Review on 4D and 5D Printing Technology

Sadiq sha H A J[1], Pradeep p patil[2]

[1]student,school of Mechanical Engineering, GITAM Deemed to be University, Nagadenahalli, Bangalore 561203, India
[2]Assistant professor, School of Mechanical Engineering, GITAM Deemed to be University, Nagadenahalli, Bangalore 561203, India

---

Abstract - 3D printing is an additive process which was invented by Japanese researcher Hideo Kodama in 1981. In 3D printing works on stereo lithographic process. It has three dimensional x, y and z axis. 3D printing requires lot of time to print the components and slow in process which is negative impact on this technology. These drawbacks of 3D printing can be overcome by 4D printing. In February 2013, Skylar Tibbits has invented 4D printing. In this technology, smart materials are incorporated because the 4th dimension is time and it has self-repair, self-assembly and it will save 70% to 90% of printing time. It is applicable in all fields like fashion, medical fields, and automobile, industrial polymer components. The drawback of 4D printing is not able to print complex shapes having curved surface. These drawbacks of 4D printing can be overcome by 5D printing. Recent manufacturing industries focus on 4D and 5D printing due to more advantages in present technology. The concept behind 5 dimensional additive manufacturing is rotation of extruder head and rotation of print bed in order to print in 5 different axes. 5D printing is3 to 4 times stronger than 3D and 4D printing. In 5D printing technology, the curved complex surfaces can be produced and its applications are mainly used in different fields like biomedical, automobile and aerospace components. In this review paper, we focus on the current applications of 3D, 4D and 5D printing and detailed case study is summarized. [1]

Key Words: *3D Printing, 4D Printing, 5D Printing.*

1. INTRODUCTION TO 3D PRINTING

The additive manufacturing (AM) is also known as 3D printing. In 3d printing it is impossible to make complex structure because in this process it has traditional fabrication method. 3D printing is a manufacturing process of physical object from the three dimensional printing, typically by laying down many successive thin layers of materials. A digital object is converted to CAD model. The cad model is sliced into different layers. The principle behind 3D printing focuses on stereolithographic process which has x, y and z axis. 3D printing has high accuracy, high-speed, diverse and robust material properties and low cost [2]. The below figure 1 shows the flow diagram of 3D Printing Technology which is widely practiced in modern industries.

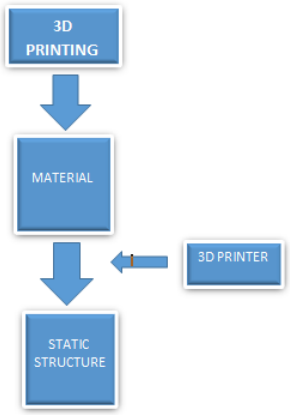

Fig- 1. Flow diagram of 3d printing

1.1 APPLICATION ON 3D PRINTING

The 3D printing application on a real world based on the engineering and manufacturing, education, aerospace, medical, theatre, fashion, design and consumer products. The application on 3D printing also used in a mass customization

like it allows consumer to create custom cases for mobile phone. It is widely used in 3D printing techniques to assist in the production of chemical compounds.

Medical Application

3D printing also used for orthopaedic implants printed casts for broken bone which is lost in major accidents. Fused filament fabrication has been used to create microstructures with three dimensional internal geometry.

Dress, Jewellery, Gifting Industry and Construction

3D printing technology has entered the world of clothing with fashion designers experimenting with 3D printing of shoes, dresses with high accuracy in limited time. [3] It is used in manufacturing of jewellery like ear rings, necklace and ornaments. 3D printing is widely used in customisable gifting industry such as personalized modes of arts and dolls, toys. It help in preparing of model of building ,hotels before building due to 3D printing we can design self-print or make a model ,planning.

1.2 CASE STUDY OF 3D PRINTING

3D printing prototypes are most commonly used in production of assembly line. 3D printing type of manufacturing system is used in future generation. The continuation of 3D printing technology further lead to 4D printing due to the drawbacks faced in 3D printing whereas 4d printing technology involves in creating a new objects with a smart material that ultimately change after reaching with properties with respective to time by using shape memory polymer.3D printing and 4D printing process that involves in additive manufacturing. In this time plays a major role in change the properties of material. 4D printing 4th dimension is time so 4D printing technology has more flexibility as compare to 3D printing.

Fig-2:3D Printed Dress Material

Fig-3:3D printed replica of skull

The above figure 2 and 3 is a dress material and replica of skull model that are manufactured in 3D printing. 3D printing is widely used in the world of fashion. The technology used in design industry will be to develop different design of dress irrespective of complexity of design. Design engineer is required to develop CAD model of the dress design which is profitable to design industry.

The above fig 3 shows the 3D printed component which is used in medical surgery. In this surgery, the skull replica of the deformed skull can be printed the type of skull replica which takes 9 to 10 hours whereas it is difficult to manufacture with conventional methods. Skull part is having smaller components which are built separately and then the parts are assembled. The thickness of the skull varies from 0.4 mm to 0.7mm. Initially, prototype of skull is manufactured and analysed and implanted.

1.3. ADVANTAGES

Faster Production

3D printing production takes few hours to print the component depending on the complexity of design. Testing methods and design of components with conventional manufacturing can take up many days.

Quality

Traditional manufacturing methods results to insignificant designs, and therefore it leads to unsatisfactory prototypes. 3D printing allows the back–to-back assembly of the object, which guarantees enhanced designs and ultimately better quality object.

Tangible Design and Product Testing

3D printing is used to create a prototype which helps to improve skills in the students and employs. They can touch and feel of the product and to test the prototype physically which helps to identify the flaws in design. If any problem is identified, then the CAD file is modified and printed the new design.

Waste Elimination

Subtractive manufacturing like CNC machining and injection moulding results in lots of resources are wasted. Unlike these two, 3D printing uses minimum resources and raw material which is required to create a prototype part. As a result, additive manufacturing reduces wastage of raw material, money and time.

1.4. DISADVANTAGES

3D Printing process is slow, 3D printed components do not have enough strength, expensive cost of raw material, and misuse of technology. 3D printer has Violation of copyrights, Harm authenticity, Printing Weapons and scan and fraud
:

Violation of Copyrights Technology: can be misused resulting in the rise of many ethical concerns as any desired objects can be printed with the help of 3d printers. An owner of a 3D printer can print object that are protected by copy rights by cutting off the availability of 3D printing design of the protected work can help to produce the copyrights.

Scan and Frauds: 3D printers can be used to scan and print I.D, All types of visa cards, any vehicle keys, as well as a many of other private belonging.

Printing Weapons: This is another major disadvantage in 3D printing which has ability to print risky objects such as plastic firearms any other object that could be used as a weapon .This advance technology will make it easier for gangsters, thieves and terrorist to bring firearms in public places. Like Canadian man has successfully printed off a working rifle from a 3D printer.

Employment: The human interaction in 3D printer is reduced and as a result 3D printing doesn't require a lot of labors. As such, adopting 3D printing leads to unemployment in manufacturing**.**

2. INTRODUCTION TO 4D PRINTING

4D printing is additive manufacturing process which has the capacity to reshape or self-assemble with respect to time. In 4d printed material act on certain parameters with respect to environment like humidity, temperature, etc. which changes its shape accordingly. 4D printing is based on smart materials and sophisticated designs that are "programmed" to prompt your 3D print to change its shape. A research branch originated from 3D printing called 4D printing it has four dimensional that involved in a smart material that can be respond to external stimuli and 4D printing permits the creation of on demand dynamically controllable shapes by integrating dimension of time. 4D printing has 4 dimensions x, y, z axis and fourth dimension is time which saves up to 90percent of the time and material. The below figure 4 shows the flow diagram of 4D Printing Technology which is widely practiced in modern industries.

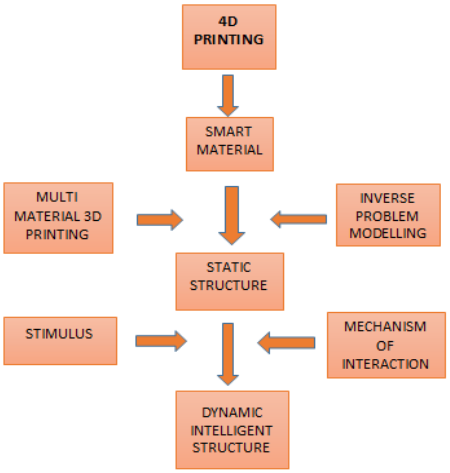

Fig-4: Flow diagram of 4d printing

2.1. APPLICATIONS OF 4D PRINTING

4D printing is used infancy as a research area. In aerospace, 4D printing can be used in future war and antenna array. The us army has already show strong interest in 4D printing.[2]4D printing is used in next generation in medical devices. Shipping volume will be flat pack manner which can be activated after delivery to resume of 3D printing. [2] 4D printing can also solve the problems of medical, dentist, and other associated fields. 4D printing changes its shape when subject to appropriate stimuli. It is used for the production of dental restorative materials. In dental, the important aspects of dental filling are strength, color stability, adhesion, longevity and failure. 4D printing can be used in removable prosthetic dentistry with the help of 4 printing that has similar tissues which can help to avoid the injury of complicated structure around implanting sites such as maxillary sinus. 4D printing handles such difficult situation easily with better accuracy in medical. [4]

2.2. ADVANTAGES OF 4D PRINTING

4D printing has a self-changing property and it can change shape can shrink and unfold. The objects that are larger can be compressed with the help of 4d printing. It helps to design a heart which can change it shape with suitable material. 4D printing has a capability of changing shape and functionalities as per the requirement. Heart valves can be produced by this process accurately without any design constraint. It can print heart, kidney and liver with smart material. [4] It is a capable for manufacture of smart valve that can control blood flow rate by increases or decreasing the diameter of the valve. Dynamically changes the configuration for all application of 3D printing. Object shape changes over time and with the change in temperature. [4] 4D printing saves up to 90percent of the time and materials.

2.3. DISADVANTAGES

4D printing has relatively low modulus when compared to 5D printing. They are less stable with respect to environment temperature. Smart material loading is a difficult in the printer head in 4D printing equipment. 4D printed components have low strength when compared with 5D printing. It cannot create a integrate parts which has curved surface or complex structures. So 5 Dimensional printing is evolved to overcome these negative impacts.

2.4. CASE STUDY 1

In the 4D printing, Shape Memory Polymer (SMP) is used as smart material to improve the structure and mechanical properties of the object. [5] The object which deforms when heated to adapt due to cooling and retain its original shape when reheated in environment. The smart material is fabricated in one printing cycle without electromechanical parts. This kind of functionality benefits are there in 4D printing. They are programmed under specific heat treatment above their glass transition temperature (tg) and it will be cooled to prefixed temporary shape free form external loading and the object retains its original shape after cooling. [6]

A case study on medical parts of stents used in heart surgery is reviewed. 3D printing had open to pharmaceutical industry to a multiple drugs. The development of 3D printing is the future trend which enhances 4D printing devices by their shape changing properties. [6] 4d printing helps in quick fabrication of customized stents used in medical field. The stent of shape memory polymer allows the minimization of surgical invasion of the implantation. At initial stage of printing, the stent of desired final diameter is designed and then programmed to a smaller diameter for ease of implantation. After the implantation the stent will return to its original diameter at body temperature.

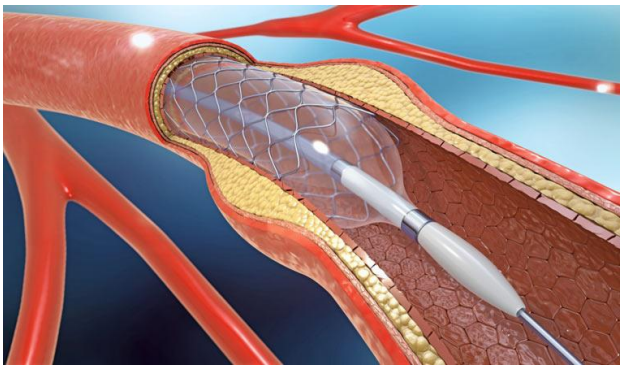

Fig-5. Stent used in heart surgery

2.5. CASE STUDY 2

The miniature Eiffel tower recovers its shape after heating the component to 60 degrees. The recovery timing of Eiffel tower are noted in intervals of 0, 7, 9, 10, 14 seconds as shown in figure 6. The figure explains the recovery timing process which occurs in smart material. The shape memory polymer which is used in Eiffel tower will expand and contract material regains upto 200% of volume and it will change in a shape and reposition of smart material. After recovery, it creates bonds in a compounds and it active in certain condition because it forms different structure depending on external stimuli that is used to contract surface which is necessary to change shape that could be water, heat, temperature and light.

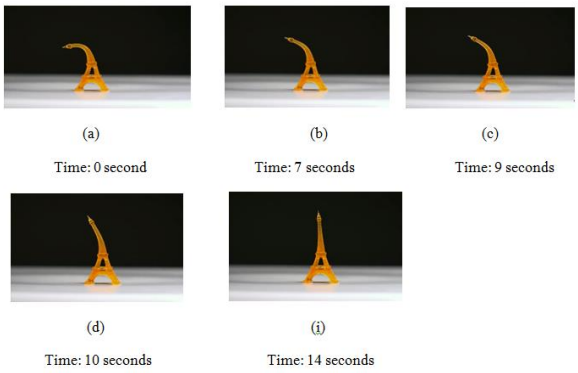

Fig-6. Eiffel tower

3. INTRODUCTION TO 5D PRINTING

5D printing is a new technology in additive manufacturing in which print head and printable object rotate along with x, y and z axis altogether five degrees of freedom. [7] It produces curved layer or concave shapes very accurately as per design constraints. In this process, printed part move while the printer head is printing in five axis printing simultaneously print bed also moves forward and backward along with x, y and z axis which allows the object to be printed from all 5 axes instead of form one point of printing. [7]

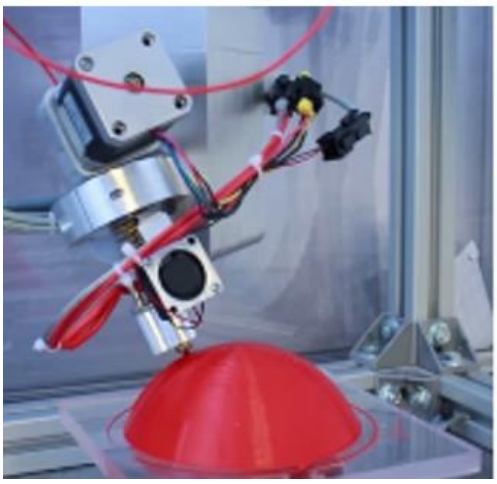

Fig-7: Rotation of printing head

Fig-8: Rotation of printing bad

3.1 APPLICATION OF 5D PRINTING

The 5D printing is mostly used in medical and automobile application. Manufacture of a tools that are related to medical that has high strength. It can create any curved surfaces that are used in automobile applications.

Surgical Tools

It is used for manufacturing or making surgical tools like mosquito forceps, monopolar diathermy, and debakeyforceps

Fig-9(a): Monopolar diathermy Fig-9(b): Debakey forceps Fig-9(c): mosquito forceps Fig-9(d): deaver retractor

Prosthetics

Prosthetics are the article devices that replaced body parts through an accident, handicap personal from birth. 5D printing manufacture artificial body parts like hand, leg, lower jaw and teeth which has complex shapes of implants with high strength. This set of the mechanism helps in straighten of bones

Fig-10(a): Prosthetics hand

Fig-10(b): Prosthetics legs

Fig-10(c): Prosthetic lower jaw

Construction and Automobile Components

It can be used in construction of house which has complex and curved designs. It help in manufacturing prototype of a parts or a compound of a vehicle or an object by accurately or perfectly.

3.2 ADVANTAGES

The main advantages of this technology is it can create a curved layer with improve strength. It provides a potential to fabricate artificial body parts for surgery. [7] 5D printing is 5 times stronger when compare to 3D and 4D printing. It has capacity to print curve implantation in medical field on complex and different parts of the body. The life span of the 5D printed products lasts years together in long term usage. It is used for a design or making of a complex prototypes in medical field.

3.3 CASE STUDY OF 5D PRINTING

A case study on 5D printed pressure cups are pressurized to show that 4D and 3D cups could only handle 0.1 mpa but in 5D printing it could with stand up to 3.7mpa before failure of components. It has a major advantage it use less than 25% of material that compare to 3d and 4d. 5d printing makes it easy print due to the capability to print curved layers. It is compound that was made of 5D printing technology is a vehicle part. That are stronger at what pressure may be. And we can make curved lines and curved path 3 to 4 times stronger. With the help of it we can design motorcycle parts and it can be with stand up to 3.5 mega Pascal's. 4D printing don't have much strength when compared with 5D printing. The loss of material in 4D printing is more as compare to 5D printing which reduces up to 25% of wastage of a material. The 5D printed object is stiffer than 4D printing because of shape memory polymers used in 4D printing. [8] It has capability to design complex and integrate shapes easily as compare to 3D and 4D printing.

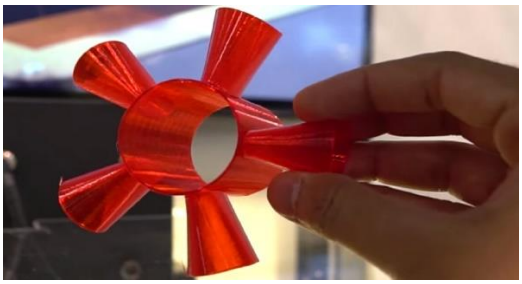

Fig-9. 5D Printed cups

4. CONCLUSION

As 4D printing continues to grow the new technology and evolve smart material and morphing structures. The 4D printing has the 4^{th} axis is time. The 4D printing is have properties of self-construction structure which changes its shape and it saves 70% to 90% of printing time. In future the 4D printing has high potential in the medical field like surgical treatment, prototype of body organs. As well as in fashion field like dress material and shoes that can change shape with respect to body temperature. It also has a better efficiency, quality compared to conventional manufacturing but there is a negative impact on

strength of material and curved surface manufacturing of components which overcomes this drawback by 5D printing. 5D printing has evolved and growing widely in future technology which has 4th axis is rotation of extruder head and 5th axis is rotation of print bed in order to print in 5 different axes. The research is still going on the 5D printing technology which has capacity to withstand the pressure up to 3.4 mega Pascal's which can be used in medical treatment, manufacturing of components etc. In this we can built a curved layer and complex shapes which reduces up to 25% to 30 % of wastage of material. Both 4D and 5D printing technology is most use full in future generation. This technology can change the medical as well as automobile industry, biomedical and orthodontics devices as per human growth. In future, this emerging technology will become more beneficial and helps in creating endless possibilities in medical, automobile and various fields. [5]

ACKNOWLEDGEMENTS

The support of management of GITAM School of Technology, GITAM deemed to be university is gratefully acknowledged. The authors would like to thank Pradeep P Patil, Assistant Professor, Mechanical Department and at the end I need to acknowledge Dr T. Nageswara Rao, Head of Mechanical department, GITAM School of Technology, GITAM, Deemed to be University.

REFERENCES

[1] Prasansha Rastogi, Balasubramanian Kandasubramanian. "Breakthrough in the Printing Tactics for Stimuli-Responsive Materials: 4D
Printing", Chemical Engineering Journal, 2019.
[2] Jing-Jun Wu, Li-Mei Huang, Qian Zhao, Tao Xie. "4D printing: History and recent progress", Chinese Journal of Polymer Science, 2017.
[3] Abid Haleem, Mohd Javaid. "3D printed medical parts with different materials using additive manufacturing", Clinical Epidemiology and
Global Health, 2019.
[4] Mohd Javaid, Abid Haleem. "4D printing applications in medical field: A brief review", Clinical Epidemiology and Global Health, 2019.
[5] Tianzhen Liu, Liwu Liu, Chengjun Zeng, Yanju Liu, Jinsong Leng. "4D printed anisotropic structures with tailored mechanical behaviors and
Shape memory effects", Composites Science and Technology, 2020.
[6] Zhizhou Zhang, Kahraman G. Demir, Grace X. Gu. "Developments in 4D-printing: a review on current smart materials, technologies, and
Applications", International Journal of Smart and Nano Materials, 2019.
[7] Abid Haleem, Mohd Javaid, Raju Vaishya. "5D printing and its expected applications in Orthopaedics", Journal of Clinical Orthopaedics and
Trauma, 2018.
[8] Mohd Javaid, Abid Haleem. "Significant advancements of 4D printing in the field of orthopaedics", Journal of Clinical Orthopaedics and
Trauma, 2020.
[9] K. Sri Ram Vikas, V.S.N. Venkata Ramana, Raffi Mohammed, G. Madhusudhan Reddy, KSrinivasa Rao. "Influence of Post Weld Heat
Treatment on Microstructure and Pitting Corrosion Behavior of Dissimilar Aluminium Alloy Friction Stir Welds" , Materials Today: Proceedings, 2019
[10] Anuj Kumar, Saeid Kargozar, Francesco Baino, Sung Soo Han. "Additive Manufacturing Methods for Producing Hydroxyapatite and
Hydroxyapatite-Based Composite Scaffolds: A Review", Frontiers in Materials, 2019
[11] Siva Prasad Dora, Shoba Chintada, Tualsi Radha Palukuri, Srinivasa Rao Pujari. "Energy dissipation in WC-Co coated A356.2/RHA composites", Engineering Science and Technology, an International Journal, 2020.