Title:
3D Printing Technologies & Applications: An Overview

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Introduction:

3D printing has evolved rapidly since the initial concept invented in the late 1970s. The main idea is to join different layers of material using a digital model input from a CAD software to create a three dimensional object, a process also widely known as Additive Manufacturing (AM) [10],[16],[22]. Nowadays, 3D printing lists a number of different applications in several industries such as medicine, manufacturing, aerospace, automotive, construction, architecture, jewelry, food and more [16],[12],[5]. The possibilities are endless due to the multiplicity of different technologies and materials, offering a wide range of geometrically complex, largely scaled models with high-precision and reliability. In this paper some of the most commonly used 3D printing technologies will be presented and compared under specific parameters that affect the final result in terms of accuracy, functionality and usability. A wide list of the printing materials is considered, as well as the advantages, disadvantages and different applications of these technologies.

This paper is a first step in assuring the quality of the printed models with regard to their geometry. Although the surface of an imported, model considers manifold and non self-intersected in several cases the printed model lacks consistency and accuracy. For this reason errors such as thin faces, overlaps, gaps, non-manifold structures and self-intersections may appear in the printed models. This comparative survey of printing technologies will facilitate, in future work, (i) the identification of geometrical issues that occur in certain printing technologies and (ii) the characterization of the corresponding frequency of occurrence.

3D Printing Technologies:

There are several types of 3D printing technologies depending on the processes they adopt for material deposition in order to create the desired 3D model. Some of them melt the material while others solidify powders or liquidize materials. The basic processes are Material Extrusion, Powder bed Fusion, Vat Photopolymerization and Sheet Lamination.

Material extrusion is an AM process which creates layers by mechanically extruding molten thermoplastic material on a build platform. In Powder bed Fusion process an electron beam is used to melt the spread material on a powder bed, while in Vat Photopolymerization process an ultraviolet laser is used to polymerize the UV resins and create a layer of solidified material. Finally in Sheet Lamination a controlled laser is used to cut the coated material on a building platform[24].

Description of Technologies:

In this section the different types of 3D printing technologies will be presented and categorized according to the process they adopt.

Stereolithography (SLA) uses an ultraviolet (UV) laser which is focused on the top surface of the resin which hardens precisely where the laser hits its surface [15],[7].

Fused Deposition Modeling (FDM) uses a continuous filament of a thermoplastic material and builds a part by heating and extruding this thermoplastic filament through a moving, heated extrusion print head one layer each time [15],[7].

Selective Laser Sintering (SLS) uses a high power laser to sinter small parts of powdered material aiming at specific points across a powder bed [15],[7],[16],[13].

Digital Light Processing (DLP) uses a digital projector screen to flash a single image of each layer across the entire platform at once [7],[20].

In Laminated Object Manufacturing (LOM) technology a laminated sheet of material is spread through a roller mechanism. A computer controlled laser cuts the coated material to form the desired shape of the object [7],[15].

In Continuous Liquid Interface Production (CLIP) technology a beam of ultraviolet light is projected through an oxygen-permeable window into the vat of liquid resin, illuminating the precise cross-section of the object [19],[21].

In Selective Laser Melting (SLM) the powdered material is spread over the fabrication bed and melted or sintered by a high powdered optic laser. In this process the metal material can be fully melted [17],[18].

In Powder bed and inkjet head 3D printing (3DP) a thin layer of the powder material is spread onto the fabrication platform and an inkjet print head moves across the powder bed depositing a liquid binding material that joins the powders [9],[3].

Electron Beam Melting (EBM) is mainly based on a melting process which uses a metal powder and an electron beam. The material is spread on the building platform and heated by an electron beam [4].

In Selective Heat Sintering (SHS) the material is fed from the powder deposition tanks (1), heated to just below its melting point, spread out into a thin layer over the movable building platform (2) and flattened using a roller (3) [2],[11].

Fig. 1 provides a schematic representation of the above 3D printing technologies and in Tab. 1 the corresponding process is presented [16],[22],[24]. The basic processes will be evaluated in terms of accuracy, surface quality finish and model resistance of the final model, material variety, printing costs and other parameters. In Tab. 2, some of these parameters are presented [15],[7],[24].

Processes	***Technologies***
Material Extrusion	FDM
Powder bed Fusion	3DP , EBM , SLM , SHS , SLS
Vat Photopolymerization	SLA , DLP , CLIP
Sheet Lamination	LOM

Tab. 1: 3D Printing processes and technologies.

Materials:

3D printing involves a wide variety of materials, such as polymers, ceramics, metals and more, making it the most suitable technique to produce a wide range of products faster and with lower cost than traditional manufacturing processes. This material variety offers excellent prospects in terms of synthetic, free-form, detailed and with high resolution, resistance, functional models. Some of the materials used in 3D printing are mentioned in Tab. 3 based on the corresponding processes [15],[16],[7],[12],[24].

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Advantages and disadvantages:

In this section we will present one more specific list for the advantages and disadvantages for 3D printing technologies. The main advantages of adapting these technologies over traditional manufacturing processes is the ability to construct complex, customized and with high accuracy models. One of the main disadvantages of 3D printing technologies, still, is the limited potential to build large-scale models. Although mass production of identical parts is possible with 3D printing technologies a printing speed and cost remain hindering factors. A comparative list of some of the main 3D printing technologies advantages and disadvantages are presented in Tab. 4 [15],[23],[7],[12],[24],[3],[1],[6].

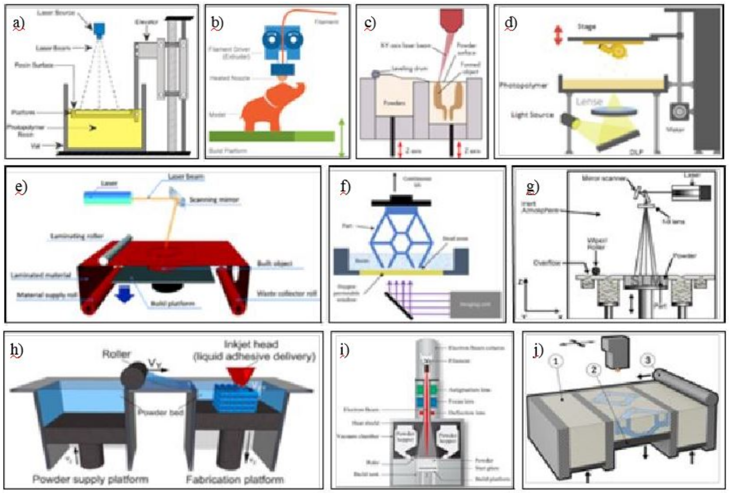

Fig. 1: 3D printing technologies: a) SLA [14], b) FDM [14], c) SLS [8], d) DLP [7], e) LOM [7], f) CLIP [19], g) SLM [17], h) 3DP [3], i) EBM [4], j) SHS [11].

Processes	***Accuracy***	***Surface quality finish***	***Material variety***	***Model resistance***	***Cost***
Material Extrusion	**	Poor	Wide	Good	*
Powder bed Fusion	**	Powdery /Porosity	Wide	High	***
Vat Photopoly-merization	***	Smooth	Wide	Moderate	**
Sheet Lamination	*	High	Limited	Good	*

Tab. 2: Critical parameters of 3D Printing processes.

Processes	***Materials***
Material Extrusion	Thermoplastic polymers, Ceramic slurries, Metal pastes, Eutectic metals
Powder bed Fusion	Polyamides, Polymer, Ceramic, Metal, Glass powders, Thermoplastics, Nylon
Vat Photopolymerization	Photopolymers, Ceramics, Semi-flexible materials, ABS
Sheet Lamination	Polymer composites, Ceramics, Paper and metal-filled tapes

Tab. 3: Materials used in 3D Printing processes.

Applications of technologies:

3D printing technologies are utilized in several industries due to combination of different materials and technologies. Biomedical customized implants, automotive models, prototypes, smart structures are only few of an extensive list of products. The last years 3D printing has entered the food industry, where it can be used to customize the nutritional value of meals [5].

In Tab. 5 [15],[7],[5],[12] and Fig. 2 [24],[12] some of the main applications of the 3D printing technologies are mentioned.

Technologies	***Advantages***	***Disadvantages***
FDM	Various colors, Simplicity Multi-materials, High speed	Requires supports for complex structures Weak mechanical properties, Limited resolution, Poor surface finish
SLS	Large part size, Variety of materials Customized products, Fast procedure High strength and stiffness	Post processing required Expensive process
SLA	Less time consuming Customized coloring, Detailed large prints High quality, Fine resolution	Limited materials Possible brittle components, Expensive Support structures for parts with overhangs
LOM	Reduced manufacturing time Variety of materials , larger structures Reducted tooling cost	Inferior surface quality Post processing required Limitations for very complex shapes
DLP	High accuracy, Fine resolution,Material variety, Fast process	Costly process, Post processing required

Tab. 4: Advantages and disadvantages of 3D Printing technologies.

Technologies	***Applications***
FDM	Prototyping , Biomedical, Toys , Advanced composite parts Home use applications , Food technology, Buildings , Construction
SLS , SLM , 3DP	Biomedical , Electronics, Aerospace, Lightweight structures, Heat exchangers
SLA	Biomedical, Excellent for form testing Best process for water resistant material, Prototyping
LOM	Paper manufacturing , Foundry industries, Electronics Biomedical , Ideal for nonfunctional prototypes, Smart structures

Tab. 5: Applications of 3D Printing Technologies.

Conclusions:

3D printing has signalled new horizons in manufacturing by facilitating a wide range of improved designs, reducing the production time and cost and simplifying complicated procedures. For instance, in medicine 3D printing has optimized the surgical pre-operative planning procedure and medical education by producing accurate human phantoms. The presented technologies are suitable for designing almost every complicated model with a sufficient percentage of accuracy.

FDM has a lower production cost and several of these printers are used for home use applications. The poor surface finish and limited resolution of the final models are two of the main drawbacks.

With SLS parts with complex interior structure, fine resolution and accuracy can be produced. It is widely used for customized parts but it is more expensive than other technologies.

SLA on the other hand is one of the most widely used technologies for making prototypes, and construct high quality and fine resolution models. It is less time consuming than other technologies but it is also expensive.

LOM might have a lower dimensional accuracy that the powder-bed methods but it is one of the best choices for larger structures. It uses a variety of materials, reduces manufacturing time and tooling costs.

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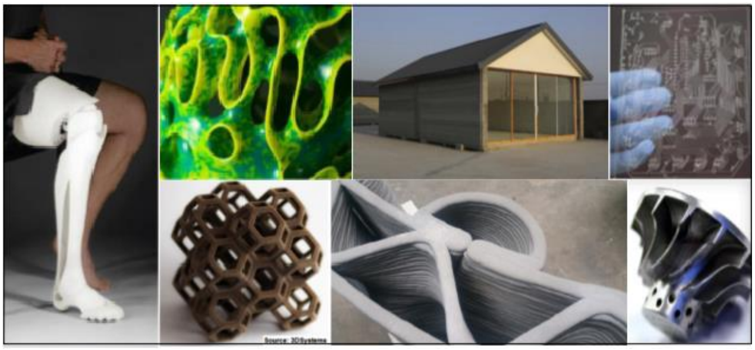

Fig. 2: Applications of 3D printing technologies: Medicine, Art, Buildings, Electronics, Food, Construction, Aerospace.

DLP might be a costly process but this is balanced by the speed and the high accuracy of the manufacturing.

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