3D Printing: Additive Manufacturing

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Abstract- This paper consists of the review of 3D Printing**.** 3D printing in the term's original sense refers to processes that sequentially deposit material onto a powder bed with inkjet printer heads. More recently, the meaning of the term has expanded to encompass a wider variety of techniques such as extrusion and sintering-based processes. Technical standards generally use the term additive manufacturing for this broader sense.

Keywords: *Manufacturing, CNC Machines, Additive Manufacturing Technologies, Applications.*

I. INTRODUCTION

The rapid growth and use of novel imaging sensors 3D printing, also known as additive manufacturing (AM), refers to various processes used to synthesize a three-dimensional object.[1] In 3D printing, successive layers of material are formed under computer control to create an object.[2] These objects can be of almost any shape or geometry, and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot.

Futurologists such as Jeremy Rifkin [3] believe that 3D printing signals the beginning of a third industrial revolution,[4] succeeding the production line assembly that dominated manufacturing starting in the late 19th century. Using the power of the Internet, it may eventually be possible to send a blueprint of any product to any place in the world to be replicated by a 3D printer with "elemental inks" capable of being combined into any material substance of any desired form.

II. TERMINOLOGY AND METHODS

Early Additive Manufacturing (or AM) equipment and materials were developed in the 1980s.[5] In 1981, Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two AM fabricating methods of a three-dimensional plastic model with photo-hardening polymer, where the UV exposure area is controlled by a mask pattern or the scanning fiber transmitter.[6][7]Then in 1984, Chuck Hull of 3D Systems Corporation[8] developed a prototype system based on a process known asstereolithography, in which layers are added by curing photopolymers with ultraviolet light lasers. Hull defined the process as a "system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed,"[9][10] but this had been already invented by Kodama. Hull's contribution is the design of the format widely accepted by 3D printing software as well as the digital slicing and infill strategies common to many processes today. The term *3D printing* originally referred to a process employing standard and custom inkjet print heads. The technology used by most 3D printers to date especially hobbyist and consumer-oriented models is fused deposition modeling, a special application of plastic extrusion.

AM processes for metal sintering or melting (such as selective laser sintering, direct metal laser sintering, and selective laser melting) usually went by their own individual names in the 1980s and 1990s. At the time, nearly all metal working was produced by casting, fabrication, stamping, and machining; although plenty of automation was applied to those technologies (such as by robot welding and CNC), the idea of a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape layer by layer was associated by most people only with processes that removed metal (rather than adding it), such as CNC milling, CNC EDM, and many others. But AM-type sintering was beginning to challenge that assumption. By the mid 1990s, new techniques for material deposition were developed at Stanford and Carnegie Mellon University, including micro casting [11] and sprayed materials.[12] Sacrificial and support materials had also become more common, enabling new object geometries.[13]

The umbrella term additive *manufacturing* gained wider currency in the decade of the 2000s.[14] As the various additive processes matured, it became clear that soon metal removal would no longer be the only metalworking process done under that type of control (a tool or head moving through a 3D work envelope transforming a mass of raw material into a desired shape layer by layer). It was during this decade that the term *subtractive manufacturing* appeared as a retronym for the large family of machining processes with metal removal as their common theme. However, at the time, the term 3D printing still referred only to the polymer technologies in most minds, and the term AM was likelier to be used in metalworking contexts than among polymer/inkjet/stereo lithography enthusiasts. The term subtractive has not replaced the term machining, instead complementing it when a term that covers any removal method is needed.

By the early 2010s, the terms *3D printing* and *additive manufacturing* developed senses in which they were synonymous umbrella terms for all AM technologies. Although this was a departure from their earlier technically narrower senses, it reflects the simple fact that the technologies all share the common theme of sequential-layer material addition/joining throughout a 3D

work envelope under automated control. (Other terms that have appeared, which are usually used as AM synonyms (although sometimes as hyponyms), have been *desktop manufacturing*, *rapid manufacturing* [as the logical production-level successor to *rapid prototyping*], and *on-demand manufacturing* [which echoes *on-demand printing* in the 2D sense of *printing*].) The 2010s were the first decade in which metal parts such as engine brackets[15] and large nuts[16] would be grown (either before or instead of machining) in job production rather than obligatory being machined from bar stock or plate.

As technology matured, several authors had begun to speculate that 3D printing could aid in sustainable development in the developing world.[17][18][19]

III. GENERAL PRINCIPLES

Modeling: 3D printable models may be created with a computer aided design (CAD) package, via a 3D scanner or by a plain digital camera and photogrammetric software. 3D printed models created with CAD results in reduced errors and can be corrected before printing, allowing verification in the design of the object before it is printed. [20]

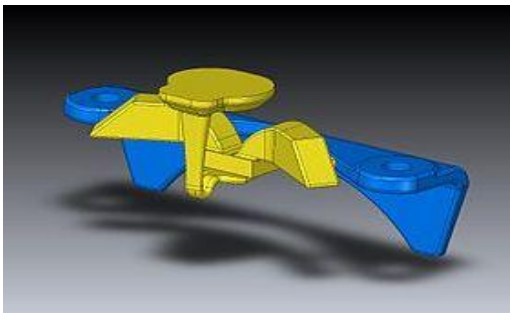

Figure 1. CAD model used for 3D printing

The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

Printing: Before printing a 3D model from an STL file, it must first be examined for errors. In fact, most of the CAD software produced errors in the STL files:[21] holes, faces normal, self-intersections, noise shells or manifold errors.[22] This step being called "repair", as the original model is needed to be fixed.[23][24] Generally STLs that have been produced from a model obtained through 3D scanning often have more of these errors.[25] This is due to how 3D scanning works : as it's often point to point acquisition, reconstruction will include errors in most cases.[26]

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 [28] with a higher-resolution subtractive process can achieve greater precision.

Some printable polymers such as ABS, allow the surface finish to be smoothed and improved using chemical vapor processes. [29]

Some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts. These techniques are able to print in multiple colors and color combinations simultaneously, and would not necessarily require painting.

Some printing techniques require internal supports to be built for overhanging features during construction. These supports must be mechanically removed or dissolved upon completion of the print.

All of the commercialized metal 3D printers involve cutting the metal component off of the metal substrate after deposition. A new process for the GMAW 3D printing allows for substrate surface modifications to remove aluminum [30] or steel.[31]

Processes: Several 3D printing processes have been invented since the late 1970s. The printers were originally large, expensive, and highly limited in what they could produce.[5]

A large number of additive processes are now available. The main differences between processes are in the way layers are deposited to create parts and in the materials that are used. Some methods melt or soften the material to produce the layers, for example. selective laser melting (SLM) or direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modeling (FDM),[32] or fused filament fabrication (FFF), while others cure liquid materials using different sophisticated technologies, such as stereo lithography (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, which is why some companies offer a choice of powder and polymer for the material used to build the object.[33] Others sometimes 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, costs of the 3D printer, of the printed prototype, choice and cost of the materials, and color capabilities.[34]

Printers that work directly with metals are generally expensive. However less expensive printers can be used to make a mold, which is then used to make metal parts. [35]

IV. MANUFACTURING APPLICATIONS

AM technologies found applications starting in the 1980s in product development, data visualization, rapid prototyping, and specialized manufacturing. Their

expansion into production (job production, mass production, and distributed manufacturing) has been under development in the decades since. Industrial production roles within the metalworking industries [36] achieved significant scale for the first time in the early 2010s. Since the start of the 21st century there has been a large growth in the sales of AM machines, and their price has dropped substantially.[37] 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.[38] There are many applications for AM technologies, including architecture, construction (AEC), industrial design, automotive, aerospace,[39] military, engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewelry, eyewear, education, geographic information systems, food, and many other fields:

Cloud-based additive manufacturing
Mass customization
Rapid manufacturing
Rapid prototyping
Research
Food
Medical applications

Industrial Applications:
Apparel
Vehicle
Firearms
Medical
Medical devices
Bio-printing
Pills
Computers and robots
Space

Sociocultural Applications:
Art
Communication
Domestic use
Education and research
Environmental use
Cultural Heritage
Specialty materials

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