Analysis of Programming Tools and Techniques in 3D Printing Technology

N.C. Brintha, J.T. Winowlin Jappes, P. Jothiraj

Abstract*: This paper explains and analyses the additive manufacturing process from its varieties, types and usage of different programming tools. Printing process need to be selected mainly based on applications and the materials used for development. More applications of 3D printing, were found to be in electronic industries which is mainly due to complexities in shape and size. Understanding of the prompt programming tool to be selected during complexity management is one of the major requirement. This requirement drives the research community from 3D to 4D-Printing. Mainly, in 4D printing concept, the object or the material system has the ability to change its form/function after it is being printed. The advantages and disadvantages of this technology towards the significant growth of applications were analyzed and presented in this paper.

***Keywords* : 3D Printing, 4D Printing, Applications, Growth Rate, Programming tools, Market.**

I. INTRODUCTION

Now-a-days, 3D printing is revolutionizing product design and its development in many sectors. It is restructuring the ways in which a product is designed, developed and released. 3D printing which can also be referred as "Additive Manufacturing", is the process of creating a prototype from digital design [1]. It helps to build components layer by layer by using materials that are available in fine powdered form. All process are controlled and monitored by computer tools and software. This concept enables flexible and digital manufacturing operations and hence it is used in many applications [2].

The 3D printing process involves the following steps.

1) *Preparation of object:*

The first step is to prepare a digital model i.e., a 3D file of the structure to be generated. In-order to achieve this, most commonly CAD software or other relevant software's is used.

2) *Conversion:*

The CAD file is transformed in to an STL (stereolithography) or other equivalent file formats.

3) *Manipulation:*

When the intermediate file is ready, the size and orientation of the printing object is defined and fed to a computer which is connected to a 3 D printer.

4) *Preparation of printer:*

Once after the digital component is complete, the other materials which are essential for the print operation like composite materials, plastics, binders, ceramic, etc. based on the job is selected.

5) *Construction:*

The time for printing varies depending on the complexity of object that is to be printed. Since the construction involves deposition of the material as thin layers, the printing span varies for each job.

6) *Finishing:*

After the construction step is complete, the printed object has to be removed carefully and may be subjected to post manufacturing operations like polishing, brushing and removal of dissolvable substances.

The major objective of this paper is to know the opportunities and challenges in 3D printing technology. This work presents the research challenges and benefits of 3D printing concepts and also describes the programming tools & techniques used in this technology. The rest of the paper is organized as follows: Section 2 focuses on the literatures reviewed for understanding the challenges in this area. The techniques used and its benefits is described in Section 3 which is followed by analysis of programming tools, techniques and challenges Section 4. Section 5, finally concludes the work.

II. BACKGROUND STUDY ON PRINTING TECHNOLOGIES

Currently, a lot of printing technologies are available and each differs in the way of how the layers are constructed to create an object [3, 4]. There are several rapid manufacturing process in 3D printing.

1) *Vat photopolymerisation:*

The photopolymers are hardened by continuous exposure to UV rays. The photopolymer which is in the form of a liquid resin is filled in to vat. Stereolithography (SLA) and Continuous Liquid Interface Production (CLIP) are the two common techniques in this approach.

Stereolithography is a process of creating models, patterns or prototypes using a photo chemical approach which makes the chemical molecule to form polymers through linkage. It is a common

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approach used in many applications of 3D printing.

Continuous Liquid Interface Production (CLIP) is a modern approach which is based on SLA but replacing SLA's nowadays due to its speed of processing. Unlike SLA, this approach does not pause layer by layer, the resign passes through a dead zone which lies above the oxygen preamble window.

2) Material Jetting:

The selected material is placed as layers one above another through a nozzle which is used to make a platform for the 3D object.

3) Binder Jetting:

In this process a powder base is dispersed equally in layers and a binder which is in the form of a liquid is poured through nozzles which glues the powder in to the shape of a programmed 3D object.

4) Material Extrusion:

It can be done using Fused Deposition Modelling (FDM) and Fused Filament Fabrication (FFF) technology.

FDM uses a filament or wire from a coil and helps in supply of material under control of the CAD program. FFF technology uses power bed fusion using either selective laser sintering (SLS) or direct metal laser sintering concept (DLS).

5) Sheet Lamination:

Sheets which are in the form of plastic, paper, metal or polymer are bonded together with huge external force.

6) Directed Energy Deposition:

This process is mostly used in large industries which is a form of rapid manufacturing. In this concept, a robotic arm which is capable of depositing material on the surface which is then followed by an energy source to form a solid object [6, 7]. A comparison on different technologies adopted in 3D printing is depicted in Table I

Table- I: Comparison of Different 3D Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES	MATERIAL USED	APPLICATION AREA
Selective Laser Sintering (SLS) [8]	Durable complex part construction, Modification to parts is easy, Material Selection flexibility, No post curing is required, does not require supporting structure	Fabricated component may be porus/rough, Polymer parts may cause thermal distortion , machinery and materials are expensive, additional powder may harden at the border line	Metal, glass, paper, composites, ceramic	Commercial products, aerospace, automotive
Fused Deposition Modelling (FDM) [9]	Fast and inexpensive, process is simple and has material flexibility, parts have high resolution	Relatively low accuracy and poor strength in vertical direction, dimensional tolerances is not accurate	Nylon, Polycarbonate, Resin, ABS Filaments	Automotive, Industry, medicine, Aerospace
Stereolithography (SLA) [10]	Has high dimensional accuracy and better surface finish, better user support round the clock, supports wide range of materials	Requires supporting structures, post-processing, post-curing operations	Composites and Liquid photo polymer	Aerospace, automotive and customer goods
Photopolymer Jetting (POLYJET) [11]	Better precision and surface finish, used with different colors and materials, support material need not be removed	Very slow build process	Wax, plastic, metal	Medical devices and prototypes
Material Jetting (MJ) [12]	Better accuracy and surface finish, multiple material usage and hands free removal of support material	Slower build process, Wax base materials are limited	Wax	Prototypes for jewellery and medical fields
Selective Laser Melting (SLM) [13]	Better speed and does not require support, resistant to heat and chemicals	Limited precision and rough surface finishing	Metals like copper, aluminium and tungsten	Dentistry and mechanical components
Electron Beam Melting (EBM) [14]	Better printing speed and subjected to lower distortion	Finishing is not proper and care should be taken when handling X-Ray	Metal, Cobalt, chrome, nickel	Dentistry & other medical models, automotive
Continuous Fibre Fabrication (CFF) [15]	Robust parts and no post curing is needed, many materials can be used	Limited fibre placement	Plastics, carbon, composites, nylon	Aerospace
Digital Light Processing [16]	Build complex shapes and sizes, better precision, simultaneous production	Limitation in product thickness and less range of materials	Liquid photopolymer, Liquid Crystals, Digital Micro mirror Device, Integrator, liquid crystal display, Projectors, resin	DLP projectors, Holographic Data Storage, PCB manufacturing
Selective Deposition Lamination [17]	Quick in making bigger parts, less expensive and non-toxic	Low accuracy and non-homogeneous parts	Paper, plastic, resin, laminates, ceramics, composites	Manufacturing and industrial applications

III. TRENDS AND APPLICATION OF 3D PRINTING

Additive Manufacturing growth has increased nearly 62% over the past two years as shown in Fig. 1 (Wohler's Report, 2019). Industries have profited by about $200 million by producing $10 billion products and services. The factors that influences this growth are design, training & education, post processing automation, good supply chains, investments, partnership & collaborations, corporate excellence and interconnectivity.

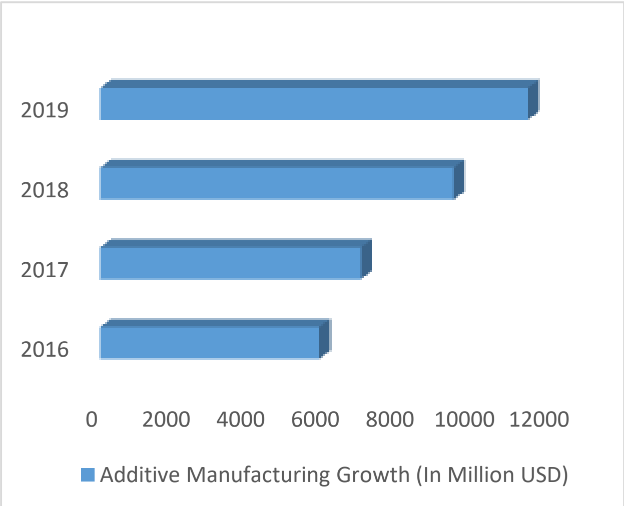

Fig. 1. Growth Rate of AM in Past 4 years

Most of the sectors like medical, automotive and aerospace are expected to use the 3D/4D printing technology by 51% in 2025. By 2025, the growth rate is predicted to about $21.50 Billion. The prediction on percentile of growth of 3D/4D printing in various sectors is illustrated in Fig 2. This is about to increase with a Compound Annual Growth Rate (CAGR) of 11% [19].

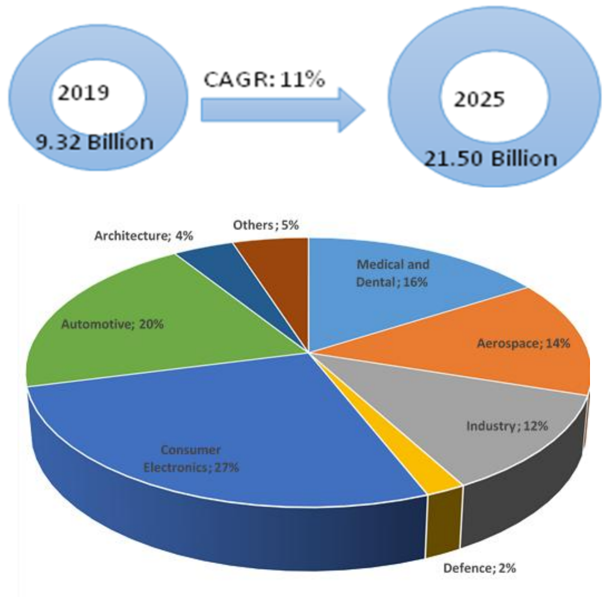

Fig. 2. Growth Rate of 3D technology in Several Applications (*frost & Sullivan, 2016*)

IV. ANALYSIS OF PROGRAMMING TOOLS AND TECHNIQUES

Programming in 3D printing is analysed in to two categories: 3D graphics programming and 3D printer programming [20, 21]. Variety of software's are required during each phase of 3D printing till the creation of 3D object. The 3D object is created by applying 3 phases: Model Designing, Testing/Repair of G-code and Generation of G-Code (Printing).

A. Model Designing

A 3D object is created using modelling, scanning and downloading from online repositories

1) Modelling: This tool is used for creating/drawing the 3D model and user can make their section an appropriate tool based on their application needs like complexity, version etc.

- *Tinkercad (Beginners)* – This is a popular user friendly educational tool used by designers and educators. The objects are saved as STL files and it offers solid/box model parameters.
- *Sketchup (Beginner and Intermediate)* – It is a powerful modelling tool available for both beginners and intermediate users. It has a lot of built-in models.
- *Free CAD (Intermediate)* – It is used for parametric modelling.
- *AutoCAD (Intermediate & Professional)* – Offers free sophisticated tools for both 2D and 3D modelling. It is used much for educational purposes.
- *OnShape (Professional)* – Cloud based CAD platform. Offers more flexibility and concurrency in applications.
- *Blender (Professional)* – Open source used for variety of applications like 3D modelling, simulation, texturing, skinning, animation and especially video editing.
- *Fusion 360 (Intermediate & Professional)* – Next level software which is cloud based and is more flexible than several other modelling software packages.
- *Morphi App (Beginner)* – Enables users to create 3D models independent of their skill level.
- *Rhino 3D (Intermediate & Professional)* – Stand-alone tool for variety of applications due to low cost, diversity, convertor of over 30 file formats.
- *3ds Max (Professional)* – Provides modelling, simulation support, animation, rendering for motion graphics applications like games, film etc.
- *Cinema 4D (Professional)* – Used for advanced 3D graphics.
- *Maya (Processional)* – This is a computer graphics software for animation, modelling, simulation and rendering. It is used for interactive 3D applications.
- *3D Slash (Beginners and Intermediate)* – It offers fun and easy to use interface. It is used for working with high level of precision.
- *123 Design (Intermediate)* – It is used to create and edit 3D models easily. This is ideal for performing collaborative works.
- *Inventor (Intermediate & Professional)* – Provides a variety of tools for automation and simulation. It has different packages with different levels of proficiency.
- *Wings 3D (Professional)* – It has advanced modelling tools which are free from complex representations.
- *Auto desk Revit (Intermediate & Professional)* – Coordinated and consistent object modelling approach.

- *Solid Works (Intermediate)* –This enables rapid creation of 3D parts, drawings.
- *Catia (Professionals)* – Best software solution used to design, analyse, simulate and manufacture products. It is used in variety of industrial sectors.

2) Scanning: This enables to capture the digital copy of the physical real world object. 3D scanning is classified based on 3 technologies: laser triangulation, scan by time-of-flight and scan by phase field. Some example scanning tools are Kinect, xyz printing, Sense, Structure etc.

3) Downloading: The 3D models can be collected and downloaded from several repositories and it may be readily available for printing with small correction if needed.

B. Programs for Testing/Repair

Before the final phase i.e. printing phase, the 3D model has to be analysed for errors and failures. Some example tools for repairing the modelled object are Autodesk Netfabb, Meshlab, Autodesk Meshmixer etc.

C. Programs for Generation of G-Code

G-Code or Geometric-Code is a programming language that instructs the printer on when, where, how much to move, how fast/slow to move, what to extrude during the printing process.

G-Code can be generated using several software's among that Cura is a specialized software used for G Code generation. Some of the printing software's are used for printing is as follows.

- *Cura (Beginner)* – This is a benchmark Slicer software optimum for printing and can be extended if needed. It provides an easy to use interface.
- *MatterControl 2.0 (Beginner)* – Slicer used for desktop applications, 3D Printer Host and provides an interface is properly structured.
- *3DPrinterOS (Beginner)* – Provides Cloud based control and App based plug-in, STL tools and printer host.
- *CraftWare (Beginner & Intermediate)* –Free, fast and easy to use slicer software which provides better Gcode visualizer and manual support.
- *KISSlicer (Intermediate)* – Cross Platform gcode generator.
- *Repetier Host (Intermediate)* – This acts as a front end for 3D printer. Uses Slic3r as default slicing engine also has Skeinforge.
- *Slic3r (Intermediate and Professional)* – Slicer program is used for preparing 3D models. Prints with multiple extruders, graphic and command line interface, simultaneous printing of multiple images etc.
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V. GROWTH OF 3D PRINTING TOWARDS 4D PRINTING

Any technology that emerges has both positive and negative impacts. 3D printing technology has invaded many industrial sectors, medical field, military, education, aerospace, construction etc. The growth of 3D to 4D technology has also several advantages and on the other side it brings out a variety of technical and legal challenges [22]. This section describes the strengths, weakness and challenges of both technology. 4D printing addresses certain challenges in 3D printing for wide adoption in industries. In 4D printing concept, the object or the material system has the ability to change its form/function after it is being printed [23].

A. SWOT Analysis of 3D Printing Technology

SWOT analysis, a strategic planning technique, is analyzed for 3D printing and the details are illustrated as follows [24].

1) *Strengths and Weakness*

The various strengths of 3D printing technology is as follows:

- With all the resources available, any design (simple/complex) can be printed and thus provides customized products.
- Better Productivity and large number of prototypes.
- This provides an affordable technique even though the initial cost may be high.
- Reduced Storage Cost and better employment opportunities for designers.
- Among several applications, Bio-printing application of 3D technology is a breakthrough in medical field.
- They can produce better products with high quality.
- Helps in development of innovated products

The various weakness of 3D printing technology is as follows:

- Size of the created object is small.
- Usage of limited raw materials which may make certain material to become scarce.
- Ability to counterfeit products easily without copyrights.
- More energy Consumption
- Some printers have harmful emissions.
- Illegal usage by criminal organization leads to production of dangerous weapons.
- Expensive in some cases.
- Requires proper skills for usage

2) *Opportunities and Threats*

The opportunities for improvement are as follows:

- 3D printers is about to invade homes (desktop computers), shops and factories.
- Advances in production of raw materials used.
- Better Resolution accuracy and speed.
- Reduction in time and cost by 10 times for production of complicated parts.
- Create a wide variety of electronic products.
- Transition to 4D printing.

The social, economic and personal threats due to usage of 3D printing is as follows:

- Hackers could intrude and may cause damage
- Usage of additive manufacturing technology may threaten jobs.
- Risk in property and bodily injury (medical application)
- Cyber and Intellectual Property Risk (IPR).
- Frequent up-gradation and compatibility issues of machines.

- Ethical issues in object model.
- Environmental issues

B. SWOT Analysis of 4D Printing Technology

Similar to the above discussion SWOT analysis is carried out for 4D printing. 4D printing is the next generation of 3D concept in which the properties and characteristics of the created object has the ability to change its shape/form after manufacturing.

1) Strengths and Weakness (4D Printing)

The various strength of 4D printing is explained as follows:

- Usage of smart materials.
- Ability to reshape after printing i.e. SME (Shape Memory Effect).
- Multiple materials and multiple colors can be used.
- Positive growth in market place.
- Speed and efficiency of printing.
- Smart materials which has the ability to be reprogrammed.
- Reduction in storage costs

The weakness in implementing 4D technology are as follows:

- Some of the disadvantages of 3D printing also applies to 4D printing. It's an evolving domain with new functionality and modifications.
- New technology so requires expertise.
- Material cost is expensive and limited.
- Requires expensive hardware.
- Very high initial cost.
- Still in the adolescence stage of science, so has to be improved

4D printing technology promotes several opportunistic challenges towards growth which are discussed as follows:

- Improves implantation of organs in medical field
- Positive growth of market size.
- Useful in extreme places
- Interactive applications like medical implantation, self-assembling construction, and soft robotics are some of its applications.

The major threats to this sector is as follows:

- Environment and public safety related problems.
- Intellectual Property Risk (IPR) issues.
- Compatibility issues in machines.
- Loss of job opportunities for people.
- Cyber-crime related issues.

C. Growth statistics of 3D and 4D Printing

Based on the Marketsandmarkets report, the growth rate of 3D printing market is about to reach 30.19 Billion USD by 2022 at an annual growth of 28.5% as shown in Table II. It is expected that this concept will flourish much more in manufacturing, medical field, aerospace, defense and consumer products [25]. It is estimated that by 2022, the market size growth is about 30.19 billion USD.

Likewise, 4D printing market is about to successful by 2020 because of its advanced programming and efficiency [26]. These industries are expected to have a compound annual growth of 42.5% between 2019 and 2025 and expected to reach 537.8 million as shown in Table II.

Table- II: Comparison of 3D/4D printing market size growth rate (USD million)

YEAR	MARKET SIZE (USD MILLION)	
	3D Printing	4D Printing
2016	6.17	-
2017	8.62	-
2018	11.08	-
2019	14.23	64.2
2020	18.29	91.49
2021	23.5	130.39
2022	30.19	185.81
2023	-	264.8
2024	-	377.38
2025	-	537.8

VI. CONCLUSION

This paper has reviewed about the possible 3D-Printing techniques towards application with the understanding of programming skill for future growth of its transition. Also it analysed the strengths and weakness towards the growth of 4D-Printing. Opportunities for researchers were found to be bright with proper understanding of the effects of different programming in complex geometrics. Vacuum in research could be identified using varieties of materials for printing. 4D-Printing create huge openings for researchers towards printing of materials with phase change capability. The cost of these techniques is found to be a limiting factor.

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