3D Printing - The Future of Manufacturing (The Next Industrial Revolution)

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Abstract - Who would have thought that modern manufacturing could be done without a factory? Since the Industrial Revolution, manufacturing has been synonymous with factories, machine tools, production lines and economies of scale. So it is startling to think about manufacturing without tooling, assembly lines or supply chains. However, this is exactly what is happening as 3D printing reaches individuals, small businesses and corporate departments.

Technology is moving so quickly, and in so many directions, that it becomes challenging to even pay attention—we are victims of "next new thing" fatigue. Yet technology advancement continues to drive economic growth and, in some cases, unleash disruptive change. Economically disruptive technologies—like the semiconductor microchip, the Internet, or steam power in the Industrial Revolution—transform the way we live and work, enable new business models, and provide an opening for new players to upset the established order. Business leaders and policy makers need to identify potentially disruptive technologies, and carefully consider their potential, before these technologies begin to exert their disruptive powers in the economy and society. In recent years, 3D printing has attracted increasing attention. The prospect of machines that can print objects much the same way that an inkjet printer creates images on paper has inspired enthusiasts to proclaim that 3D printing will bring "the next industrial revolution." Other observers have reacted with skepticism and point to the technology's current limitations and relatively low level of adoption. '3D Printing or 'additive manufacturing' as it is also known, has the potential to become the biggest single disruptive phenomenon to impact global industry.

This paper will cover the concept of 3D printing; then explore in depth how a 3D printer produces a physical model; and discusses the potential economic impact by 2025 and specific reference to barriers enablers and the implications of technology in future.

Key words: additive manufacturing, disruptive technologies, 3D printing, economic impact, implications

I. INTRODUCTION

For most of us, the notion of printing calls to mind the process of putting ink on paper. By contrast, 3D printing is the process of creating an object using a machine that puts down material layer by layer in three dimensions until the desired object is formed. A 3D printer extrudes melted plastic filament or other material, building objects based on specifications that come from modeling software or from a scan of an existing object.

Today you can make parts, appliances and tools in a wide variety of materials right from your home or workplace. Using a computer, simply create, modify or download a digital 3D model of an object. Click "print," just as you would for a document, and watch your physical 3D object take shape. No longer the stuff of science fiction, 3D printing is a new reality.

3D printing changes the calculus of manufacturing by optimizing for batches of one. 3D printers are being used to economically create custom, improved and sometimes even impossible-to-manufacture products right where they will be used. A single printer can produce a vast range of products, sometimes already assembled. It's a factory without a factory floor and it has created a platform for innovation, enabling manufacturing to flourish in uncommon areas and spawning a new generation of Do It- Yourself (DIY) manufacturers. The new players, with their innovative processes and technology, will disrupt manufacturing as we know it. The Economist calls 3D printing the third Industrial Revolution, following mechanization in the 19th century and assembly-line mass production in the 20th century. [1]

3D printing, also referred to as additive manufacturing or rapid prototyping technologies, has gained popularity during recent years due to rapid technical development in the area. The first 3D printers were developed in the late 1980s, mostly to create prototypes with which to speed up product development; at that time, the technology was referred to as rapid prototyping. Subsequently, technical development has progressed rapidly, and both companies and the general public are beginning to understand the potential of 3D printing. As the technology developed further and more applications became available, the name of the technology changed to additive manufacturing. The technology is now known as 3D printing by the general public.

Nowadays, 3D printing is mostly employed in three areas: medical, aerospace, and automotive industries. However, it has also been adopted in other fields such as fashion, food, and metal manufacturing. There is also a global 3D printing open community with active users and hobbyist who rapidly develop the technology, and related applications and services. New business models are emerging around the world due to the availability of 3D software, 3D scanners, 3D printers, and information relating to the development and application of the technology. Production does not require huge amounts of initial investment. There are active individuals and companies creating software applications and services, designing 3D models, and printing out physical objects. Intellectual property rights and standardization are endeavoring to keep up with these developments.

II. CLASSIC DISRUPTION

All disruptive technologies start out inferior to the dominant technology of the time. When the first experimental 3D printers emerged 20 years ago, they were nowhere near the production quality of traditional manufacturing processes. However, as Christensen observed in his research, the new technologies find a market that is underserved by the current technology which is often focused on the higher end of the market. 3D printing found rapid prototyping, which was an extremely costly and labor-intensive process using traditional manufacturing techniques. 3D printing enabled cheap, high-quality, one-off prototypes that sped product development.

3D printing is a classic disruptive technology according to the disruption pattern identified by Harvard Business School professor Clayton Christensen. It is simpler, cheaper, smaller and more convenient to use than traditional manufacturing technology. Current 3D printing technology is “good enough” to serve markets that previously had no manufacturing capability at all. [2]

Another disruptive element of 3D printing is the fact that a single machine can create vastly different products. Compare this to traditional manufacturing methods, where the production line must be customized and tailored if the product line is changed, requiring expensive investment in tooling and long factory down-time. It is not hard to imagine a future factory that can manufacture tea cups, automotive components and bespoke medical products all in the same facility via rows of 3D printers. Flexibility to build a wide range of products, coupled with the fact that 3D printing can be done near the point of consumption, implies a serious change to supply chains and business models. Many steps in the supply chain can potentially be eliminated, including distribution, warehousing and retail.

As the history of disruptive technologies has shown, 3D printing will not be stopped. Competition will drive the market forward, and over time barriers will come down. History has also shown that once a disruption starts, adoption occurs much faster than anyone imagines possible.

The difference between traditional manufacturing and 3D printing is how the objects are formed. Traditional manufacturing processes generally use a subtractive approach that includes a combination of grinding, forging, bending, molding, cutting, welding, gluing and assembling. Take the production of a seemingly simple object such as an adjustable wrench. Production involves forging components, grinding, milling and assembling. Some of the raw material is wasted along the way, and vast quantities of energy are expended in heating and reheating the metal. Specialist tools and machines, optimized to produce wrenches of one size and nothing else, are required. Almost all everyday objects are created in a similar but usually even more complex manner.

III. 3D PRINTING PROCESS

3D printing starts with a virtual 3D model of an object, for example, a blueprint. Blueprints can be created with a computer aided design (CAD) program or a physical object can be scanned with a 3D scanner to create a digital file. Digital designs can be edited by a designer or anyone who understands the technology, and the digital design files can be widely distributed as with any other computer file. A 3D printer creates a physical object of a three dimensional data file that is first converted into a format suitable for the 3D printer. The printer builds an object from raw material, layer by layer. One of the benefits of the technology is that the printer can create internal movable parts without the need to assemble those parts afterwards. The amount of suitable raw material is constantly increasing as research and development progress, and comprises, for the majority of 3D printed objects, various polymers, waxes, aluminium, and brass or steel alloys; raw material can be in the form of powder, pellet, or string. Each 3Dprinter recommends suitable materials, printing temperatures, and printing pace. It is still a challenge to print out an object comprising several materials.

The process is widely used in industry to create prototypes more quickly than traditional methods, and in some situations it has begun to replace conventional manufacturing processes, such as injection molding. The technology has caught the attention of educators as prices for 3D scanners and extrusion printers have dropped, making it feasible to use them for design, production, or preservation in a wide range of educational venues.

3D printing belongs to a class of techniques known as additive manufacturing. Additive processes build objects layer-by-layer rather than through molding or subtractive techniques such as machining. Today, 3D printing can create objects from a variety of materials, including plastic, metal, ceramics, glass, paper, and even living cells. These materials can come in the form of powders, filaments, liquids, or sheets. With some techniques, a single object can be printed in multiple materials and colors, and a single print job can even produce interconnected moving parts such as hinges, chain links, or mesh.

A variety of 3D printing techniques are in use today, each with its own advantages and drawbacks. Major techniques include selective laser sintering, direct metal laser sintering, fused deposition modeling, stereolithography, and inkjet bioprinting. In all cases, objects are formed one layer at a time, each layer on top of the previous, until the final object is complete. With some techniques this is accomplished by melting material and depositing it in layers, while other techniques solidify material in each layer using lasers. In the case of inkjet bioprinting, a combination of scaffolding material and live cells is sprayed or deposited one tiny dot at a time. [3]

IV. ADDITIVE MANUFACTURING TECHNIQUES

Selective Laser Sintering (SLS): In this technique, a layer of powder is deposited on the build platform, and then a laser "draws" a single layer of the object into the powder, fusing the powder together in the right shape. The build platform then moves down and more powder is deposited to draw the next layer. SLS does not require any supporting structure, which makes it capable of producing very complex parts. SLS has been used mostly to create prototypes but recently has become practical for limited-run manufacturing. General Electric, for example, recently bought an SLS engineering company to build parts for its new short-haul commercial jet engine.

Direct Metal Laser Sintering (DMLS): DMLS is similar to selective laser sintering but deposits completely melted metal powder free of binder or fluxing agent, thus building a part with all of the desirable properties of the original metal material. DMLS is used for rapid tooling development, medical implants, and aerospace parts for high-heat applications.

Fused deposition modeling (FDM): A filament of plastic resin, wax, or another material is extruded through a heated nozzle in a process in which each layer of the part is traced on top of the previous layer. If a supporting structure is required, the system uses a second nozzle to build that structure from a material that is later discarded such as polyvinyl alcohol. FDM is mainly used for single- and multipart prototyping and low-volume manufacturing of parts, including structural components.

Stereolithography (SLA): A laser or other UV light source is aimed onto the surface of a pool of photopolymer a light-sensitive resin. The laser draws a single layer on the liquid surface; the build platform then moves down, and more fluid is released to draw the next layer. SLA is widely used for rapid prototyping and for creating intricate shapes with high-quality finishes, such as jewelry.

Laminated Object Manufacturing (LOM): A sheet of material (paper, plastic, or metal) is fed over the build platform, adhered to the layer below by a heated roller, and a laser cuts the outline of the part in the current layer. LOM is typically used for form/fit testing, rapid tooling patterns, and producing less detailed parts, potentially in full color.

Inkjet-Bioprinting: Bioprinting uses a technique similar to that of inkjet printers, in which a precisely positioned nozzle deposits one tiny dot of ink at a time to form shapes. In the case of bioprinting, the material used is human cells rather than ink. The object is built by spraying a combination of scaffolding material (such as sugar-based hydrogel) and living cells grown from a patient's own tissues. After printing, the tissue is placed in a chamber with the right temperature and oxygen conditions to facilitate cell growth. When the cells have combined, the scaffolding material is removed and the tissue is ready to be transplanted.

3D printing has several advantages over conventional construction methods. With 3D printing, an idea can go directly from a file on a designer's computer to a finished part or product, potentially skipping many traditional manufacturing steps, including procurement of individual parts, creation of parts using molds, machining to carve parts from blocks of material, welding metal parts together, and assembly. 3D printing can also reduce the amount of material wasted in manufacturing and create objects that are difficult or impossible to produce with traditional techniques, including objects with complex internal structures that add strength, reduce weight, or increase functionality. In metal manufacturing, for example, 3D printing can create objects with an internal honeycomb structure, while bioprinting can create organs with an internal network of blood vessels. Current limitations of 3D printing, which vary by printing technique, include relatively slow build speed, limited object size, limited object detail or resolution, high materials cost, and, in some cases, limited object strength. However, in recent years rapid progress has been made in reducing these limitations. [4]

V. THE 3D PRINTING CYCLE

Our 3D printing process is clean and highly automated. All the steps described here take place without any input from you.
Preparation: Once you click on “3D Print” from machine, the printer initiates a pre-build routine. First, it warms the air inside the printer to create the optimum operating environment for 3D printing. At the same time, the machine fills the build chamber with a 3.18 mm layer of powder so that the parts, when finished, rest on this powder for easy removal. The machine may also run an automatic head alignment routine. This routine consists of printing a pattern onto the powder, reading the pattern with an electronic eye, and aligning its own print heads accordingly.

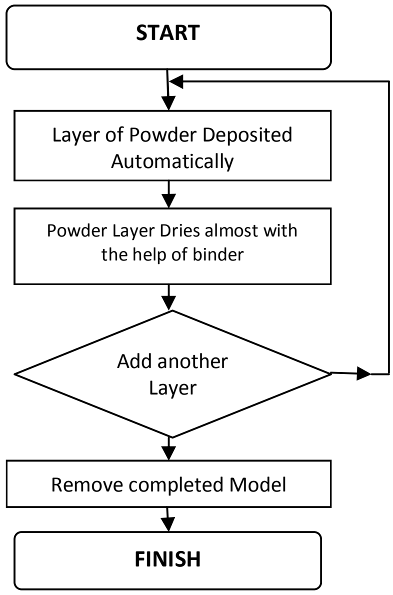

Fig.3D Printing Process

Printing: Once the pre-build routine is complete, the printer immediately begins printing the layers created in the machine software. The machine deposits powder from the hopper in the back of the machine, spreading a thin 0.1 mm layer forward across the build platform. The print carriage then moves across this layer, depositing binder in the pattern of the first slice that was sent from machine. The binder solidifies the powder in that cross-section of the model, leaving the rest of the powder dry for recycling. At this point, the piston below the build chamber lowers the powder bed 0.1 mm, preparing for the next layer. The cycle repeats itself until the model is complete.
Depowdering/recycling: When finished, the model is suspended in powder to cure. At the end of the curing time, the machine automatically removes most of the powder from around the model by applying vacuum pressure and vibration to the bottom of the build chamber. The loose powder is pneumatically conveyed through the system, filtered, and returned to the hopper for use in subsequent builds. Next, you open the front of the machine and move the part to the fine-depowdering chamber. Here you spray the part with compressed air to remove any last traces of powder. All of the powder that enters a machine eventually becomes a model. None is wasted or lost. All powder loading, removal and recycling is part of a closed-loop system supported by persistent negative pressure for containing airborne particles within the machine.

VI. POTENTIAL ECONOMIC IMPACT BY 2025

The Wohler’s report estimates that 3D printing could generate economic impact of $230 billion to $550 billion per year across our sized applications by 2025. The largest source of potential impact among the sized applications

would come from consumer uses, followed by direct manufacturing i.e., using 3D printing to produce finished goods and using 3D printing to make molds.
The estimated consumer use of 3D printing could have potential economic impact of $100 billion to $300 billion per year by 2025, based on reduced cost compared with buying items through retailers and the value of customization. 3D printing could have meaningful impact on certain consumer product categories, including toys, accessories, jewelry, footwear, ceramics, and simple apparel. These products are relatively easy to make using 3D printing technology and could have high customization value for consumers.
Global sales of products in these categories could grow to $4 trillion a year at retail prices by 2025. It is possible that most, if not all, consumers of these products could have access to 3D printing by 2025, whether by owning a 3D printer, using a 3D printer in a local store, or ordering 3D-printed products online. We estimate that consumers might 3D print 5 to 10 percent of these products by 2025, based on the products' material composition, complexity, cost, and the potential convenience and enjoyment of printing compared with buying for consumers. A potential 35 to 60 percent cost savings is possible for consumers self-printing these goods despite higher material costs as the materials required for the products we focus on here, primarily plastics, are relatively inexpensive and getting cheaper. The savings over retail come not only from eliminating the costs of wholesale and retail distribution, but also from reducing the costs of design and advertising embedded in the price of products. It is possible that consumers will pay for 3D printing designs, but it is also possible that many free designs will be available online. Finally, customization might be worth 10 percent or even more of the value for some 3D-printed consumer products. For example, Nike currently offers customizable NikeID shoes at a surcharge of approximately 30 percent over the price of standard designs of similar quality.
Even in 2025, traditional manufacturing techniques will almost certainly have a large cost advantage over additive manufacturing for most high-volume products. However, 3D printing could become an increasingly common approach for highly complex, low-volume, highly customizable parts. If used in this way, we estimate that 3D printing could generate $100 billion to $200 billion in economic impact per year by 2025 from direct manufacturing of parts. The market for complex, low-volume, highly customizable parts, such as medical implants and engine components, could be $770 billion annually by 2025, and it is possible that some 30 to 50 percent of these products could be 3D-printed. These products could cost 40 to 55 percent less due to the elimination of tooling costs, reduction in wasted material, and reduced handling costs.
Even by 2025, the large majority of parts and products will still be manufactured more efficiently with techniques such as injection molding. 3D printing, however, has the potential to create significant value by shortening setup times, eliminating tooling errors, and producing molds that can actually increase the productivity of the injection molding process. For example, 3D-printed molds can more easily include "conformal" cooling channels, which allow for more rapid cooling, significantly reducing cycle times and improving part quality .We estimate that 3D printing of tools and molds could generate $30 billion to $50 billion in economic impact per year by 2025, based on an estimated $360 billion cost base for production of injection molded plastics in 2025 and assuming that about 30 to 50 percent of these plastics could be produced with 3D-printed molds at around 30 percent less cost. [5]

VII. BARRIERS AND ENABLERS

Despite improvements in 3D printing technology, remaining limitations, particularly material costs and build speeds, could constrain wide-scale adoption. However, both materials costs and speed could improve dramatically by 2025 for many techniques based on the current evolution of the technology. If materials costs and build speeds fail to improve significantly, it could substantially lessen the economic impact of 3D printing.
Much of the potential value of 3D printing for consumers and entrepreneurs will depend on the emergence of an "ecosystem" to support users. Online 3D object exchanges like thing verse point to a potential future in which object designs are widely exchanged and purchased like music files, greatly facilitating the spread of 3D printing adoption. The success of 3D printing also depends on improvements in products such as design software, 3D scanners, and supporting software applications and tools.

VIII. IMPLICATIONS

While the range of products that consumers and companies choose to 3D print could be limited at first, the ability to easily design and self-manufacture products could create significant consumer surplus and even influence consumer culture. Access to 3D printers is already inspiring a "maker" subculture in which enthusiasts share designs and ideas. For example, the 3D printing service Shape ways already has more than 10,000 crowd-sourced 3D models for jewelry and other items that have been uploaded by consumers. 3D printing could eventually spawn the same kind

of dynamic, complex ecosystem that exists in software and Web development—in which developers can easily share and collaborate with one another—extending this kind of innovation ecosystem to the creation of physical objects.
Budding product designers and entrepreneurs can use 3D printing to quickly reach a mass, even global, audience. Makers of 3D printing devices and service providers should consider how best to stake out the most favorable positions within this ecosystem, whether by establishing a brand for consumer 3D printers, establishing a marketplace for 3D designs, or opening go-to 3D print shops either online or in brick-and-mortar locations.
Ultimately, a gradually rising share of sales in categories such as toys and personal accessories could shift to either home production or 3D printing centers. Leaders in these categories should identify how to add value for consumers in ways that home-printed products cannot. Manufacturers of consumer products that could become 3D-printable should consider new ways to customize products to match some of the advantages of home printing. At the same time, they should follow closely the evolution of online exchanges for 3D printable designs and carefully manage their intellectual property rights while proactively leveraging these exchanges to distribute their products. Internally, these manufacturers should take advantage of 3D printing for rapid prototyping to speed designs to market and keep careful watch for the moment when improvements in technology might make 3D printing an economically viable production method for them.
Materials, manufacturing, and logistics value chains related to products that are candidates for 3D printing could also be affected by this technology. Direct production of goods by consumers could affect demand for some materials and global shipping volumes (although only in a small way initially). Leaders of businesses that could be affected by this new production ecosystem should think about what role they want to play and develop strategies to compete. For example, Staples' decision to experiment with 3D printing services suggests that there may be opportunities to offer other services and products to entrepreneurs and consumers who use 3D printing.
Access to 3D printing could actually make some manufacturing sectors more competitive. For industries with high-value goods, in which rapid innovation is more important than absolute cost, the combination of 3D printing of products and advanced robotics could make proximity to end markets and access to highly skilled talent more important than hourly labor rates in determining where production is located. This could lead some advanced economy companies to produce more goods domestically, boosting local economies. However, this may not create many manufacturing jobs, as the 3D printing process is highly automated.
3D printing poses opportunities as well as challenges for policy makers in both advanced and developing economies. Societies can benefit from products that are made with less waste that do not require transport over great distances and, therefore, have less impact on the environment Policy makers should consider supporting the development of 3D printing, in particular by funding research in 3D printing technologies. [6]
The challenges for policy makers include addressing regulatory issues—such as approving new materials for use—ensuring appropriate intellectual property protections, and assigning legal liability for problems and accidents caused by 3D-printed products. Governments will also be called upon to clarify how intellectual property rights will be protected. 3D printers have already been used to make handguns, raising another set of issues. Policy makers face the challenge of evaluating and addressing these risks without stifling innovation or limiting the value that this technology can provide.
It has been estimated that in 2012 up to 30% of finished products already involve some kind of 3D printing. By 2016, this is expected to rise to 50% and by 2020 potentially up to 80%.
At the moment the following areas are in line for transformation:
NOW
Production Prototypes
Small manufacturing runs of High Value/High Complexity products
Dental/Aural healthcare forms/aids
SOON
Almost all service parts
Complex high volume/high value forms
Products related to fashion/trends that have a high volume/short lifespan profile
LATER
Mass produced fast moving consumer goods
It is difficult to see that industry will undergo complete transformation for many years – probably decades – to come. What could happen, though, is that that some sectors are penetrated by the technology at a much earlier stage, such as the manufacture of spare parts. In this case, the most enlightened logistics companies could even become early adopters of the technologies – investing in the 3D Printers and providing facilities for engineers – rather than kicking against the progress. This would also provide a way of leveraging their capital and their own technological capabilities.

IX. FUTURE

It is predicted by some additive manufacturing advocates that this technological development will change the nature of commerce, because end users will be able to do much of their own manufacturing rather than engaging in trade to buy products from other people and corporations.
3D printers capable of outputting in colour and multiple materials already exist and will continue to improve to a point where functional products will be able to be output. With effects on energy use, waste reduction, customization, product availability, medicine, art, construction and sciences, 3D printing will change the manufacturing world as we know it.

X. CONCLUSION

If the new technology is to completely transform global industry, 3D Printing must be able to mass produce goods in the same volumes as traditional manufacturing techniques. At present the jury is still out on whether this is feasible. Some in the sector, such as GE foresee a time when a whole engine, for example, could be printed. Others believe that at least in the medium term, hybrid solutions will develop, which combine new technologies with more traditional techniques.
However what 3D Printing is certainly not is science fiction. Its ability to create strong but light parts has been identified by the aerospace sector; components for the automotive sector are already being printed and the technology is being adopted by the mobile telecoms sector.

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