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3D Printing: An Emerging Trendsetter

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Abstract: **Although scientists and technicians have long been fascinated with the idea of replicating technology, it was not until the 1980s that the concept of 3D printing really began to be taken seriously. In 1982 , the first published account of a printed solid model was made by Hideo Kodama of Nagoya Municipal Industrial Research Institute. However, the man most often credited with inventing the language of 'modern' 3D printer is Charles W. Hull, who first patented the term 'stereolithography' (defined as "system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed") in 1984. The term *additive manufacturing* refers to technologies that create objects through a sequential layering process. Objects that are manufactured additively can be used anywhere throughout the product life cycle, from pre-production (i.e. *rapid prototyping*) to full-scale production (i.e. *rapid manufacturing*), in addition to tooling applications and post-production customization.**

In manufacturing, and machining in particular, subtractive methods are typically coined as traditional methods. The very term *subtractive manufacturing* is a retronym developed in recent years to distinguish it from newer additive manufacturing techniques. Although fabrication has included methods that are essentially "additive" for centuries (such as joining plates, sheets, forgings, and rolled work via riveting, screwing, forge welding, or newer kinds of welding), it did not include the information technology component of model-based definition. Machining (generating exact shapes with high precision) has typically been subtractive, from filing and turning to milling and grinding.

1. INTRODUCTION

Additive manufacturing or 3D printing is a process of making a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using an *additive process*, where successive layers of material are laid down in different shapes. 3D printing is also considered distinct from traditional machining techniques, which mostly rely on the removal of material by methods such as cutting or drilling (*subtractive* processes).

A materials printer usually performs 3D printing processes using digital technology. The first working 3D printer was created in 1984 by Chuck Hull of 3D Systems Corp. Since the start of the 21st century there has been a large growth in the sales of these machines, and their price has dropped substantially. According to Wohlers Associates, a consultancy, the market for 3D printers and services was worth $2.2 billion worldwide in 2012, up 29% from 2011.

The 3D printing technology is used for both prototyping and distributed manufacturing with applications in architecture, construction (AEC), industrial design, automotive, aerospace, military, engineering, civil engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewelry, eyewear, education, geographic information systems, food, and many other fields. It has been speculated that 3D printing may become a mass market item because open source 3D printing can easily offset their capital costs by enabling consumers to avoid costs associated with purchasing common household objects.

2.General principles

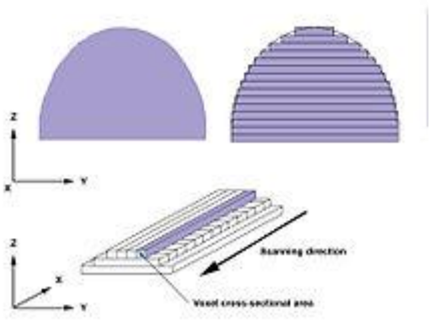

Figure 1. 3D model slicing.

Modeling :Additive manufacturing takes virtual blueprints from computer aided design (CAD) or animation modeling software and "slices" them into digital cross-sections for the machine to successively use as a guideline for printing. Depending on the machine used, material or a binding material is deposited on the build bed or platform until material/binder layering is complete and the final 3D model has been "printed."

A standard data interface between CAD software and the machines is the STL file format. An STL file approximates the shape of a part or assembly using triangular facets. Smaller facets produce a higher quality surface. PLY is a scanner generated input file format, and VRML (or WRL) files are often used as input for 3D printing technologies that are able to print in full color.

Printing: To perform a print, the machine reads the design from an .stl file and lays down successive layers of liquid, powder, paper or sheet material to build the model from a series of cross sections. These layers, which correspond to the virtual cross sections from the CAD model, are joined or automatically fused to create the final shape. The primary advantage of this technique is its ability to create almost any shape or geometric feature.

Printer resolution describes layer thickness and X-Y resolution in dpi (dots per inch), or micrometers. Typical layer thickness is around 100 micrometers (µm), although some machines such as the *Objet Connex* series and 3D Systems' *ProJet* series can print layers as thin as 16 µm. X-Y resolution is comparable to that of laser printers. The particles (3D dots) are around 50 to 100 µm in diameter.

Construction of a model with contemporary methods can take anywhere from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to a few hours, although it varies widely depending on the type of machine used and the size and number of models being produced simultaneously.

Traditional techniques like injection molding can be less expensive for manufacturing polymer products in high quantities, but additive manufacturing can be faster, more flexible and less expensive when producing relatively small quantities of parts. 3D printers give designers and concept development teams the ability to produce parts and concept models using a desktop size printer.

Finishing : Though the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the desired object in standard resolution, and then removing material with a higher-resolution subtractive process can achieve greater precision.

Some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts. Some are able to print in multiple colors and color combinations simultaneously. Some also utilize supports when building. Supports are removable or dissolvable upon completion of the print, and are used to support overhanging features during construction.

Additive processes:

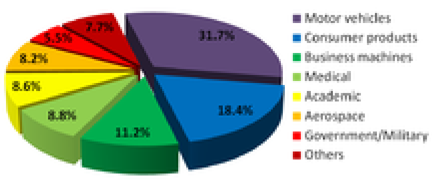

Figure 2.Rapid prototyping worldwide 2001

Figure 3: The Audi RSQ was made with rapid prototyping industrial KUKA robots.

Several different 3D printing processes have been invented since the late 1970s. The printers were originally large, expensive, and highly limited in what they could produce.

A number of additive processes are now available. They differ in the way layers are deposited to create parts and in the materials that can be used. Some methods melt or soften material to produce the layers, e.g. selective laser melting (SLM) or direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modeling (FDM), while others cure liquid materials using different sophisticated technologies, e.g. stereolithography (SLA). With laminated object manufacturing (LOM), thin layers are cut to shape and joined together (e.g. paper, polymer, metal). Each method has its own advantages and drawbacks, and some companies consequently offer a choice between powder and polymer for the material from which the object is built. Some companies use standard, off-the-shelf business paper as the build material to produce a durable prototype. The main considerations in choosing a machine are generally speed, cost of the 3D printer, cost of the printed prototype, and cost and choice of materials and color capabilities. Printers that work directly with metals are expensive. In some cases, however, less expensive printers can be used to make a mould, which is then used to make metal parts.

Lamination: In some printers, paper can be used as the build material, resulting in a lower cost to print. During the 1990s some companies marketed printers that cut cross sections out of special adhesive coated paper using a carbon dioxide laser, and then laminated them together.

In 2005, Mcor Technologies Ltd developed a different process using ordinary sheets of office paper, a Tungsten carbide blade to cut the shape, and selective deposition of adhesive and pressure to bond the prototype. There are also a number of companies selling printers that print laminated objects using thin plastic and metal sheets.

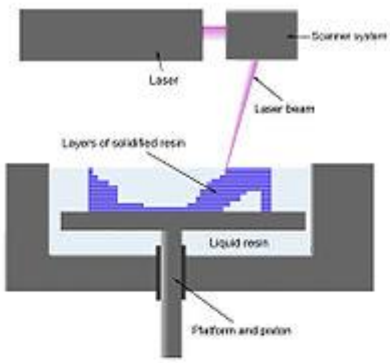

Figure 4.

Photopolymerization: Stereolithography was patented in 1987 by Chuck Hull. Photopolymerization is primarily used in stereolithography (SLA) to produce a solid part from a liquid.This process dramatically redefined previous efforts, from the Photosculpture method of François Willème (1830-1905) in 1860 through the photopolymer process of Mitsubishi`s Matsubara in 1974.

In digital light processing (DLP), a vat of liquid polymer is exposed to light from a DLP projector under safelight conditions. The exposed liquid polymer hardens. The build plate then moves down in small increments and the liquid polymer is again exposed to light. The process repeats until the model has been built. The liquid polymer is then drained from the vat, leaving the solid model. The *EnvisionTec Ultra* is an example of a DLP rapid prototyping system.

Inkjet printer systems like the *Objet PolyJet* system spray photopolymer materials onto a build tray in ultra-thin layers (between 16 and 30 µm) until the part is completed. Each photopolymer layer is cured with UV light after it is jetted, producing fully cured models that can be handled and used immediately, without post-curing. The gel-like support material, which is designed to support complicated geometries, is removed by hand and water jetting. It is also suitable for elastomers.

Ultra-small features can be made with the 3D microfabrication technique used in multiphoton photopolymerization. This approach traces the desired 3D object in a block of gel using a focused laser. Due to the nonlinear nature of photoexcitation, the gel is cured to a solid only in the places where the laser was focused and the remaining gel is then washed away. Feature sizes of under 100 nm are easily produced, as well as complex structures with moving and interlocked parts. Yet another approach uses a synthetic resin that is solidified using LEDs.

Printers: Printers for domestic use

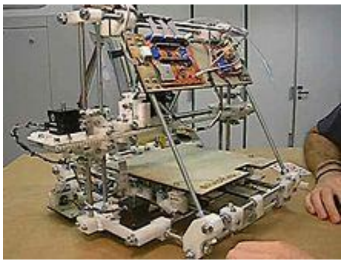

Figure 5.RepRap version 2.0 (Mendel).

Several projects and companies are making efforts to develop affordable 3D printers for home desktop use. Much of this work has been driven by and targeted at DIY/enthusiast/early adopter communities, with additional ties to the academic and hacker communities.

RepRap is one of the longest running projects in the desktop category. The RepRap project aims to produce a free and open source software (FOSS) 3D printer, whose full specifications are released under the GNU General Public License, and which is capable of replicating itself by printing many of its own (plastic) parts to create more machines. Research is under way to enable the device to print circuit boards and metal parts.

Because of the FOSS aims of RepRap, many related projects have used their design for inspiration, creating an ecosystem of related or derivative 3D printers, most of which are also open source designs. The availability of these open source designs means that variants of 3D printers are easy to invent. The quality and complexity of printer designs, however, as well as the quality of kit or finished products, varies greatly from project to project.

This rapid development of open source 3D printers is gaining interest in many spheres as it enables hyper-customization and the use of public domain designs to fabricate open source appropriate technology through conduits such as Thingiverse and Cubify. This technology can also assist initiatives in sustainable development since technologies are easily and economically made from resources available to local communities.

Printers for commercial and domestic use

The development and hyper-customization of the RepRap-based 3D printers has produced a new category of printers suitable for both domestic and commercial use. The least expensive assembled machine available is the Solidoodle 2, while the RepRapPro's Huxley DIY kit is reputedly one of the more reliable of the lower-priced machines, at around US$680. There are other RepRap-based high-end kits and fully assembled machines that have been enhanced to print at high speed and high definition. Depending on the application, the print resolution and speed of manufacturing lies somewhere between a personal printer and an industrial printer. A list of printers with pricing and other information is maintained.] Most recently delta robots have been utilized for 3D printing to increase fabrication speed further.

Applications[: Three-dimensional printing makes it as cheap to create single items as it is to produce thousands and thus undermines economies of scale. It may have as profound an impact on the world as the coming of the factory did....Just as nobody could have predicted the impact of the steam engine in 1750—or the printing press in 1450, or the transistor in 1950—it is impossible to foresee the long-term impact of 3D printing. But the technology is coming, and it is likely to disrupt every field it touches.

An example of 3D printed limited edition jewellery. This necklace is made of glassfiber-filled dyed nylon. It has rotating linkages that were produced in the same manufacturing step as the other parts.

Additive manufacturing's earliest applications have been on the toolroom end of the manufacturing spectrum. For example, rapid prototyping was one of the earliest additive variants, and its mission was to reduce the lead time and cost of developing prototypes of new parts and devices, which was earlier only done with subtractive toolroom methods (typically slowly and expensively). With technological advances in additive manufacturing, however, and the dissemination of those advances into the business world, additive methods are moving ever further into the production end of manufacturing in creative and sometimes unexpected ways. Parts that were formerly the sole province of subtractive methods can now in some cases be made more profitably via additive ones.

Standard applications include design visualization, prototyping/CAD, metal casting, architecture, education, geospatial, healthcare, and entertainment/retail.

Industrial uses

Rapid prototyping: Industrial 3D printers have existed since the early 1980s and have been used extensively for rapid prototyping and research purposes. These are generally larger machines that use proprietary powdered metals, casting media (e.g. sand), plastics, paper or cartridges, and are used for rapid prototyping by universities and commercial companies.

Rapid manufacturing : Advances in RP technology have introduced materials that are appropriate for final manufacture, which has in turn introduced the possibility of directly manufacturing finished components. One advantage of 3D printing for rapid manufacturing lies in the relatively inexpensive production of small numbers of parts.

Rapid manufacturing is a new method of manufacturing and many of its processes remain unproven. 3D printing is now entering the field of rapid manufacturing and was identified as a "next level" technology by many experts in a 2009 report. One of the most promising processes looks to be the adaptation of laser sintering (LS), one of the better-established rapid prototyping methods. As of 2006, however, these techniques were still very much in their infancy, with many obstacles to be overcome before RM could be considered a realistic manufacturing method.

Mass customization: Companies have created services where consumers can customize objects using simplified web based customization software, and order the resulting items as 3D printed unique objects. This now allows consumers to create custom cases for their mobile phones. Nokia has released the 3D designs for its case so that owners can customize their own case and have it 3D printed.

Mass production: The current slow print speed of 3D printers limits their use for mass production. To reduce this overhead, several fused filament machines now offer multiple extruder heads. These can be used to print in multiple colors, with different polymers, or to make multiple prints simultaneously. This increases their overall print speed during multiple instance production, while requiring less capital cost than duplicate machines since they can share a single controller. Distinct from the use of multiple machines, multi-material machines are restricted to making identical copies of the same part, but can offer multi-color and multi-material features when needed. The print speed increases proportionately to the number of heads. Furthermore, the energy cost is reduced due to the fact that they share the same heated print volume. Together, these two features reduce overhead costs.

Clothing: 3D printing has spread into the world of clothing with fashion designers experimenting with 3D-printed bikinis, shoes, and dresses. In commercial production Nike is using 3D printing to prototype and manufacture the 2012 Vapor Laser Talon football shoe for players of American football, and New Balance is 3D manufacturing custom-fit shoes for athletes.

3D printing services: Some companies offer on-line 3D printing services open to both consumers and industries. Such services require people to upload their 3D designs to the company website. Designs are then 3D printed using industrial 3D printers and either shipped to the customer or in some cases, the consumer can pick the object up at the store.

III. CONCLUSION

Future applications for 3D printing might include creating open-source scientific equipment or other science-based applications like reconstructing fossils in paleontology, replicating ancient and priceless artifacts in archaeology, reconstructing bones and body parts in forensic pathology, and reconstructing heavily damaged evidence acquired from crime scene investigations. The technology is even being explored for building construction.

As of 2012, 3D printing technology has been studied by biotechnology firms and academia for possible use in tissue engineering applications in which organs and body parts are built using inkjet techniques. In this process, layers of living cells are deposited onto a gel medium or sugar matrix and slowly built up to form three-dimensional structures including vascular systems. Several terms have been used to refer to this field of research: organ printing, bio-printing, body part printing, and computer-aided tissue engineering, among others.

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