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Research Article

Additive Manufacturing–A Brief Foray into the Advancements in Manufacturing Technologies

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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. There is a wide range of technologies accommodated under the umbrella of Additive Manufacturing, with varying potential, benefits, and disadvantages. Any analysis of the sector must differentiate between the kinds of technologies used and the value they can create. This paper aims to disaggregate the elements with an appreciation of the diverse benefits, challenges and areas of application that Additive Manufacturing methods present are also discussed.

Keywords: *Additive Manufacturing, Rapid Prototyping, 3D-Printing, Stereolithography, Vat Photopolymarization, Polyjet, Binder Jetting, Fused deposition modeling, Powder bed fusion, Sheet lamination, Directed energy diposition.*

1. Introduction

Due to the daily increase in complexity of industrial manufacturing, international competition and market globalization, there is demand for higher flexibility and greater efficiency and traditional manufacturing processes may not be able to meet all the requirement of today's products. Additive Manufacturing (AM) processes are identified as an effective approach to overcome these challenges. AM, also known as 3D-printing or rapid prototyping, is a process of joining materials to make objects from 3D CAD model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Main applications of additive manufacturing include rapid prototyping, rapid tooling, direct part production and part repairing of plastic, metal, ceramic and composite materials. As the technology evolved, it started to be used to directly manufacture niche or custom goods in low volumes. AM has been successful in serving the needs of the higher-end market while evolving rapidly, with practical examples in numerous industries including defense, aerospace, automotive and healthcare. Although AM has been applied mainly to low-volume production, the products can be far superior (lighter, stronger, customized, already assembled) and cheaper than if created with traditional manufacturing processes which point it takes over the dominant players. According to Wohlers Report 2014, the worldwide 3D printing industry is now expected to grow from $3.07B in revenue in 2013 to $12.8B by 2018, and exceed $21B in worldwide revenue by 2020. Wohlers Report 2013 had forecast the industry would grow to become a $10.8B industry by 2021.

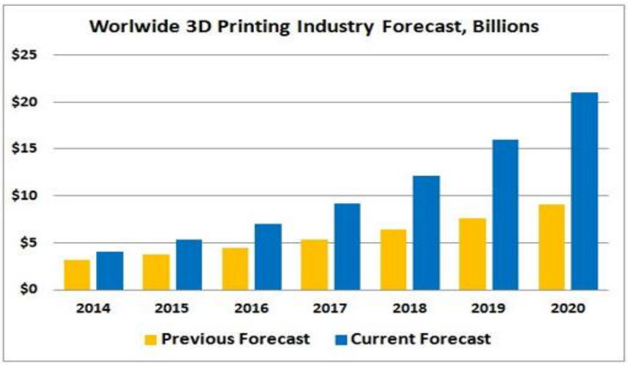

Figure 1: Worldwide 3D printing industry forecast

Prototyping, product development and innovation are the three most common reasons companies are pursuing 3D printing. Of those companies surveyed in a recent Gartner study, 37% had just one 3D printer within their organizations, with 18% owning 10 or more. The average number of printers per organization was 5.4.

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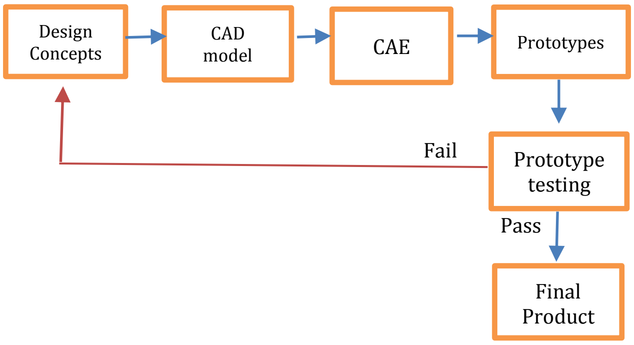

Figure 2: Steps involved in product development

The steps involved in product development using rapid prototyping are shown in Figure 2. Here, it can be seen that creating models faster save a lot of time and there is the possibility of testing more models.

2. Vat Photopolymerization

It is an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light activated polymerization. The process starts when the build platform is lowered from the top of the resin vat downwards by the layer thickness. A UV light cures the resin layer by layer. The platform continues to move downwards and additional layers are built on top of the previous. Some machines use a blade which moves between layers in order to provide a smooth resin base to build the next layer on. After completion, the vat is drained of resin and the object removed. The main advantage of vat photopolymerization is that typically large build areas are available: object dimensions 1000 mm x 800 mm x 500 mm and max model weight of 200 kg. The process is relatively quick, accurate and good surface finish is obtained. The process often requires support structures and post curing for parts to be strong enough for structural use. It also has lengthy post processing time and removal from resin. The overall process is expensive.

3. Stereolithography

Stereolithography (SL), developed by 3D Systems, Inc., was the first and is most widely used process of rapid prototyping, therefore, in the past the two terms were used synonymously. The basic principle of this process is the photopolymerization, which is the process where a liquid monomer or a polymer converts into a solidified polymer by applying ultraviolet light which acts as a catalyst for the reactions; this process is also called ultraviolet curing. The process starts with a CAD model and then it is translated to a STL file in which the pieces are "cut in slices" containing the information for each layer. The thickness of each layer as well as the resolution depend on the equipment used. A platform is built to anchor the piece and support the overhanging structures. Then the UV laser is applied to the resin solidifying specific locations of each layer. When the layer is finished the platform is lowered and finally when the process is done the excess is drained and can be reused. A contemporary version of this process has been developed with a higher resolution and is called microstereolithography. This process can achieve a layer thickness of less than 10μm. In Figure 3 are shown the basic parts of a stereolithography machine. It is also possible to have powders suspended in the liquid like ceramics. There are a few errors induced to the final piece from the process of stereolithography. One is over curing, which occurs to overhang parts because there is no fusing with a bottom layer. Another is the scanned line shape, which is introduced by the scanning process. Because the resin is a high-viscosity liquid the layer thickness is variable and this introduces an error in the border position control.

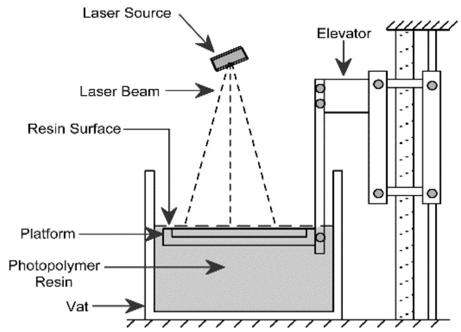

Figure 3: Stereolithography

Another error caused could be if the part needed to have a surface finished process that has to be normally done by hand. All these errors are minimized in equipment of high quality. The main advantage of stereolithography is very complex parts can be made with high resolution and smooth surface finish.

4. Polyjet

This is an additive manufacturing process that uses inkjet technologies to manufacture physical models. The inkjet head moves in the x and y axes depositing a photopolymer which is cured by UV lamps after each layer is finished. The layer thickness achieved in this process is 16μm, so the produced parts have a high resolution. However, drawback would be that the parts produced by this process are weaker than others like stereolithography and selective laser sintering. A gel-type polymer is used for supporting the overhang features and after the process is finished this material is water jetted. With this process, parts of multiple colors can be built.

5. Binder jetting

The binder jetting process uses two materials; a powder based material and a binder. The binder acts as an adhesive between powder layers. The binder is usually in liquid form and the build material in powder form. A print head moves horizontally along the x and y axes of the machine and deposits alternating layers of the build material and the binding material. After each layer, the object being printed is lowered on its build platform. Another layer of powder is spread over the previous layer. The object is formed where the powder is bound to the liquid. Unbound powder remains in position surrounding the object. The process is repeated until the entire object has been made. The technology is often referred to as 3DP technology and is copyrighted under this name. The process is pretty simple and inexpensive. Large jobs are scalable and a wide variety of colors and material are available for selection. One drawback of the process is that it is not always feasible to manufacture structural parts, due to the use of binder material.

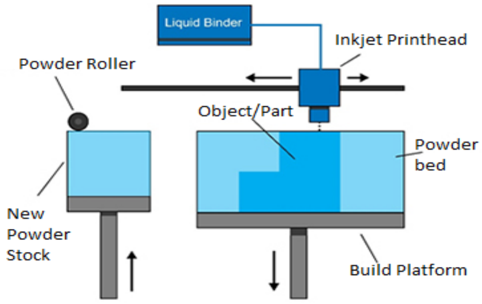

Figure 4: Binder jetting

6. Fused deposition modeling

Fused deposition modeling (FDM) is an additive manufacturing process in which a thin filament of plastic is fed into a machine where a print head melts it and extrude it in a thickness typically of 0.25 mm. Materials used in this process are polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polyphenylsulfone (PPSF), PC-ABS blends, and PC-ISO, which is a medical grade PC. First layer is built as a nozzle deposits material where required onto the cross sectional area of first object slice. The following layers are added on top of previous layers. Layers are fused together upon deposition as the material is in a melted state. The main advantages of this process are that no chemical post-processing is required, no resins to cure, less expensive machine, and materials resulting in a more cost effective process. The disadvantages are that the resolution on the z-axis is low compared to other additive manufacturing process (0.25 mm), so if a smooth surface is needed a finishing process is required and it is a slow process sometimes taking days to build large complex parts. To save time some models permit two modes; a fully dense mode and a sparse mode that save time but obviously reducing the mechanical properties.

7. Powder bed fusion

Powder bed fusion (PBF) methods use either a laser or electron beam to melt and fuse material powder together. Electron beam melting (EBM), methods require a vacuum but can be used with metals and alloys in the creation of functional parts. All PBF processes involve the spreading of the powder material over previous layers. A layer, typically 0.1mm thick of material is spread over the build platform. A laser fuses the first layer or first cross section of the model. A new layer of powder is spread across the previous layer using a roller. Further layers or cross sections are fused and added. The process repeats until the entire model is created. Loose, unfused powder is remains in position but is removed during post processing. In the sintering process, the part is heated to 350º F for 24 hours hardening the binder fusing with the steel in a 60% porous specimen. In the infiltration process, the piece is infused with bronze powder when they are heated together to more than in an alloy of 60% stainless steel and 40% bronze.

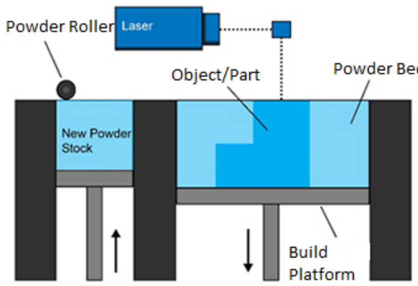

Figure 5: Powder bed fusion

The same process, but with different sintering temperatures and times, has been used with other materials like a tungsten carbide powder sintered with a zirconium copper alloy for the manufacturing of rocket nozzles; these parts have better properties than CNC (Computer Numerical Control) machined parts of the same material. Selective Heat Sintering differs from other processes by way of using a heated thermal print head to fuse powder material together. As before, layers are added with a roller in between fusion of layers. A platform lowers the model accordingly. A few limitation in the powder bed fusion are relatively slow speed, high power usage and the finish is dependent on the powder grain size.

8. Sheet lamination

The process is also called Laminated Object Manufacturing (LOM) that combines additive and subtractive techniques to build a part layer by layer. In this process the materials come in form of sheet. The material is positioned in place on the cutting bed. The material is bonded in place, over the previous layer, using the adhesive. The required shape is then cut from the layer, by laser or knife. The next layer is added.

The LOM process uses a cross hatching method during the printing process to allow easy removal post build. A carbon dioxide laser cuts the material to the shape of each layer given the information of the 3D model from the CAD and STL file. The advantages of this process are the low cost, no post processing and supporting structures required, no deformation or phase change during the process, and the possibility of building large parts. The disadvantages are that the fabrication material is subtracted thus wasting it, low surface definition, the material is directional dependent for machinability and mechanical properties, and complex internal cavities are very difficult to be built. This process can be used for models with papers, composites and metals.

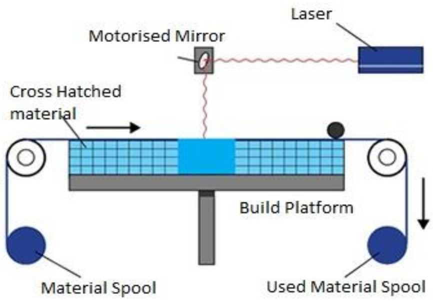

Figure 6: Sheet lamination

9. Directed Energy Deposition (DED)

DED covers a range of terminology in the field of AM and these are 'Laser engineered net shaping, directed light fabrication, direct metal deposition, 3D laser cladding'. It is a more complex printing process commonly used to repair or add additional material to existing components. The process can be used with polymers, ceramics but is typically used with metals, in the form of either powder or wire.

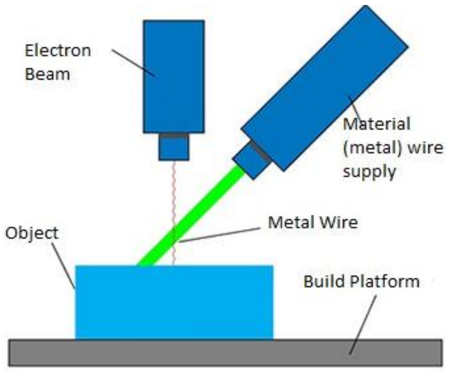

Figure 7: Directed Energy Deposition

A 4 or 5 axis arm with nozzle moves around a fixed object. Material is deposited from the nozzle onto existing surfaces of the object. Material is melted using a laser, electron beam or plasma arc upon deposition. Further material is added layer by layer and it solidifies, creating or repairing new material features on the existing object. The grain structure can be controlled to a high degree which will lend a high quality repair work of functional parts. The finished job may require post processing to achieve the desired effect. Also, the availability of material that can be used is low.

10. Applications

In the **automotive** and **aerospace** industry the main goal is to make the lightest practical car or aircraft while ensuring safety. Additive manufacturing technologies have enabled the manufacture of complex cross sectional areas like the honeycomb cell or every other material part that contains cavities and cut-outs which reduce the weight-strength relation. Engineers at BMW have leveraged 3D printing to create ergonomic, lighter versions of their assembly tools to increase worker productivity. By improving the design, workers are carrying 2.9 pounds (1.3 kilograms) less and have improved handling and balance. As BMW engineer Günter Schmid says, "This may not seem like much, but when a worker uses the tool hundreds of times in a shift, it makes a big difference".

Additive manufacturing technologies can provide **architects** a very powerful tool for their business, by being able to create a physical model faster without worrying about the complexity of their design. It also achieves a better resolution than other processes used in architecture. Architects work with CAD software, so there is no need for them to adapt to anything because the STL file is created from a CAD file. Stereolithography is a process very suitable for the architectural modeling because of the materials used and the printing resolution.

Components used in **military** equipment must be strong, durable and, above all, reliable, as failure can put lives at risk. Consider the mount for camera gun sights on the M1 Abrams tank and Bradley fighting vehicles. These high-precision components are mounted on the external body of the tanks, where they must survive incredibly harsh shock, vibration and environmental conditions. EOIR Technology, a leading defense system design and development Company, was able to manufacture mounts durable enough for use on the tanks using a 3D printer. By switching to 3D printing technology, the company reduced the manufacturing costs from over $100,000 per unit to under $40,000. In the future, it may be possible for the military to print replacement parts on the battlefield instead of relying on limited spares or the supply chain.

The most inspiring use of 3D printing is in the **healthcare** industry, where 3D printing has the potential to save lives or dramatically improve them. Using a patient's own cultured cells or stem cells, the Wake Forest Institute for Regenerative Medicine has developed a 3D printing technique for engineering tissue and organs. They are transforming the practice of medicine through the possibilities of making rapid prototypes and very high quality bone transplants and models of damaged bone of the patients for analysis. 3D printing in healthcare still has some years to go before mass adoption, but early developments to create tissue, organs, bones and prosthetic devices provide a glimpse of how lives may be improved. According to PC Magazine, an 83-year-old Belgian woman became the first-ever person to receive a transplant jawbone tailor-made for her face using a 3D printer and the surgery time and recovery were a lot less than other patients that received the same procedure. The shapes of bones differ too much between each person and additive manufacturing printing produces transplants that fit better, and are easier to insert and secure, reducing the time for the procedure and produce a better cosmetic result.

Additive manufacturing technologies are a very powerful tool to **artist** in the fashion, furniture, and lightning industry given the possibility of virtually manufacturing the most complex form imaginable. There are companies that manufacture furnishing complements, lightning, and accessories including clothes using SLS.

In addition to ergonomics, another area where additive manufacturing can make a big difference is **marketing**. Imagine showing a full-scale 3D model instead of a CAD drawing as part of a bid proposal. One company has done that with car interiors, showing front and back with all the attachment points as part of its presentation. Pictures may tell a thousand words, but touch and feel make it real.

Conclusion

Additive manufacturing processes take in the information from a CAD file that is later converted to an STL file. In this process, the drawing made in the CAD software is approximated by polygons and sliced containing the information of each layer that is going to be printed. There is also the discussion about the relevant additive manufacturing processes, their advantages and disadvantages and a review of how the parts are made using these additive manufacturing processes. Additive manufacturing technologies have been welcomed in the aerospace industry because of the possibility to manufacture lighter structures to reduce weight, which is the common goal of aircraft and spacecraft designers. In the automotive industry, additive manufacturing is advantageous also in reproducing difficult-to-find parts, for example, parts for classic cars. Additive manufacturing is transforming the practice of medicine; now it is possible to have a precise model of a bone before a surgery and the possibility of creating an accurate transplant, no matter how complex its form is. Additive manufacturing is making work easier for architects, who now can print the 3D models of whatever complex shape for a civil project they have in mind. In addition, studies are reviewed which were about the strength of products made in additive manufacturing processes. The changes surrounding 3D printing are significant; we are only scratching the surface of what the ultimate impact will be. Customized, no-ship manufacturing will one day be as common as desktop printing. When that happens, and factories without factory floors are the norm, it will be hard to imagine how companies and consumers once lived without Additive manufacturing.

References

I. Gibson, T. Kvan, and W. Ling (2002), *Rapid prototyping for architectural models*, Rapid Prototyping Journal, vol. 8, no. 2, pp. 91–99.

https://novoed.com/3d-opportunity

V. Wong and Aldo Hernandez, *A Review of Additive Manufacturing,* Department of Mechanical and Aerospace Engineering, University of Miami, Coral Gables, FL 33146, USA. CSC Leading Edge Forum, *3D Printing and the Future of Manufacturing*.

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/vatphotopolymerisation/

www.raeng.org.uk - *Additive manufacturing*: *opportunities and constraints*.

R. Singh (2011), *Process capability study of polyjet printing for plastic components*, Journal of Mechanical Science and Technology,vol. 25, no. 4, pp. 1011–1015.

B. Vaupotic, M. Brezocnik, and J. Balic (2006), "*Use of PolyJet technology in manufacture of new product*, Journal of Achievements in Materials and Manufacturing Engineering, vol. 18, no. 1-2, pp. 319–322.

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/binderjetting/

J. P. Kruth, P. Mercelis, J. van Vaerenbergh, L. Froyen, and M. Rombouts (2005), *Binding mechanisms in selective laser sintering and selective laser melting*, Rapid Prototyping Journal, vol. 11, no. 1, pp. 26–36.

T. Wohlers,Wohlers Report 2011, Wholers Associates, http://www.forbes.com/sites/louiscolumbus/2015/03/31/2015-roundup-of-3d-printing-market-forecasts-and-estimates/

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/materialextrusion/

D. T. Pham and C. Ji (2000), *Design for stereolithography,* Proceedings of the Institution of Mechanical Engineers, vol. 214, no. 5, pp. 635–640.

A.D.Taylor,E., U. Bletzinger and E. Ramm (2001), *Structural optimization and form finding of light weight structures* , Computers and Structures, vol. 79, no. 22–25, pp. 2053–2062.

A. Williams (2002), *Architectural modelling as a form of research*, Architectural Research Quarterly, vol. 6, no. 4, pp. 337–347.

SweetOnionsCreations (2007), *Architecture model and 3D printing—sweet onion creations*.

http://www.youtube.com/watch?v=rEzugxybKmA.

http://www.industryweek.com/articles/additive_manufacturing_goes_mainstream_26805.aspx?showall=1

http://www.stratasys.com/resources/casestudies/automotive/bmw

http://www.stratasys.com/resources/case-studies/defense/eoir-technology

Moscaritolo (2012), *Woman receives 3D printer? created transplant Jaw*, PC Magazine Online, ,

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/sheetlamination/

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/materialjetting/

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/powderbedfusion/

http://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/directedenergydeposition/