

# A COMPREHENSIVE STUDY ON 3D PRINTING TECHNOLOGY

Hardial Singh <sup>1</sup>

<sup>1</sup> Assistant Professor, Department of Mechanical Engineering, Amity University Haryana, 122413

## ABSTRACT

In the world of developing technology, 3d printing has replaced the entire manufacturing firm/system with its improved version of building parts layer by layer using additive approach and new trends. In the present article, a comprehensive study has been carried out for comparing it with traditional manufacturing method for production of components, complex objects for hundreds of different applications. 3D printing technology is extremely versatile and rapid process, accelerate innovation and reduce energy usage, minimise material and compress supply chains. This paper also describes the feed mechanism and process related information, supporting material, software used in 3D printer and some recent developments on 3D printing technology.

Keywords: 3D printer, manufacturing, printing technology, software

## 1. INTRODUCTION

In the manufacturing area a new technology has proven to be very promising and is called rapid prototyping also called as additive manufacturing technology [1-2]. This technology has been substantially improved and has evolved into a useful tool for many fields like researchers, manufacturers, designers, engineers and scientists. Collaborating different fields in single package formed 3D printer as it includes Design, manufacturing, electronics, materials and business .3D printing is the process of creating an object with material layer by layer in three dimension formations. The difference between traditional manufacturing and 3D printing is that the 3d printer involves additive approach but most of the traditional manufacturing processes involve subtractive approach that includes a combination of grinding, bending, forging, moulding, cutting, gluing, welding and assembling. At the beginning 3D printing was mostly seen as a tool to shape and bring it to the artistic or different designs, but in the last few years this technology is developing to a point where mechanical components and some required parts can be printed [3]. It completely change not only the industrial/manufacturing field, but also our entire way of life in the future as 3D printer makes possible to complete model in a single process. For consumer level additive manufacturing, currently two main techniques to 3D print objects: Fused Deposition Modelling and Stereo lithography. Both processes add material, layer by layer, to create an object's. Stereo lithography (SLA) uses a Ultra-Violet light source to particular cure resin while Fused Deposition Modelling (FDM) extrudes semi-liquid plastic in a required layout to create objects [4]. The fast growth of this technology has allowed great inventions and 3D printing (mainly Fused Deposition Modelling or FDM technique) reduced the cost of manufacturing, the build time, and the weight of the object, reduction of waste compared to some traditional manufacturing processes therefore making 3D printings attainable to the average consumer (Figure 1) shows the graph of manufacturing cost reduction and days consumption in 3D printer comparison to the traditional manufacturing techniques.

## 2. LITERATURE REVIEW

Charles W. (Chuck) Hull [5] is generally credited with developing the first working robotic 3D printer in 1984, 3D printing has been changing the manufacturing and prototyping industries since the late 1980's, but it wasn't until 2009 that "desktop" 3D printers were readily available to the public. A desktop 3D printer is industry jargon for a smaller, less expensive 3D printer that a typical consumer can buy. S. Scott and Lisa Crump patented fused deposition modelling (FDM) in 1989 and co-founded the printer manufacturer Stratasys, Ltd. This technology (more generically called FFF, for fused filament fabrication) feeds a plastic filament into a heated extruder and then precisely lays down the material. When key patents expired in 2005, this technology became the basis of the Rep Rap movement.

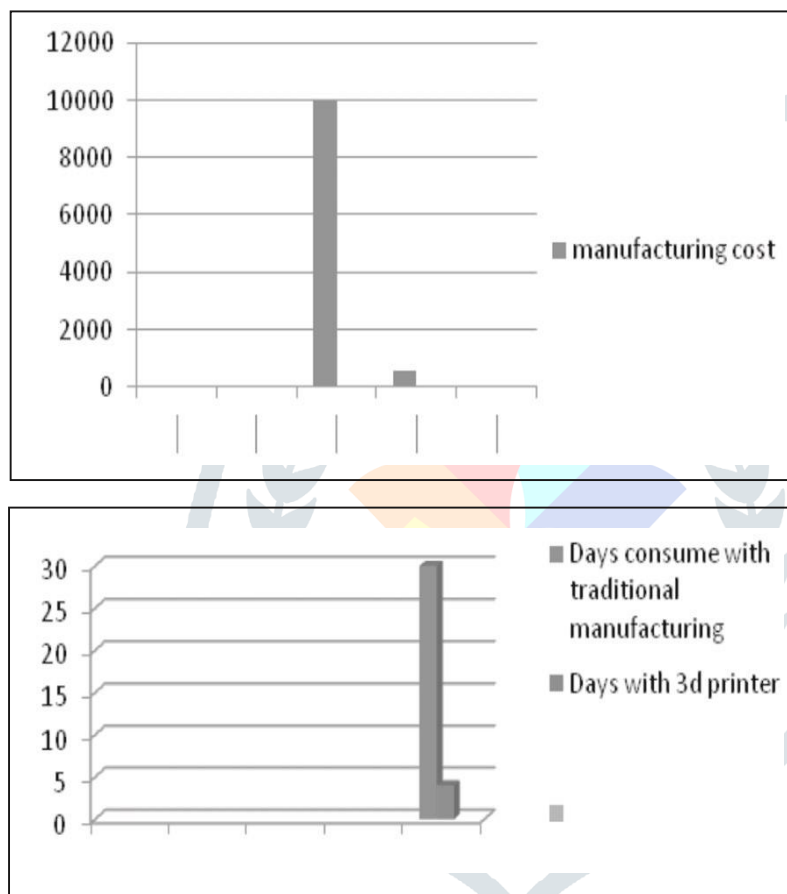
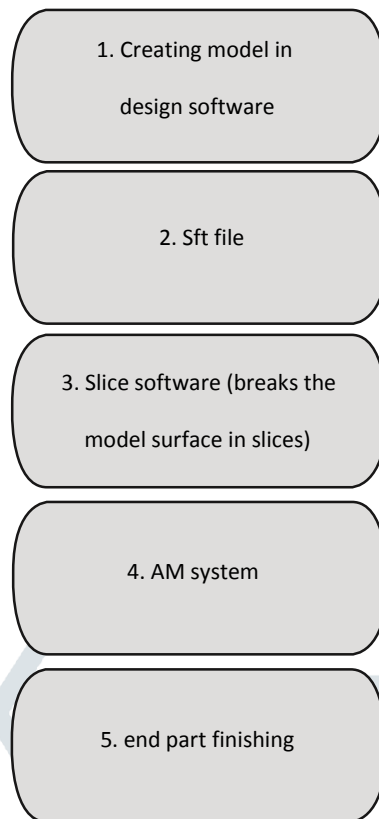


Fig. 1: Reduction of manufacturing cost, and build time of object consume in 3D printing as compared to the traditional manufacturing techniques.

Bowyer published the designs for the parts for his 3D printers and encouraged others to improve them and in turn post to improve versions [6]. He called this source concept, the Rep project and obtained some initial funding from the UK's Engineering and Physical Sciences Research Council (EPSRC). Bowyer's team called their first printer as Darwin (released in March 2007) and the next as Mendel (released in 2009). Since 2010, 3D printer technology has shown explosive growth with the help of the open source and DIY communities. It was superseded by the Maker Bot Thing-O-Matic in 2010. These were mostly made of laser cut wooden parts with some 3D-printed parts (plus, of course, motors and electronics). Eventually, Maker Bot became one of the earlier commercial consumer printer companies and was purchased by Stratasys in 2013. The Fused Deposition Manufacturing Technology is the mostly available and comparably less expensive [7].

### 3. METHODOLOGY



**Fig. 2: Process Steps in 3D Printing**

In 3D printing technologies, the process involves certain steps which are firstly a CAD based model is created and then converted to a Stereo-lithographic file which is in (.STL) .This files breaks down the surface into logical series of triangles which represents a part of the surface of a 3D model that is then used for the slicing algorithm. The STL file slices the model into thin cross-sectional layers that allowed the required model to be 3D printed (Figure 2).

#### 3.1 Feed Mechanism or Types of Technologies

##### A. Binder Jetting:

Creating object by joining the powdered material through jet deposition of binding agent, examples of Materials are metal, polymer, and ceramic. Developers (Country) are: exOne (US), Voxel Jet (Germany) 3D System (US).

##### B. Material Jetting:

Build parts by set down small droplets of the filament, which are then cured by exposure to light (UV) and it has a high resolution of about 16 microns of layer height. Material: photopolymer and wax. Developers (Country) are: stratasys (US), LUXeXcel (Netherlands), 3D system (US) [8].

##### C. Direct Energy Deposition:

Focused thermal energy is used for fusing material to builds part as they are deposited on a substrate. Materials are powder and wire. Developer's (countries) are: DM3D (US), NRC-IMI (Canada), Irepa Laser (France), Trumpf (Germany) [9-10].

**D. Powder Bed Fusion:**

Creates object by using thermal energy to fuse regions of a powder bed, Materials used are metal, polymer, ceramic. Developers (country): EOS (Germany), Renishaw(UK), Matsuura Machinery (Japan), ARCAM(Sweden) 3D system (US), Phenix System (France) [11-12].

**1. Direct Metal Laser Sintering (DMLS):** forming an object by melting and fusing metal powder using a focused laser beam in a chamber of inert gas

**2. Electron Beam Melting (EBM):** It fabricates an object uses an electron beam that melts powder inside a vacuum.

**3. Selective Heat Sintering (SHS):** It applies heat using a thermal print head to layers of thermoplastic powdered using which cures the powder.

**4. Selective Laser Melting (SLM):** this process melts a metal powder forming a melt pool by using a laser process held in inert gas chamber and then roller adds the material again on the top of it and the same procedure is repeated to build an object.

**5. Selective Laser Sintering (SLS):** The process is similar to the SLM where a laser sinters a powdered material and a roller adds new layer of material to form the part. The difference is that material is heated below the melting point until this particles fuse with each other

**E. Sheet Lamination:**

Build parts by trimming sheets of material and binding them together in layers [13].

Materials used are Hybrid, metallic and ceramic.

Developers (Country) are: fabrisonic (US), CAM-LEM (US).

**1. Laminated Object Manufacturing (LOM):** this process works by adding layers of adhesive coated paper, plastic or metal which are non-toxic. Each layer or sheet of thin material are cut to shape with a laser cutter and then successively glued together

**2. Ultrasonic Additive Manufacturing (UAM):** It uses the sheet lamination process where thin sheets of metal are joined together until the object is build. An ultrasonic welding is used to bond the sheets and then a CNC mill cuts the excess material.

**F. Light Photopolymerization:**

Build parts by using light to selectively curing layers of material in a vat of photopolymer.

Materials used are photopolymer and ceramic.

Developer's countries are 3D system (US), Encision TEC (Germany) DWS Sri (Italy) Lithoz (australia).

**1. Digital Light Processing (DLP):** an image of the object is projected in layers into a vat of photopolymer that reacts to the projecting light in order to cure and harden the desired part.

**2. Stereo-lithography (SLA):** a liquid photopolymer resin is melt using a beam of UV light sent from a laser which causes the resin in contact to react and solidify [14].

### G. Extrusion:

creating objects by depositing material through a heated nozzle to build a layer that instantly harden so the next layer bond on top and this process is repeated until an object is formed also called Fused Deposition Modelling (FDM).

Material is polymer.

Developer (Country): Stratasys (US), Delta Micro factory (China), 3D systems (US)

### 3.2 Classification of Material

Table 1 shows the most common 3D printing materials .

#### A. Wire filament materials

**1. ABS (acrylonitrile Butadiene styrene):** the cheapest of the three, ABS creates mild, generally sufferable fumes that may be dangerous to sensitive people or certain, ABS can be quite versatile. It can be sanded, and by hybridize ABS with acetone, it can be easily stick together or smoothed to a glass-like finish. (co-polymer of Acrylonitrile, Styrene, and Butadiene). ABS is subject to even violent heat shrinkages and warping during printing and therefore it is very demanding on the build platform. Printed parts can tolerate higher temperatures than PLA, as the glass transition temperatures for ABS are higher [15].

**2. PLA (Poly-lactic acid or Poly-lactide):** It is a biodegradable plastic typically made from corn or potatoes. When heated, PLA smells a bit like sweet, toasted corn. PLA is stiffer than ABS. While PLA does not require heating of a printed bed but warping of PLA during cooling will improve by heated bed only. Note that there is a “flexible PLA” variant generates a squishy objects but it is complex to use.

**3. PVA (Polyvinyl alcohol):** It is a specialty plastic used to print support material on multiple-extruder printer. PVA is water soluble. It absorbs water like a sponge, which can make for extremely problematic use in high-humidity environment Water soluble will absorb moisture once opened and may require drying before usage. Described to be used as a support material and supposedly will work best with PLA because it’s extruded at lower temperatures – ABS is extruded at 260°C and may cause degradation if printed on PVA [16].

**4. TPE (Thermoplastic Elastomer):** Soft PLA, Flexible, rubber-like materials of different varieties. Extruder has to be more rigid in construction for these filaments because the materials are very flexible. The extruder idler pressure also has to be adjusted correctly to be holding it under just the right pressure to avoid squashing the filament.

#### B. Powder materials

Many different powder materials can be printed, either by fusing or melting them together, or by using a binder material, mostly water with colour additives whereas the powder is a mixture of plaster and polymers

(supposedly PVA or other water solvent polymer or glue). Wood filament: These filaments are mixtures of ground wood material and PLA or some other plastic. Spools of wood filament were printed with extruder nozzle diameter 0,6mm without blockages or miss-feed. Material properties are similar to PLA, but the objects are much softer and weaker.

### C. Printable waxes

Waxes could be printed, such as those used in the Thermo-jet printer. The Thermo-jet uses waxes described as thermoplastics, made out of Hydrocarbons, Amides and Esters

### D. Liquid materials

The stereo-lithography and the inkjet printers use UV curable resins made up of thermosetting plastic and very different in properties to the thermoplastics used in the extrusion-based printer's, mechanical properties for the plastics such as tensile- and impact strengths and glass transition temperatures.

## 4. 3D PRINTER SOFTWARE

3D models require three kinds of software .the use of software to prototype physical objects has been referred to as computer aided design (CAD). Second, there's the computer-aided manufacturing (CAM) program also referred to as slicer that converts your model into specific, mechanical instructions for the printer robot. Third, there's the printer control software that sends instructions to the printer at the right time, and provides a real-time interface to the printer's functions and settings. (Figure 3)

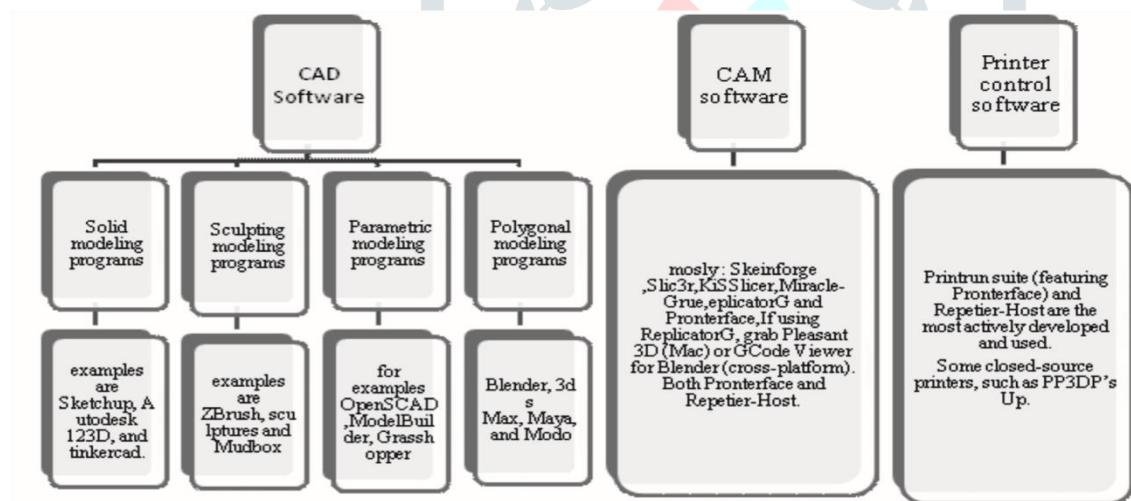


Fig. 3: Software hierarchy used in 3d printing

## 5. HARDWARE AND SOFTWARE CONTROLLING OF 3D PRINTER

Printing with filament of 3d printer use series of command called G-code. Figure shows the interfacing between hardware and software, g-code flow's one command at a time in printer from a source computer through USB port, although some printers used reading through SD card as other options. The firmware (running software on the printer) then interpret the G-code at a time and ship it off to the printer for further execution. Status information (example: temperature) return to the user's computer through the USB. In other cases interpretation of G-code done on the host computer and controls are sent to the printer. (Figure 4).

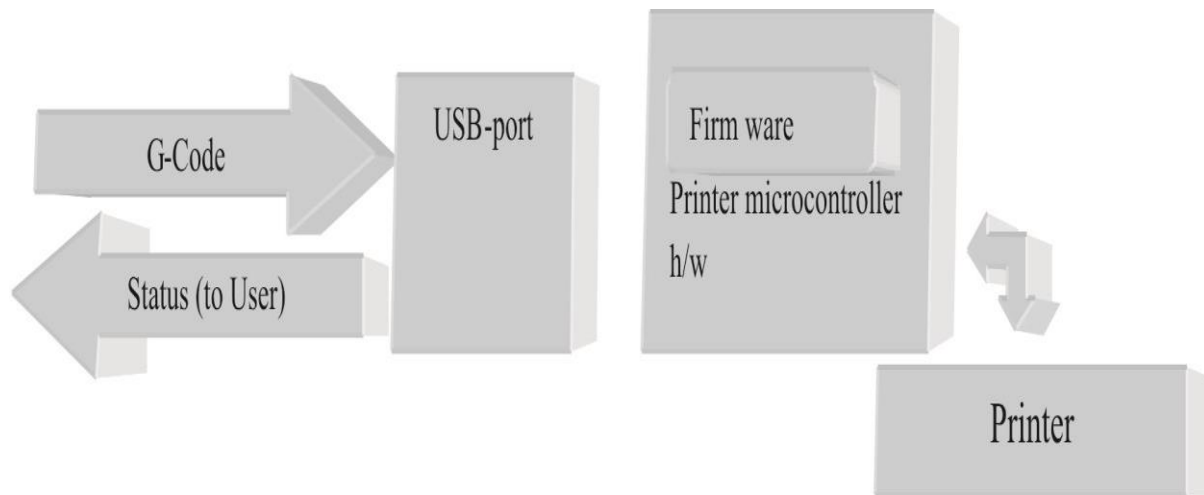


Fig. 4: Controlling of 3D printing

Table 1: Most commonly used 3D printer materials

SOME COMMON WIRE FILAMENT MATERIALS					
MATERIAL	EXTRUDED TEMP	BED TEMP	FORMATION	PROPERTIES	PROS AND CONS
ABS (Acrylo-nitrile Butadiene Styrene)	215°C– 250°C	80-110 ° C	It can be sanded, and by mixing ABS with acetone, it can be easily glued together or smoothed to a glass-like finish (petroleum)	Durable Strong Slightly flexible Heat resistant	PRONS :Great plastic properties, Smooth finish, Solidifies quickly, Durable and difficult to break, Ideal for mechanical parts CONS: Petroleum-based ,Non-biodegradable, Heated print bed necessary, Fumes, Deterioration through sunlight
PLA (Poly-lactic Acid)	170°C to 220°C	20-55 ° C	Biodegradable plastic typically made from corn or potatoes (produced from plant starch)	Tough Strong	PRONS: Bio-plastics – good environmental properties, Good smell when heated, Nontoxic ,No heated print bed necessary ,High print speed and resolution, Less warping or

					shrinking issues, Ideal for small parts, Hard or soft/flexible variants CONS :Slow cooling down, Low heat resistance, Easier to break then ABS, Needs thicker walls then ABS
PVA (Polyvinyl Acetate)	160°C to 170°C	° C	PVA is a special plastic that is water-soluble, Water-soluble, Excellent film formation, High bonding power, Good barrier properties (petroleum)	Used to print support material	PRONS: Biodegradable Recyclable Non toxic. CONS: Expensive Deterioration due to air moisture, Special storage necessary.
TPE (Thermoplastic Elastomers)	180°C to 230°C.	20-55 ° C	Flexible, rubber-like materials of different varieties.	The properties of a soft rubber, making it even more flexible and elastic than our Soft PLA filament.	PRONS: Because of lower melting point and flexibility, printing settings have to be adjusted correctly CONS: The resultant balls were not as flexible as expected because of the honeycomb structure making it rigid on the edges.

## 6. RECENT DEVELOPMENTS

As 3D printing technology accelerating day by day, some recent research and developments has been made on 3D printer for fixing damaged cartilage in knees, noses and ears through 3D bio-print the shape of an ear using



human cells which build up cartilage, they have successfully tested it in an vivo mouse model in March 16,2016 (Figure 5). In 2015 from NASA's Marshall Space Flight Centre(MSFC), Deputy Manager Dr Raymond "Corky" Clinton will give envoy the opportunity to see how 3D printing and additive manufacturing is being utilized to advance 'In Space Manufacturing' this is the first successful experiment on 3D printing on the International space station (ISS). In MSFC successfully test fired a liquid fuelled breadboard engine in which 75% of the components were produced by Additive Manufacturing (AM). Published in, July 2016 Disney Research developing 3D printed Knitting machines. It can produce seamless and very fine 3D surface quickly and autonomously. Disney team thankful to the change developed in manufacturing principles to digitally controlled 3D printing and CNC milling innovations. In 13 July 2016 Airbus Group subsidiary in metal additive manufacturing, will use the on - demand 3D printing services announced recently by SAP to operate a bionics network in which 3D printing experts and end users are connected.

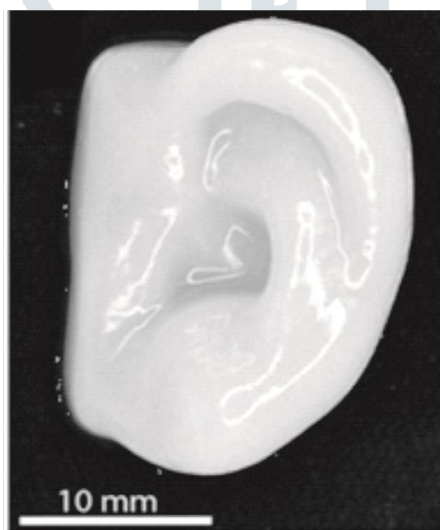


Fig. 5: Scientist can 3D bio-print the shape of an ear using human cells that build up cartilage

This allowed service of AP Works for manufacturing of on-demand 3D printed aerospace components and maintain the standard quality necessary for aircraft to fly.

## 7. CONCLUSION

The concept of 3D printing technology in an encapsulated way including the comparison chart of cost and build time with the traditional manufacturing method for building parts. After presenting, in the introduction, a brief history of 3D printing, the second section is depicted the additive technology and its feed mechanism and highlighted the most significant wire filaments used in 3D printing technology, while in the fourth section the survey of classification of firmware's used in 3D printing and its controller process flow . One can conclude that the 3D printing technology revolutionize and reshape the world as it is very exciting technology with huge potential also comprising the different technologies at one place, taking into account their economic benefits and social impact. This technology improved the whole status of manufacturing industries as well as the way of living of entire universe through its rapid developments in different applications like in medical,

manufacturing, aerospace, biotechnology, space research etc, as it produce object or products and complex structure according to the need whenever and wherever required.

## REFERENCES

- [1] ISO/PRF 17296-1, "Additive manufacturing -- General principles -- Part 1: Terminology", 2015.
- [2] Bernard, A. and Fischer, A., New trends in rapid product development, CIRP Annals - Manufacturing Technology, Vol. 51, pp. 635- 652, 2002.
- [3] Birtchnell, T. and Urry, J., "3D, SF and the Future", Futures ,2013, Vol. 50, pp. 25-34.
- [4] L. Ze-Xian, T.C. Yen, M. R. Ray, D. Mattia, I.S. Metcalfe, & D. A. Patterson, "Perspective on 3D printing of separation membranes and comparison to related unconventional fabrication techniques," Journal of Membrane Science, Vol 523, No.1, pp. 596-613, 2016.
- [5] P. Holzmann, J. Robert, A. Aqeel Breiteneker, Soomro, & J. S. Erich, "User entrepreneur business models in 3D printing," Journal of Manufacturing Technology Management, Vol. 28, No. 1, pp. 75-94, 2017.
- [6] Bob Hayward, David Moschella, Jon Schreiber, Simon Wardley, Howard Smith, "3D printing and the future of manufacturing" CSE, the rise of 3D printing.
- [7] A. Pirjan & D. M. Petrosanu, "The impact of 3D printing technology on the society and economy," Journal of Information Systems & Operations Management, pp. 1-11, 2013.
- [8] A. M. T. Syed, P. K. Elias, B. Amit, B. Susmita, O. Lisa, & C. Charitidis, "Additive manufacturing: scientific and technological challenges, market uptake and opportunities," Materials today, Vol. 1, pp. 1-16, 2017.
- [9] M. Lang, "An overview of laser metal deposition," A publication of the Fabricators & Manufacturers Association, 2017. [Online]. Available: <https://www.thefabricator.com/article/additive/an-overview-of-laser-metal-deposition>. [Accessed 2019].
- [10] M. D. Ugur, B. Gharehpapagh, U. Yaman, & M. Dolen, "The role of additive manufacturing in the era of Industry 4.0," Procedia Manufacturing, Vol. 11, pp. 545-554, 2017.
- [11] S.K. Tiwari, S. Pande, S. Agrawal, & S. M. Bobade, "Selection of selective laser sintering materials for different applications," Rapid Prototyping Journal, Vol. 21, No.6, pp.630-648, 2015.
- [12] C. L. Ventola, "Medical Application for 3D Printing: Current and Projected Uses," Medical Devices, Vol. 39, No.10, pp. 1-8, 2014.
- [13] S. Vikayavenkataraman, Y.H.F. Jerry, & F.L. Wen, "3D Printing and 3D Bioprinting in Pediatrics," Bioengineering, Vol. 4, No.63, pp. 1-11, 2017.
- [14] P. Reddy, "Digital Light Processing (DLP)," Think 3D. 2016. [Online]. Available: <https://www.think3d.in/digital-light-processing-dlp-3d-printing-technology-overview/>. [Accessed 2019]
- [15] Chris Anderson, Makers: The new industrial revolution (New York: Crown Business, 2012), p. 210.
- [16] Joan Horvath, Mastering 3D printing technology.