-effectiveness and sustainability:** 3DP, when adequately connected to Computer Aided Design (CAD) drawings and BIM information, allows for a more precise material usage when creating a structure. This requires less material and generates less waste at the jobsite. Additionally, there is no need to purchase a safety stock, allowing for a reduction of both purchase and storage costs.
- **Higher quality and operational efficiency:** Prefabricated parts are produced at specialized sites with more stringent quality controls and optimal conditions than on-site.
- **Less on-site space and labor requirements:** 3DP is of great help in locations where there is a shortage of space or labor. By automating the creation of a structure through 3D printers, companies can see reduced labor costs. By prefabricating parts off-site, they can be delivered just in time and just in sequence, optimizing logistics and inventory levels, like at automotive OEMs.
- **Safety:** One of the most important benefits 3D printing brings to construction is in the health and safety of on-site employees. By knowing how to work effectively with printers, workers can do their jobs more easily and reduce injuries in the field.
- **Design flexibility:** Not only does 3DP support unusual designs, including giant hydroelectric dams, but it also allows for continuous, and even last-minute changes to the design, without a need to delay the construction process. 3DP allows changes until just before starting the printing of the actual part of a larger structure.

Obstacles

- **R&D:** Construction firms may not have areas or functions responsible for experimenting with 3DP.
- **Process and system integration:** Product life cycle management (PLM) tools, BIMs, CAD and supply chain systems aren't optimized for 3DP.
- **Adoption speed:** Architectural and construction software has been slow to adopt 3DP optimization modules.
- **Costs:** Limited numbers of 3D printer suppliers drives up prices.
- **Personnel:** 3DP requires skilled personnel to design optimized structures, operate the equipment, provide maintenance or outsource tasks to.
- **Regulations and legislation:** No clear guidelines on 3DP usage for or at construction sites.
- **Size and development of printers:** Many limit the size of the structure to be printed.
- **Material or formula of the mixture:** Limited track record and number of material suppliers.
- **Difficulties of integration:** Existing material, software and structure printing limitations make it harder to incorporate 3D printing into the construction process.

User Recommendations

To adequately assess whether 3DP can be used for projects:

- **Determine which materials can be used.** Although most 3D printers use mortar, some use plaster or natural materials such as soil or mud. Talk to the engineers to understand what works best.
- **Define the best print location.** Many builders opt to move the 3D printer to print locally on-site, but increasingly companies prefabricate components in a factory and then transport them to the construction site.
- **Understand the required applications.** Some 3D printers print entire houses, parts of houses, structures or objects, such as street furniture. No printer is good at everything and integration requirements may vary markedly. Sometimes a hybrid approach may work best.

Sample Vendors

Aeditive; Apis Cor; COBOD; Constructions-3D; MOBBOT; Pikus 3D; Tvasta; WASP; XtreeE; Yingchuang Building Technique (Winsun)

Gartner Recommended Reading

Innovation Insight for Building Information Modeling

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

How Technology and Data Can Be Used to Develop Smart Building Solutions

Generative Design

Analysis By: Marc Halpern, Ivar Berntz

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Generative design is an automated process that systematically evolves a design, using algorithms that learn from prior designs and from changes to current designs. The approach continually improves its ability to create designs, based on an objective and conditions that the design must meet.

Why This Is Important

Generative design is at the Peak of Inflated Expectations because:

- Generative design can automate design activities, particularly time-consuming repetitive tasks.
- It encourages more innovation because 3D printing can produce output from generative design that could not be produced conventionally using computerized numerical control (CNC).
- It opens new opportunities to adopt 3D printing to produce industrial parts.

- It advances digitalization of design and engineering practice.

Business Impact

Generative design improves design and engineering productivity by:

- Eliminating manual design iterations
- Generating new design knowledge through automation
- Helping designers and engineers focus on more innovative work by offloading repetitive design work to generative design
- Making engineer-to-order (ETO) activities more scalable

Drivers

- Engineers seek accelerated means of optimizing designs for weight, cost, strength and material use, thus producing the most relevant solution for a specific combination of goals and constraints.
- Manufacturers seek ways to recreate, retain and improve knowledge, as experienced designers and engineers retire and their knowledge leaves with them. While generative design cannot fully recreate the cultivated knowledge acquired over decades of experience, it can partially offload the design burden from remaining and new employees.
- Manufacturers need greater ability to manage the periodic changes in demand for design and engineering skills, a challenge that manufacturers face. Designers and engineers leave with the knowledge they gained when laid off during low-demand periods. Manufacturers struggle with sufficient design capacity during high-demand periods. Generative design offsets the business risks caused by fluctuations in demand and available design and engineering talent.
- The hype surrounding AI encourages the exploration and adoption of generative design, which is AI applied to design activities.
- Generative design technologies continue to gain capability, as technologists continue to advance the maturity of generative design, making it increasingly attractive to adopt.
- Generative design provides opportunities to automate the production of parts for customized products, particularly when applied with 3D printing those parts.

Obstacles

- The need to validate AI-generated designs may raise doubts about the efficacy of this technology since the capabilities are still evolving.
- Managers, designers and engineers express legitimate concerns that the AI software is less capable than the human brain to suggest legitimate designs that meet complex variations in requirements.
- Designers and engineers often confuse design optimization techniques with generative design. Therefore, designers and engineers may adopt the wrong categories of technology as generative design.
- Like many AI applications, generative design algorithms require “training” to reliably automate certain categories of design. This training need and insufficient confidence in the training delay the actual use of generative design.
- Veteran designers and engineers may be resistant to adopting this technology because they view it as a job threat.

User Recommendations

- Set expectations for generative design value by working with design and engineering leaders to assess and determine how generative design performs and its limitations before adopting and implementing.
- Increase the likelihood of generative design success by suggesting a knowledgeable resource be assigned to input design goals and constraints into the software. This requires skills in describing requirements in a syntax and semantics that the generative design engine can digest.
- Provide training in generative design processes for designers and engineers.
- Acquire extensive compute power for generative design algorithms to work. Assess the extensive compute capabilities of the cloud.
- Explore and pilot the use of generative design with 3D printing.

Sample Vendors

Autodesk; Dassault Systèmes; nTop; PTC; Siemens; Synergy

Gartner Recommended Reading

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Innovation Insight for Generative AI

Predicts 2023: How Innovation Will Transform the Software Engineering Life Cycle

IT/OT/ET Alignment With 3D Printing Enhances Scalability

Market Trend: Emergence of Design and Manufacturing Marketplaces

Sliding into the Trough

Directed Energy Deposition

Analysis By: Ivar Berntz

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Directed energy deposition (DED) is a 3D printing (3DP) process in which focused thermal energy is used to fuse materials by melting them as they are being deposited. The energy source may be a laser, electron beam or plasma arc. DED technologies inject material powder into a melt pool, which solidifies as the head moves. DED can also be used to repair and rebuild damaged components.

Why This Is Important

Exclusive among 3DP technologies, DED printheads have been installed within five-axis computer numerical control (CNC) machines to print at varied angles — and not only in horizontal layers. This hybrid machining and printing capability enables DED printheads to create new parts, and remanufacture and rework damaged parts by removing damaged surfaces and adding new ones. The resulting piece can be ground and polished while still within the CNC machine, thus reducing postprocessing time and cost.

Business Impact

DED's ability to add metal to three-dimensional surfaces and create additional features is useful in various industries such as aerospace, automotive and heavy equipment, foundry, oil and gas, shipbuilding and military. The technology has been tested in the supply chain of military organizations to repair parts at forward bases, remote locations and at sea. However, postproduction work — such as grinding and polishing — is generally necessary to enhance the quality of the product.

Drivers

- DED can make highly dense parts with mechanical properties as good as or better than those of comparable cast or wrought materials. Parts created with DED can also reach near-net shapes, meaning that they will require little postprocessing.

- Some proprietary DED methods can make larger metal parts than powder-bed metal additive manufacturing processes, which typically produce smaller, highly defined components.
- DED can create strong metallurgical bonds and fine, uniform microstructures. This allows for reconditioning of components like turbine blades and injection molding tool inserts.
- As DED can repair worn parts, 3D print new components and add more than one metal material simultaneously, this innovation significantly reduces downtime and costs associated with parts' replacement while extending useful life by repairing worn parts, molds, or dies.
- Supply chain and maintenance professionals are looking into having DED printers in remote locations and at sea. However, they must ensure connectivity and secure data transfer and communication.
- Most of the materials that can be printed with DED are available commercially. DED can create bimetallic structures by blending multiple streams of powder material to create alloys with varying physical characteristics, such as heat and corrosion resistance.
- Growth will accelerate as soon as the availability and performance of more materials meet established engineering standards.

Obstacles

- Because DED printers have unique metal processing, multiple material handling and multiaxis motion capabilities, they often require vacuum or inert gasses, thus making them quite expensive compared to other additive manufacturing technologies — costing up to $5 million per machine.
- Deep knowledge of material science is needed, as combining materials can cause undesirable interactions on DED devices.
- DED requires extensive testing by engineers, material scientists and operations personnel. Testing properties such as tensile strength, high-cycle fatigue, hardness and compression determines the constraints of DED for user applications.
- DED prints a small portion of metals used worldwide every day, thus limiting its usefulness.

- Getting older parts up to standard again — one of the advantages of additive manufacturing — requires organizations to implement new capabilities, like computer-aided design (CAD) workflow and 3D scanning or editing.

User Recommendations

- Ensure feasibility of adoption by comparing the cost and availability of DED repairs to the cost of conventional plasma spraying and machining.
- Engineering and operations managers should implement DED in production where the material significantly improves performance, reduces raw material waste or enables a part repair.
- Supply chain managers should work with partners and contractors to repair worn parts with DED instead of purchasing new items, thus helping drive cost savings and quick repairs.
- Asset owners and evolutionary maintenance, repair and operations suppliers — whose purchases are necessary to keep the business running — may use DED to displace their traditional supply of replacement parts.
- Manufacturing CIOs need to assess the potential of combining the capabilities of DED with generative design tools (especially topology optimization), given the many constraints based on material combinations, thermal load, energy consumption and cost optimization.

Sample Vendors

AddUp; DMG MORI; FormAlloy; InssTek; Norsk Titanium; Optomec; RPM Innovations; Sciaky; TRUMPF; Yamazaki Mazak

Gartner Recommended Reading

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Guide for 3D Printer Manufacturers

Quick Answer: Mapping Design for Additive Manufacturing Tools to 3D Printing Use Cases

IT/OT/ET Alignment With 3D Printing Enhances Scalability

Mass Customized Discrete Manufactured Products

Analysis By: Marc Halpern, Michelle DeClue, Ivar Berntz

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Mass customization is a design, manufacturing and product delivery approach that allows customers to personalize a product based on selections of predefined features and constraints. This allows for personalization of assembled products without a significant increase in the time or cost to produce.

Why This Is Important

This innovation, moving beyond the Peak of Inflated Expectations, gains considerable attention because:

- Manufacturers seek means to personalize products and software technologies to attract new customers and increase customer loyalty.
- Manufacturers seek to deliver personalized assembled products in an efficient, scalable way using software and technologies such as 3D printing.
- The enabling technologies and processes available to deliver mass customization are sufficiently mature.

Business Impact

The transformational value of this innovation will come from these benefits:

- Mass customization increases profitability.
- Manufacturers operate more efficiently by designing product platforms rather than individual products, reducing workload.
- More agile manufacturing operations produce products with multiple assembled options.
- Online platforms allow customers to easily select combinations of product features.

- Configuration tools raise visibility, providing more comprehensive access to customer-specific product configurations.

Drivers

- Manufacturers recognize that customers increasingly want personalized products within every market.
- Digital technologies enable expanded access to broader markets with more diverse preferences for customized products.
- A great number of commercial technologies for mass customization are available. Therefore, manufacturers want to achieve scalable mass customization before their competitors.
- Manufacturers can improve customer loyalty and brand recognition by providing personalization. Customers are also willing to pay more for customized products, resulting in a significant revenue generation opportunity.
- The customer data can be monetized internally through aggregation and analysis to improve new product ideation and reduce time to market.
- Design and manufacturing marketplaces are further enhancing this capability.

Obstacles

- Product development must be refocused from product design to product platform design, which requires engineering skills.
- Supply chain management becomes more challenging as the demand for parts and materials fluctuates more. Operating lean also becomes more challenging.
- Investments in manufacturing operations must address the need for greater agility. Delivering individualized products for different customers requires rethinking manufacturing operations.
- Mass customization involving 3D printing involves steep learning curves to achieve sufficient quality of printed parts.
- Servicing individualized products becomes more challenging. Service organizations need investment to track configurations and service history of individualized products.
- Manufacturers are reluctant to replace existing product configurators, which contain tacit product knowledge that manufacturers may risk losing if they adopt a new configurator.

User Recommendations

CIOs must work with:

- Data architects to enable data access across product specifications, product configurators, ERP software, product life cycle management applications, manufacturing execution system software and supply chain applications.
- Business leaders to coordinate workflow across R&D, regulatory and supply chains to ensure compliance with regional government regulatory issues, including documenting and labeling individual products.
- R&D leaders to ensure designers and engineers have the software and training to design product platforms.
- Business leaders across product development, sourcing, manufacturing and service to revise how bills of materials are defined and managed.
- Service leaders to ensure that field organizations have information to service individualized products.

Sample Vendors

Configit; Dopple; Epicor; Modular Management; Tacton; Valtech; ZeroLight

Gartner Recommended Reading

How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread

CG Manufacturing CIOs Must Enable Organizations to Deliver Personalized Products at Scale

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023

Top Strategic Technology Trends in Manufacturing and Transportation for 2023

3D-Printed Parts for Maintenance and Spares

Analysis By: Ivar Berntz

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

3D-printed parts for maintenance and spares refer to the use of additive manufacturing techniques to produce replacement parts and spare parts for products and systems already in service.

Why This Is Important

Manufacturers of assembled products, like white goods and medical devices, sell to clients that eventually will require maintenance or replacement parts. Given capital and opportunity costs associated with keeping parts in inventory, manufacturers often opt to make clients and customers wait for spare parts, rather than risk having obsolete inventory. Being able to print replacement parts on demand allows for more-optimal capital allocation and higher customer satisfaction levels.

Business Impact

Manufacturing margins are often single-digit or low double-digit. Tying up working capital by keeping inventory for parts for older models of equipment eats further into the margins. 3D printing (3DP) of replacement parts is a just-in-time way of connecting cost with revenue and, thus, has a solid value proposition.

Drivers

While 3D printing has been around since the 1980s, manufacturers preferred to start using it for prototypes and one-offs, like tools, fixtures and jigs. Recently, manufacturers have started to use 3DP more frequently, allowing additional use cases to be detected and addressed:

- Manufacturers need replacement parts faster than in years past, so they are considering or adopting 3DP for those parts.
- There could be a significant market for aftermarket sales of modified parts meant to address specific market segments or needs, like the ones for the Ford Maverick (see Ford Releases Blueprint Files for Tons of 3D-Printable Maverick Accessories, The Drive. These can often be produced on demand by 3D printers.
- Manufacturers find it increasingly difficult to locate parts with the specific features they need. Therefore, a growing number of them are looking into 3D-printing their own parts. According to a recent study from PwC's strategy&, "50% of customers have been looking into 3D-printing their own parts," and estimate that "85% of spare parts suppliers will incorporate 3D printing into their business" (see The Future of Spare Parts Is 3D: A Look at the Challenges and Opportunities of 3D Printing, strategy&).
- Manufacturers are seeking ways to reduce the cost of spare and replacement parts, as part costs continue to increase with the acceleration of inflation. Transitioning to on-demand manufacturing leads to cost savings by eliminating or significantly reducing inventory requirements.
- Digital files provide the ability to quickly produce new, updated designs at little to no additional cost. Businesses that utilize 3DP service providers deal with less risk and more control, having a single manufacturing method for a variety of parts.
- As manufacturers embark on the journey of meeting their sustainability goals, 3D-printing spare parts helps all organizations to extend the end of life of their products and machinery.

Obstacles

- The need to evaluate the suitability of 3DP for parts of particular materials and features can inhibit 3DP adoption, given the extra time and resources needed to make that assessment.
- Manufacturing purchasing organizations are not familiar with 3DP and often hesitate to quote parts production with it.
- Supplying spare parts for products can be challenging, as these are generally composed of numerous unique parts, some being replaced over time as new generations of the product come to market. A lack of proper documentation can result in the absence of adequate drawings to produce those parts.
- 3DP spare parts for obsolete parts require additional technologies, such as 3D scanning and integration with the necessary design tools, creating an entry barrier for manufacturers.
- Additive design skills aren't readily available in the market, slowing 3DP adoption speed by the market in general.
- Finished goods made with 3DP sometimes look unrefined or require additional finishing after printing.

User Recommendations

- Analyze and organize part designs by technology to determine which process is imperative for overall spare parts production. Some parts may be better suited for material extrusion technology, with its large build capabilities and thermoplastic materials. Other complex, detailed designs may require the robust, specialized nylon materials offered with laser sintering (powder bed fusion) technology.
- Select carefully the appropriate 3DP technology(ies) to be used. If multiple technologies are needed, it means that production of the parts will also require experienced engineering help in additive manufacturing, postprocessing and finishing services, or industry-specific quality standards, requiring a 3D printing service provider or external consultant to find the ideal choice.
- Conduct a classic "make versus buy" analysis to determine whether to purchase in-house machines to build spare parts or outsource to a 3D printing service provider.

Sample Vendors

3D Systems; 3YOURMIND; Fictiv; HP Inc.; Markforged; Protolabs; Siemens; Spare Parts 3D; Stratasys; Xometry

Gartner Recommended Reading

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

The Manufacturing CIO's Role in Adopting and Scaling 3D Printing

3D Printing in Life Sciences

Analysis By: Michael Shanler

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

3D printing in life sciences refers to the use of 3D printing to design, deliver and manufacture products in the pharmaceuticals and medical devices industry segments. This includes applications across a wide range of disciplines, such as surgical and implantable products, the use of additive manufacturing in pharmaceutical formulation of pills, and the creation of unique tooling used in manufacturing centers.

Why This Is Important

3D printing (3DP) software, hardware and services have enabled life sciences (LS) companies to rethink how products are designed and manufactured. 3DP enables a wide array of disciplines, including early drug and device R&D for innovative product concepts, as well the manufacturing of unique product design and small-lot production runs. This technology lowers the barrier for new and existing players' entry into new product space.

Business Impact

3DP provides pharmaceuticals with:

- Accelerated research and improved physiological relevance through the use of bioprinted 3D cellular models
- Reduced production bottlenecks via jigs, fixtures and end-of-arm tooling
- New products, such as personalized doses and form factors for medicines

3DP provides medical devices with:

- Faster prototyping and inventive product design
- Innovative products, such as surgical tools, components and devices
- Marketing aids, such as anatomical models of organs, for sales and medical affairs staff

Drivers

- 3DP manufacturers have improved hardware and lowered the costs for entry models, reducing the barrier to entry for additive manufacturing in research.
- Enterprise-grade 3DP manufacturers used for the production of 3DP parts have improved resolution, speed and quality. This enables manufacturing teams to more easily incorporate 3DP as another tool in the manufacturing suite.
- The number of medical-grade and nontoxic materials and technologies available for validation for U.S. Food and Drug Administration (FDA) Class I, II and III devices is expanding.
- Improvements to 3DP user experience (UX) and key integrations to software that are important to R&D roles are on the rise. An example of scientific R&D is tailored applications for bioprinting with integration to informatics software. Examples for medical device R&D engineering include improved part designs for 3DP simulation modeling integrations to product life cycle management (PLM), computer-aided design (CAD) and computer-aided engineering (CAE) software.
- 3DP vendors see a lucrative LS segment and are expanding service offerings. The extra process steps — for sterilization, good x practice (GxP), design history file (DHF) controls, and regulatory compliance and validation — command premiums as opposed to service offerings that address non-LS segments.
- The push toward developing alignment on outcome-based therapies is driving LS organizations to develop more personalized products, such as ones that are 3D printed, and develop ecosystems for tailored or personalized products for delivery.
- The potential for “manufacturing deglobalization” due to geopolitical and economic instability is causing companies to rethink their risks. Organizations are beginning to move away from large, centralized manufacturing capabilities toward extending dynamic sourcing in more localized, regional environments.

Obstacles

- Many 3DP vendors still do not understand the regulatory requirements in the LS industry.
- LS organizations tend to have document-centric, not data-centric, processes. The inability to atomize content means the interfaces to 3DP software and input/output files from 3DP equipment during production runs cannot be readily ingested into other systems associated with LS processes, which creates extra costs and technical debt.
- Quality and inspection systems are often not integrated into 3DP equipment. This creates integration complexity, delays and costs.
- Typical LS production and quality software companies have not developed strategic partnerships with 3DP vendors. Current PLM solutions with computer-aided design modeling often require middleware and custom workflows for regulatory processes.
- Personalized products tailored for individual patients still require serialization and design history. Most LS organizations are only familiar with batch manufacturing, and are not set up to handle individual production DHFs at such a large scale.

User Recommendations

- Align 3DP with the corporate vision for your company before making investments. 3DP creates new opportunities, but having 3DP doesn't ensure success by itself.
- Develop a plan to meet the compliance requirements by focusing on GxP processes for the printing life cycle (from design to archival) by engaging validation planning teams early in the process.
- Focus on IT integration to enable workflow management, leveraging different business models, service bureaus, contract manufacturers and marketplaces.
- Pilot 3DP in specific areas, create measurable outcomes and establish key performance indicators to help the organization agree on what is a success. R&D cycle times, production milestones and model costs are the more obvious items to model and develop metrics around. However, you must also outline what can be considered a success from the functional perspectives of market access, authorization, marketing, sales, validation and quality.

Sample Vendors

3D Systems; Aprecia; Aspect Biosystems; Brinter; CELLINK; EOS; FABRX; Formlabs; Organovo; Stratasys

Gartner Recommended Reading

Predicts 2023: Digital Transformation of Healthcare Beckons New Era for Life Sciences

Healthcare and Life Science Business Driver: Medical Technology Innovation

Innovation Insight for Consumer Experiences in Healthcare and Life Sciences

Consumer 3D Printing

Analysis By: Sohard Aggarwal, Ivar Berntz

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Consumer 3D printing (3DP) is the market for devices that are typically used by hobbyists and amateur home users, as well as by professional consumers (prosumers). These 3D printers are generally based on low-cost material extrusion technology and start in the $300 to $1,000 price band but can range up to $2,500.

Why This Is Important

The market consists of home users, prosumers, educational institutions and enterprises looking to print the occasional spare part, household equipment or customized item. This remains an emerging market, but consumer demands are evolving to include complex applications in terms of physical properties or functional prototypes. There are, however, several challenges such as cost, capabilities and accuracy limiting adoption. Thus, the scope and technology of 3D printers must continue to evolve.

Business Impact

Consumer awareness of the technology and application is increasing steadily. The curiosity about printing custom-designed items, ranging from jewelry to prostheses, has increased. 3D printers can deliver personalized and customized products and services much more agilely than in the past. The 3D print service bureaus have become part of the consumer 3DP ecosystem, and desktop 3D printers will find more frequent usage and applications.

Drivers

- Consumers are increasingly demanding personalization in the consumer goods industry: for example, customized cases for electronics, apparel and gift items. Consumer 3D printers provide many of these capabilities. Recently, MakerBot and UltiMaker announced a merger to develop innovation capabilities and enhance the range of desktop 3DP applications for this market segment.
- Several shared marketplaces are evolving, allowing users to upload their own designs, select materials and product aspects, and receive the finished goods. Emerging marketplaces like MakerBot, Thingiverse and MyMiniFactory offer a source for increased collaboration and design monetization for end users and 3DP vendors.
- The cost of desktop 3D printers that extrude plastic and other low-cost materials for personal use is decreasing steadily and capabilities are improving, which may invigorate consumer adoption. The 3D printer creation software and applications are also becoming more intuitive.
- 3DP can be used to generate cost-effective spare parts replacement, especially for proprietary items, as well as the production of operational equipment such as sign holders, promotional stands and in-store hardware. It could also be used to rapidly set up stores or warehouses.
- 3D scanners and enhanced CAD modeling SW are becoming more affordable, which when aligned with AR/VR/MR could be leveraged to print custom parts that conform to spatial requirements.

Obstacles

- Consumer goods companies want to offer customers the ability to personalize products. Given current price points, consumers receive industrial levels of quality and safety at a cost lower than that of the 3D printer and material.
- Consumer 3D printers have limited capabilities in terms of technology, material, speed and output.
- A 3D printer purchase is an investment in an ecosystem of 3D modeling software, materials, the 3D printer itself and, depending on the need, a 3D scanner.
- For enterprises and schools, currently available printers offer poor reliability, repeatability and quality. Service is often strictly by phone and web chat, not by an in-person technician.
- There is a risk of IP theft due to consumers printing proprietary spare parts. This also adds product quality and safety risk if consumers do not use the right materials, printing process or designs.

User Recommendations

3D printer manufacturers must:

- Focus on after-sales support and service basics — essential things such as stock availability, warranties, software updates and maintenance.

Consumers, CIOs and online service bureaus must:

- Explore the use of 3D printing by experimenting with low-volume manufacturing of high-margin, custom-designed pieces — for example, one-offs or spares, fashion jewelry and eyeglass frames.
- Take on the burden of connecting everything, from design to postprocessing.

Retailers selling 3D printers or online service bureaus producing items with 3D printers must:

- Investigate the legal implications of customers using these printers to manufacture potentially protected IP or lethal weapons. Take steps to ensure that 3D-printed items made per their customers' orders comply with local copyright and related laws.

- Optimize ownership costs by collaboration with the 3DP solution providers to streamline the creation and production of new and innovative product offerings and to reduce inventory waste.

Sample Vendors

Afinia 3D; Beijing Tiertime Technology; Fargo 3D Printing; MakerBot; Polar3D; Prusa Research; Robo 3D; UltiMaker; XYZprinting

Gartner Recommended Reading

CG Manufacturing CIOs Must Enable Organizations to Deliver Personalized Products at Scale

Future of Supply Chain: Consumer Products Must Transform Amid Accelerating Change

3 Types of Process Agility Enable Supply Chains to Thrive During Change and Uncertainty

Future Consumer Digital Culture Trends: 2023

Powder Bed Fusion

Analysis By: Ivar Berntz

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

Powder bed fusion is a 3D printing (3DP) process in which thermal energy selectively fuses regions of a powder bed. A laser, electron beam or other energy source sinters a region of the powder layer that has been deposited on a surface. Metal materials, polymers or ceramic powders, as well as materials that can’t be cast or easily machined, such as tungsten and titanium, can be printed depending on the type of powder bed fusion printer.

Why This Is Important

Powder bed fusion printing, one of the most widely offered 3DP technologies, is well-suited for aerospace, automotive and medical device industries due to the wide variety of materials that can be printed. Powder bed fusion technology is also used in hybrid applications that incorporate computer numerical controlled (CNC) machining, which enables a part to be printed and then ground and polished in one pass, enhancing the quality of the finished products.

Business Impact

Powder bed fusion enables new product designs and business models driven by material usage. It has the ability to produce complex parts with useful physical properties and also recycle raw materials. However, the technology is energy-intensive. As the technology can produce intricate parts, it is well-suited for parts created through additive manufacturing tools such as computer-aided design (CAD) with generative capabilities and simulations using a topology optimization function.

Drivers

- Powder bed fusion printers produce complex, fully functional pieces with fine features, making them ideal for the production of both prototypes and finished goods.
- Though limited to a single material per build, printing fine powder grains with a small beam size enables powder bed fusion printers to produce high-precision parts. Small and complex geometries, such as thin walls, fine-lattice structures, honeycomb features and small internal channels, are possible in plastic and metal.
- Due to the array of materials that can be printed, depending on the energy source, the technology has a wide application base across various manufacturing industry verticals that have a demand for the production of low-volume, customized and complex parts.
- The powdered base provides significant support to the part during production, so there is limited need for the support structures that would be necessary otherwise.
- Further, the unused raw material powder can be collected and recycled, thereby minimizing waste. It also extends the life of products, which can be converted back to a powdered state and printed again.
- We expect more entrants to join in as private and public initiatives to develop metal 3DP technologies and printers come to fruition. Moreover, the entrance of lower-priced devices foretells significant unit shipment growth.

Obstacles

- Powder bed fusion impacts traditional manufacturing technologies, including casting, forming, machining and molding, but will not replace those processes completely, as traditional technologies have compelling price points, less lead time for large quantities and finished-goods quality.
- Powder bed fusion printed parts need postprocessing such as heat treatment to incorporate structural properties and decrease residual stress. Additionally, the resolution depends on the powdered material's grain size and sometimes requires machining to achieve the expected quality.
- The technology's high energy requirement, long print cycle times and limited build size make it difficult for manufacturers to identify relevant use cases.
- As devices from different providers can produce tighter or looser tolerances, skilled labor is needed to design parts for the appropriate tolerance for the most widely available suppliers and equipment.

User Recommendations

- Qualify first the use of a given 3D printable powder for a given application, even though the list of available metal materials for powder bed fusion is comprehensive. Focus on having the printer(s) produce short-run finished goods, including spare parts, and then plan for further scalability.
- Identify the right 3DP technology based on the use case(s), such as electron-beam-based technology for faster production cycle but laser-based systems for better surface finish.
- Compare the performance of powder bed fusion parts with conventionally manufactured parts prior to rolling it out into finished-goods manufacturing. As powder is sintered at high temperatures, its performance may differ from identical metal, polymer or ceramic parts made using traditional technologies.
- Orchestrate the collaboration of engineers, designers and marketers to maximize the benefits of powder bed fusion. Use generative design and topology optimization tools to think and design parts in a completely new way.

Sample Vendors

3D Systems; Additive Industries; EOS; General Electric (GE) Additive; HP Inc.; Renishaw; SLM Solutions Group; Stratasys; Velo3D; voxeljet

Gartner Recommended Reading

Market Trend: 3D Printing Increases Production Flexibility for Manufacturers

Market Guide for 3D Printer Manufacturers

Quick Answer: Mapping Design for Additive Manufacturing Tools to 3D Printing Use Cases

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Climbing the Slope

3D Printing of Industrial Parts

Analysis By: Ivar Berntz, Marc Halpern

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

3D printing (3DP) of industrial parts refers to the use of 3DP to produce a finished item, subassembly or intermediate product. It can also be used to print tools, jigs, fixtures, dies and molds that would be used during the production of finished goods. This applies to OEMs and their suppliers, which can produce items on an assembly line or in a machining, casting or forming line using 3DP.

Why This Is Important

Manufacturers continue to use 3DP, for its perceived cost and time advantages, to produce customized complex products just in time (JIT) and simplify supply chain logistics and manufacturing operations. CIOs must become familiar with 3DP because it is an operational technology (OT) enabled by engineering technology (ET), but depends on IT to operate efficiently and effectively.

Business Impact

3DP for industrial parts is being used to eliminate bottlenecks in manufacturing and supply chain operations and enhance business resiliency. It reduces the inventory required for spare parts and tools and can quickly produce customized products with new material combinations and complex geometries. It transforms manufacturing operations and service with its ability to produce industrial parts JIT instead of purchasing them or using a service bureau.

Drivers

- 3DP advances the popular goal of lean manufacturing for industrial, asset-intensive organizations and offers shorter lead times, since inventories of spare parts can be reduced and supply chain operations streamlined.

- 3DP helps in improved cost position, higher design reuse, faster product launch and introduction and better aftermarket services for industrial manufacturers, resulting in improved competitive value.
- 3DP directly uses 3D data from geometric design models, either created from scratch or scanned from existing products. 3DP eliminates the additional work needed to translate 3D data into execution instructions for mainstream manufacturing operations.
- 3DP offers design and structural freedom, leading to the development of in-house capabilities such as prototyping and design verification. Since it is an additive procedure, expensive raw material and resources are not wasted.
- The technology advances the ability to increase the energy efficiency and durability of products, especially across the aerospace, defense and automotive industries. It can produce products with complex shapes, and high strength and weight resistance, that cannot be produced with traditional manufacturing techniques.
- Consumers increasingly demand personalized products, which can be delivered more rapidly through 3DP. These individualized products are also more scalable and less costly than other manufacturing approaches, where the major cost arises from the molding process for low-volume products.
- 3DP is part of a technology convergence trend that stimulates innovation where there are advances in material science and the ability to embed technologies (e.g., sensors, actuators, computer chips) in larger 3D-printed industrial parts through nano 3DP.

Obstacles

- 3DP's investment cost and production time continue to be a major challenge for producing industrial parts. This can be overcome by planning the technology's adoption roadmap and leveraging service bureaus to scale production.
- The multiple parties involved in the 3DP process lead to siloed adoption. This results in poor integration between 3D printers and designing software (the OT and ET components), and workflow software such as manufacturing execution systems (MES), ERP and SCM (the IT component).

- Owing to limited materials available for industrial parts production, there are concerns around the reliability and performance of these products, especially under adverse environmental conditions of high temperature, resistance and chemical exposure.
- Insufficient training, education and awareness to use 3DP technologies and materials efficiently is decreasing the technology's uptake.
- IP related to industrial products' ideas and design must be safeguarded, or it will be subject to financial losses and lost growth opportunities.

User Recommendations

- Partner with the decision-making teams in the organization (finance, engineering and operations) to validate the viability of 3DP technologies by building an investment case.
- Align the involved parties to create a connected workflow to create an IT-ET-OT alignment.
- Audit and invest in IT components needed to connect 3D printers with workflow and design applications such as CAD, PDM, ERP and MES that capture content needed for 3DP operation.
- Augment the production of tools and fixtures by encouraging the use of 3DP. This will result in a shorter lead time and pay for the initial cost and time investment.
- Work with supply chain leaders to assess the potential impact of 3DP on your extended supply chain across activities such as sourcing of parts, maintenance, overhaul and repair.
- Monitor the advances in 3DP and materials technology and discuss with decision makers to evaluate the benefits to manufacturing and supply chain operations.

Sample Vendors

3D Systems; Desktop Metal; EOS; Fictiv; GE Additive; Markforged; Materialise; Protolabs; Stratasys; Xometry

Gartner Recommended Reading

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

The Manufacturing CIO's Role in Adopting and Scaling 3D Printing

Market Guide for 3D Printer Manufacturers

Quick Answer: Mapping Design for Additive Manufacturing Tools to 3D Printing Use Cases

3D Printing in Healthcare

Analysis By: Michael Shanler

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

3D printing in healthcare refers to the use of 3D printing across the healthcare provider sector. Use cases include customized medical devices, surgical guides, bioprinted human tissue and organs for therapy, presurgical anatomical training models, and personalized dental correction devices.

Why This Is Important

3D printing (3DP) software, hardware and services have enabled healthcare delivery organizations (HDOs) to rethink how care is delivered. It supports a wide array of medical disciplines, including surgical planning, education, prosthetics, and wound, tissue and bone repair. 3DP in healthcare enables new ways to enhance care delivery and improve patient outcomes and experience.

Business Impact

HDO executives will find that 3DP:

- Improves surgical outcomes and reduces recovery times by enabling surgeons to extend wound environment knowledge and practice techniques.

- Facilitates physician and caregiver education using unique 3D-printed models based on a specific patient's anatomy.
- Enables on-demand creation of custom or specialty surgical instruments.
- Drives growth and evolution of prosthetic and cosmetic surgical strategies and procedures in fields such as pediatrics and 3D-printed casts.

Drivers

- 3D printer manufacturers servicing healthcare have improved hardware and lowered the costs for entry models. This has reduced the barrier to entry for specialty or low-volume devices required for care delivery.
- Major 3DP vendors have increased their focus on the healthcare segment, where sterilized products and validated models become requirements.
- The number of 3DP service bureaus that cater to healthcare and specialty disciplines, such as dentistry and surgical planning, has exploded, improving networks for 3DP activities.
- 3D printer manufacturers have improved resolution, speed and quality. On-site 3DP solutions easily incorporate printed models into healthcare workflows.
- The number of medical-grade and nontoxic materials and technologies available for validation for FDA class I, II and III devices is expanding.
- Improvements to 3DP software for R&D roles, such as tailored applications for prosthetic design, surgical planning and surgical implants, are now being integrated into workflows for care delivery, including reimbursement.
- The push toward developing alignment on health value, where outcomes of patients become more reimbursable, is increasing.
- The two-decades-long trend in manufacturing of moving from mass production to configured production to more personalized production capabilities and unique experiences with customized products and services is impacting all industries. The push toward customized experiences and products is driving adoption of 3DP.

Obstacles

- 3DP products in healthcare environments require significant quality and design controls, but these settings cannot support nonstandard procedures or leverage new equipment.
- 3DP labs require skilled engineering and design capabilities, and dedicated “shop space” to run the equipment. Often, 3DP equipment will sit idle until it is needed. This negative financial impact on business models can be better managed by workflow optimization software tools.
- The quality and inspection systems commonly used with production equipment are often not integrated into 3DP equipment. This creates complexity in ensuring only the best-quality printed tools are in use.
- 3DP shares the ongoing cybersecurity concerns of laboratory instruments in healthcare.
- 3DP systems still do not integrate well with healthcare software, such as imaging, laboratory information system (LIS), electronic health record (EHR) and electronic medical record (EMR), and require complex consulting and automation to develop end-to-end workflows.
- Poor material availability and lengthy print times are often limitations.

User Recommendations

- Start with the alignment of 3DP to specific care areas before making investments or attempting to scale the technology. Beyond healthcare organizations that have research programs, 3DP usage has been very deliberate and narrow in focus.
- Partner with science, technology, care and medical leads on the technology strategy for supporting 3DP activities. Identify where it makes sense to create an internal capability versus using a service bureau to deliver 3DP parts, guides or materials.
- Pilot 3DP in specific areas and create measurable outcomes. Agree on “what success looks like” with the business leads before making any significant investments.

Sample Vendors

3D Systems; BCN3D Technologies; Desktop Metal; ExOne; Formlabs; HP Inc.; Materialise; Mimaki Engineering; Stratasys; TRUMPF Group

Gartner Recommended Reading

Industry Insights: Healthcare Providers Should Embrace Medical Technology Innovation

Advancing Digital Innovation in Clinical Education and Training

Market Guide for 3D Printer Manufacturers

Predicts 2023: Digital Transformation of Healthcare Beckons New Era for Life Sciences

3D Printed Tooling, Jigs and Fixtures

Analysis By: Ivar Berntz

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

By being able to print tooling, jigs and fixtures using 3D printing, manufacturers can more easily experiment on their own than when using traditional technologies. These 3D printed items are then used in an assembly line or in a machining, casting or forming line using discrete or continuous processes. They are not finished products for end users.

Why This Is Important

3D printers can make practical alternatives to specialized machined jigs and fixtures as well as one-size-fits-all tools used in manufacturing. Use cases include, but are not limited to:

- Gloves with integrated tooling
- Soft jaw inserts for vises and grippers to grasp, hold and move items
- Drilling tool alignment guides
- “Go/no-go” quality assurance gauges
- Assembly, disassembly and bonding jigs
- Labeling, masking and mounting templates

Business Impact

Tooling, jigs and fixtures can be produced with satisfactory finish quality and strength to enable process and efficiency improvements. Organizations are no longer forced to keep inefficient tooling, jigs and fixtures because of the difficult and time-consuming redesigning process. Assembly line workers with ideas on how to improve their output can now work with engineers to tweak these support items to increase throughput and reduce the number of unacceptable parts.

Drivers

- The majority of organizations print tools, jigs and fixtures to support existing or new production processes using the traditional supply chain operations. This means that they need to quote with three suppliers a drawing and wait for the purchase process' completion. Eventually they may find out there was a minute mistake somewhere that renders the part unusable. They need to fix the drawing and restart the process. This can be slow and wasteful.
- "Local production for local consumption" enables manufacturers to unlock the technology's capability to incorporate specific requirements into the tool, jig or fixture. It also ensures high quality by printing said part on a layer-by-layer basis and incorporating changes as required, reducing the lead time to create custom complex tooling, jig or fixture.
- Producing tooling, jigs and fixtures on demand assists manufacturers in creating a lean manufacturing setup by creating items only when required. This approach reduces the warehousing and transportation required for parts that can be 3D printed.
- The ability to 3D print a replacement tool, jig or fixture within a matter of hours also speeds the adoption of engineering changes. For example, changes driven by either product improvement or process optimization are much faster to implement when tooling is reproduced rapidly.
- Discrete goods manufacturers can benefit from the use and flexibility of 3D printed tooling, jigs and fixtures and benefit from faster changeovers and shorter lead times.
- For semidurable manufacturers, the ease of creating and refining tooling, jigs and fixtures enables them to reduce the time to production of saleable items or increase the uptime of production assets.
- Contract manufacturers use 3D printers to quickly make, and redesign, the tooling, jigs and fixtures needed for their constantly changing order mix.

Obstacles

- The initial investment is higher for manufacturers setting up an in-house 3D printed unit (as opposed to say using a 3D printing [3DP] service bureau).
- As not all parts can be 3D printed, the lead time for conventionally produced complex tools and fixtures can be long, and may jeopardize the start up of new production processes. This problem will only get worse as tool and die makers reach retirement age and are not replaced.
- Manufacturers may not have employees with the technical ability to utilize additive manufacturing principles nor systems capable of integrating longer 3D printing processes.
- Given the increased availability of contract manufacturers, there may not be a need in many manufacturing organizations for customized jigs or tools.

User Recommendations

- Prepare for the evolution of conventionally produced complex tools and fixtures and begin the use of 3D printed tooling, jigs and fixtures made of plastic, composite materials and metal. This will result in increased productivity and quality by allowing for rapid and iterative changes to the initial shapes and facilitating quick production-line changeover or maintenance activities.
- Partner and create an environment of collaboration between engineers and assembly workers. Adjusting an assembly jig or fixture based on input from the assembly worker can result in better communication between engineering and production personnel, improved worker productivity, and finished-part quality.
- Leverage 3D printed tooling, jigs and fixtures to train engineers and designers who are new to additive manufacturing. Compared to finished goods, these parts are relatively low risk as manufacturing personnel can explore a 3D printer’s capabilities and constraints while making or redesigning parts.

Sample Vendors

3D Systems; Desktop Metal; EOS; HP Inc.; Markforged; Protolabs; Stratasys; UltiMaker; Xometry

Gartner Recommended Reading

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Stereolithography

Analysis By: Ivar Berntz

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Stereolithography (SLA) or vat photopolymerization is a 3D printing (3DP) technology in which a liquid photopolymer contained within a vat is selectively cured by light-activated polymerization. The photopolymer “cross-links” or hardens into a solid on contact by the energy source. The light draws subsequent layers of the original computer model onto the surface of the liquid until the part is completed.

Why This Is Important

SLA continues to move along the Hype Cycle curve, now climbing to the Plateau of Productivity. Significant technological advances have improved SLA throughput and lowered prices, driving installations. Owing to the ability to print high-precision complex geometries with photopolymers, biomaterials, ceramic-filled photopolymers and epoxy hybrids, it is one of the most widely adopted 3DP technologies.

Business Impact

SLA does not displace traditional manufacturing technologies such as machining, molding, casting and forming used for high-volume manufacturing. Rather, SLA works as a supplement to traditional manufacturing processes and offers mass customization. This technology enables manufacturers to create parts with high precision and accuracy; however, the material range is limited. This 3DP technology is perfectly suited for creating prototypes and models and is often used in the casting processes.

Drivers

- As the number of SLA printer providers increases, the cost of printers is becoming competitive, along with an increase in the list of printable materials and new approaches to printer design and usage.
- The primary driver for the adoption is the quality of the products printed. The printed parts have a high level of detail and can be of complex designs generally suitable for prototyping use cases and for products required in small lots.
- The technology results in production of isotropic parts that are watertight, making it suitable for parts where the flow of air or fluids needs to be controlled.
- SLA providers are at the forefront of efforts to expand the range of standard 3D printable materials, sometimes co-developing new materials with their enterprise clients.
- SLA is used to print photopolymers, biomaterials (e.g., scaffolds for tissue engineering), ceramic-filled photopolymers (e.g., highly detailed parts with high-temperature resistance used to produce vulcanized rubber molds) and epoxy hybrids (e.g., accurate, durable, environment-tolerant parts), and the list is continuously growing.
- Further, while the industrial printers have large build volumes, they are often slow to print. On the other hand, desktop printers are affordable and next in line to material extrusion printers.
- Typical applications include: proof-of-concept models; form, fit and function testing; investment casting patterns (lost wax manufacturing); and jigs, fixtures and assemblies. Small quantities of parts can become saleable items, but generally only after they have been painted or finished in some way.

Obstacles

- SLA has its drawbacks, particularly the need for a two-step procedure of printing and postprocessing that requires special handling of polymers and cleaners. These drawbacks restrict buyers to individuals and organizations that are comfortable with special handling.
- Printed resins have limited mechanical and thermal strength, and they are not suitable for functional prototypes that must endure any sort of rigor.
- The postprocessing phase is a major need as support structures are required while printing.
- Since the printed parts do not respond well to sunlight, SLA-printed parts are not suitable for outdoor applications.

User Recommendations

- Be prepared to support the infrastructure, security and intellectual property protection aspects of the broad ranges of SLA uses.
- Use SLA printers for product conceptualization and prototyping processes and to produce finished goods that either stand alone or are part of a larger assembly.
- Consider purchasing an SLA printer (or using a service bureau or a supply chain partner with SLA printers) as an alternative to basic material extrusion. The material range and detailed items that are possible with SLA compared with material extrusion printers make it suited for refinement of prototypes like snap-lock electrical connectors, models and other products with low lot sizes and complex shapes such as figurines and jewelry.

Sample Vendors

3D Systems; Carbon; Cubicure; Desktop Metal (ETEC); DWS Systems; Formlabs; Lithoz; Nexa3D; Shanghai Union Technology (UnionTech); Stratasys

Gartner Recommended Reading

Market Guide for 3D Printer Manufacturers

Market Trend: 3D Printing Increases Production Flexibility for Manufacturers

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Quick Answer: Mapping Design for Additive Manufacturing Tools to 3D Printing Use Cases

IT/OT/ET Alignment With 3D Printing Enhances Scalability

Binder Jetting

Analysis By: Ivar Berntz

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Binder jetting is a 3D printing (3DP) technology in which a liquid bonding agent is selectively deposited to join powdered materials. The technology uses two materials. It first disperses a fine layer of powder across the imaging table, followed by the jetting of a binder fluid.

Why This Is Important

Despite more than two decades of development, binder jetting is growing at a steady rate. Its usage is not as widespread as other 3DP technologies like material extrusion (off the Hype Cycle). Manufacturers use binder jetting to produce proof-of-concept models, demonstration models and investment and sand-casting patterns with materials such as ceramics, composites, metals and polymers. In the near term, binder jetting will remain a key technology for 3DP of colored prototypes and finished goods.

Business Impact

Binder-jetting 3D printers are used in product conceptualization and prototyping processes across industrial, aerospace and defense and consumer goods. They are typically used to create low-cost and nonstructural prototypes and, to a lesser extent, to produce finished goods that stand alone or are part of a larger assembly. But their use to create molds for subsequent casting processes and finished goods is of long-term value, especially with large or out-of-production castings.

Drivers

- Binder jetting has gained a footing in a wide range of industries: aerospace, architecture, automotive, casting/foundry consumer goods, machine building, manufacturing in the military and oil and gas. The major vendors in the binder jetting market offer a slightly different type of binder and material system from the other, increasing the potential of the technology's advancement. However, this also results in low interoperability. Materials that can be used, depending on the 3D printer model, are ceramics, composites, metals and polymers.

- The use of binder jetting to produce foundry castings could grow significantly. The ability to 3D-print large molds used to make castings offers compelling value to heavy equipment manufacturers. Even when the casting size is one-to-one with the finished part, binder jetting means the physical molds can be stored digitally and reprinted on demand.

- The technology is well-suited for production of products in batches due to multiple nozzles in printers. This helps manufacturers reduce the production cycle time and the time to market in the case of finished goods.

- Similar to powder-bed fusion technology, binder jetting does not require support structures to be incorporated into designs of products because of the support provided by the powdered material. Also, multiple powdered materials can be combined to achieve the required physical properties driving the adoption for creating prototypes.

- Since the technology does not use heated nozzles while printing, manufacturers are able to avoid manufacturing defects such as warping and residual stress.

Obstacles

- Although this technology is economical compared with other 3DP technologies because it can produce multiple parts at the same time, it is not suitable for single-part production. This is because the printer's production capacity is not utilized for producing one unit at a time. Also, the unit price of printers is high.

- Binder jetting uses an adhesive that inhibits the printed parts to incorporate mechanical properties such as structural strength and thermal resistance, and it requires postprocessing to incorporate those properties.

- Alternative 3DP technologies such as material jetting and powder-bed fusion printers, now available with color printing, could possibly cut significantly into this portion of the binder jet market.

User Recommendations

- Evaluate binder jetting as a viable alternative to casting for creating complex or large castings as well as castings used in the mass production of parts.
- Work with engineers to evaluate the binder jetting technology market, assess the potential total cost of ownership (TCO) and identify whether to set up an in-house facility or outsource it.
- Incorporate binder jetting when rapid production of a full-color, 3D model of an item is a critical element of the development process.
- Assess binder-jet-printed models not only to develop a concept, but also to illustrate your plans to buyers and regulatory agencies. Use this technology in an office environment to create everything from figurines to topological maps to architectural models.

Sample Vendors

3D Systems; Desktop Metal (ETEC); ExOne; GE Additive; HP Inc.; Höganäs Group (Digital Metal); voxeljet; XYZprinting

Gartner Recommended Reading

Market Guide for 3D Printer Manufacturers

Market Trend: 3D Printing Increases Production Flexibility For Manufacturers

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Trend: Emergence of Design and Manufacturing Marketplaces

Entering the Plateau

Material Jetting

Analysis By: Ivar Berntz

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Material jetting is a 3D printing (3DP) technology in which droplets of build materials, including ceramics, composites, metals and polymers, are selectively deposited layer by layer. The process is similar to traditional 2D inkjet printing but uses materials that change phase from liquid to solid once dispensed from the printhead and cured.

Why This Is Important

Material jetting enables printing of multiple materials with multiple colors and different durometers. These materials can either be jetted continuously or dropped on demand. Buyers adopt the technology when high-performance and high-color-quality 3D-printed pieces are necessary. Material jetting's accelerating trajectory is being driven by continued development of the material range, finished-piece quality and evolving productivity of material-jetting devices.

Business Impact

Material Jetting (MJ) is a process in which droplets of build and support materials are selectively jetted onto the build platform and cured by either ultraviolet light or heat to form a 3D object. It is a mature technology for plastics and delivers full-color objects with production-quality finish and performance plus solid prototyping use cases. As a result, material jetting has gained traction in industries such as jewelry, dental, automotive, aerospace, medical devices and consumer goods.

Drivers

- Material jetting in plastic and possibly metal is an ideal process for prototyping products to test for handling and feel. Furthermore, its multicolor capability allows models to be printed with colored and clear components to enable the review of internal structures.

- As the technology uses drops of materials to print, the printers have the ability to produce high-resolution, nano-size parts. Additionally, while the final parts have good surface finish, this is achieved after postprocessing the parts.
- Material jetting has multiple industry-specific use cases, such as the use of nanoparticle inks in electronics, as well as aircraft parts with flight-certified flame- and smoke-retardant materials. The process is also an enabler of mass customization when used for casting in jewelry and dentistry.
- Additionally, considerable applications have been created in the healthcare industry, where color material-jetted models are used not only to plan surgeries, but also to practice on body parts that have a lifelike response.
- A nascent variation on material jetting is "direct-write" technology, in which functional materials are deposited. Direct-write enables printing of conductive materials onto curved surfaces and around corners.

Obstacles

- Material jetting is a costly process with a high initial cost of investment due to the high cost of printers that can focus on production of smaller parts or prototypes. Further, there are no desktop printers available with this technology.
- The technology is not suitable to produce functional parts with certain physical properties as the printed parts are generally brittle and unable to bear weight. Additionally, the printed parts are photosensitive; hence, the use cases need to be identified accordingly.
- Further, support structures are needed while printing parts with material-jetting printers; hence, they require effort in the postprocessing stage of the 3DP value chain.

User Recommendations

- Engineers should use this technology for product design and testing; it is especially suitable for small runs of handheld and wearable devices. Typical applications include proof-of-concept models; form, fit and function testing; investment-casting patterns; and jigs, fixtures and assemblies.
- Engineering and operations management must investigate material-jetting technology developments. Material jetting with thermoset plastics can be used for short-run injection molding.

- Chief marketing officers should encourage their staff to use material-jetted prototypes in their product development work, with printers employing multiple heads, multiple colors and multiple materials. Brilliant colors and varying durometers within the piece simulate finished goods for use by focus groups and even preproduction photography for marketing collateral.
- Healthcare providers must make material-jetted parts available (along with other 3DP technologies) to surgical teams and other professionals. The realistic look and feel of 3D-printed models enable professionals to plan and practice a procedure.

Sample Vendors

3D Systems; KEYENCE; Mimaki Engineering; Nano Dimension; Prodways Group; Stratasys; Xerox; XJet; XYZprinting

Gartner Recommended Reading

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Market Trend: Emergence of Design and Manufacturing Marketplaces

3D Printing in Automotive

Analysis By: Mike Ramsey

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

3D printing in automotive refers to the use of 3D printing across automotive supply chains to produce prototypes, parts used in vehicles or tools, and equipment needed to support manufacturing.

Why This Is Important

Automotive companies can use 3D printing (3DP) to more quickly iterate on new part and assembly design, and create tools, jigs and customized parts for manufacturing. While 3DP has largely remained in the province of prototyping, it is beginning to have a bigger impact on other parts of the value stream.

Business Impact

3DP delivers the following benefits in new automotive product development and manufacturing:

- Faster time and lower cost to produce prototypes than creating traditional prototypes
- Opportunity to change development to a systems approach that reduces the number of parts in an assembly
- Shorter time to validate design function and integrity when 3DP augments virtual models during design reviews
- Ability to make custom or specialized parts for production

Drivers

- Reducing inventories of parts to be assembled and spare parts.
- Reducing inventories of the tools, fixtures and molds needed for manufacturing operations.
- Increasing flexibility to create custom tooling and fixtures for manufacturing operations.
- Increasing flexibility to create small-batch parts on vehicles.
- Reducing cost to meet regional requirements for specific parts or variations in production.
- The improvement in printing metal or carbon fiber parts could lead to an uptake in 3D printing for finished goods in automotive.
- Some automakers have begun to use 3D printing techniques for engine parts, interior parts and other specialized or difficult-to-machine components.

- 3DP provides expanded opportunities to use material properties and complex geometric shapes to improve performance and cost of parts during the design process. There is also the ability to simultaneously produce multiple models of the same item in multiple locations, facilitating designers' and others' understanding compared to two-dimensional CAD models.

Obstacles

- 3D-printed parts can take hours to create, making it difficult to scale to high-volume production or to large parts.
- It is difficult to certify the strength and safety of 3D-printed parts for certain safety-critical components.
- 3D-printing metal parts still requires some finishing after the printing process that can slow the application of these parts into finished goods.
- 3D printing is relatively more expensive than making parts using other methods for high-volume production.

User Recommendations

Automotive companies using 3D printing should:

- Assess whether 3DP can achieve quality and consistency levels in the final product that traditional manufacturing can achieve in order to realize the benefits of flexibility and lower tooling costs.
- Identify opportunities to produce parts that improve vehicle performance or quality that could not be economically produced by traditional means.
- Identify opportunities to replace spare part inventories and associated logistics with 3DP spare parts as they are needed.
- Avoid delays in receiving tooling and parts for fixturing from suppliers by identifying opportunities to produce tooling and fixturing with 3D-printed parts.
- Ensure 3D-printed materials cannot become a bottleneck that shuts down a factory if there is a single machine failure by having duplicate or redundant capabilities.

Sample Vendors

3D Systems; Carbon; Desktop Metal; Divergent Technologies; INTAMSYS Technology; Markforged; Materialise; Stratasys; Ultimaker; voxeljet

Gartner Recommended Reading

Top Automotive Trends for 2023

2023 CIO and Technology Executive Agenda: An Automotive Perspective

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

Appendixes

See the previous Hype Cycle: Hype Cycle for 3D Printing Technology in Manufacturing, 2022

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 2: Hype Cycle Phases

(Enlarged table in Appendix)

Phase	Definition
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant media and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the innovation is pushed to its limits. The only enterprises making money are conference organizers and content publishers.
Trough of Disillusionment	Because the innovation does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the innovation's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the innovation are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the innovation to reach the Plateau of Productivity.

Source: Gartner (July 2023)

Table 3: Benefit Ratings

Benefit Rating	Definition
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2023)

Table 4: Maturity Levels

(Enlarged table in Appendix)

Maturity Levels	Status	Products/Vendors
Embryonic	In labs	None
Emerging	Commercialization by vendors Pilots and deployments by industry leaders	First generation High price Much customization
Adolescent	Maturing technology capabilities and process understanding Uptake beyond early adopters	Second generation Less customization
Early mainstream	Proven technology Vendors, technology and adoption rapidly evolving	Third generation More out-of-box methodologies
Mature mainstream	Robust technology Not much evolution in vendors or technology	Several dominant vendors
Legacy	Not appropriate for new developments Cost of migration constrains replacement	Maintenance revenue focus
Obsolete	Rarely used	Used/resale market only

Source: Gartner (July 2023)

Document Revision History

Hype Cycle for 3D Printing Technology in Manufacturing, 2022 - 29 July 2022

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Hype Cycle for 3D Printing, 2017 - 12 July 2017

Hype Cycle for 3D Printing, 2016 - 19 July 2016

Hype Cycle for 3D Printing, 2015 - 27 July 2015

Hype Cycle for 3D Printing, 2014 - 21 July 2014

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Quick Answer: How 3D Printing Helps Manufacturing CIOs Contribute to Sustainability and Circular Economy

Future of Work Trends: Future of Work-Life Integration in Smart Cities

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Table 1: Priority Matrix for 3D Printing Technology in Manufacturing, 2023

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Transformational		Mass Customized Discrete Manufactured Products Powder Bed Fusion	Generative Design Mobile Factories	3D Printing of IoT and Embedded Sensors 4D Printing
High	3D Printing in Automotive Material Jetting Stereolithography	3D-Printed Parts for Maintenance and Spares 3D Printed Tooling, Jigs and Fixtures	3D Printing in Construction 3D Printing in Life Sciences Directed Energy Deposition IP Protection in 3D Printing	Nanoscale 3D Printing
Moderate		3D Printing of Industrial Parts Binder Jetting	3DP of Consumable Personal Products 3D Printing in Healthcare 3D Printing Workflow Software Consumer 3D Printing Managed 3D Print Services	Blockchain in 3D Printing Sheet Lamination
Low				

Source: Gartner (July 2023)

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