

A Review on the Advancements in Additive Manufacturing – 4D Printing

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Abstract - Additive Manufacturing can be described as a process to make 3D objects by adding layer-by-layer of material, the material traditionally being plastics, metals or ceramics; however 'smart' materials are now in use. Nowadays, the term "3D Printing" has become a much-used synonym for additive manufacturing by using the computer. This technology was being used in Medicine, industries, education field and the automotive sectors. Skylar Tibbits, Research Scientist & Director, Self-Assembly Lab, MIT had introduced another dimension to 3D object i.e., the 4th dimension namely time heat, temperature, light, electronic upgrading 3D printing to 4D printing technology which has wide applications in Medicine, industries, education field and the automotive sectors. In this review, we look into the aims to review of 4D printing technology, focusing on its industrial applications and materials, providing the great capability for tissue and organ regeneration as well as current and future applications.

Keywords: Additive Manufacturing, 3D Printing, 4D Printing, External Stimuli, Smart Materials.

I. INTRODUCTION

Additive Manufacturing (AM) technologies have been used in many applications nowadays and it is the construction of three-dimensional objects from a CAD model or a digital 3D model. It can be done in a variety of processes in which material is deposited, joined or solidified under computer control, with material being added layer by layer process. AM types of the printing process are carried out by a layer-by-layer method. With the advance in technology, different techniques can be used in 3D printing methods, which are divided into several categories are Stereolithography Apparatus (SL/SLA), Laminated Object Manufacturing (LOM) Digital Light Processing (DLP), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Selective Laser Melting (SLM), Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) The 4D printing technology is defined by a person called Skylar Tibbits, he is a computer scientist and designer from the USA. He is best known for his

work on self-assembly and pioneering the field of 4D printing technology, having coined the term in his 2013 TED talk. Skylar Tibbits says the 4D printing technology is the programming of biological and physical materials, and robotics, but without the cables and drives. 4D printing technology includes a similar procedure to the 3D printing technology, in that the object is built layer-by-layer. These 3D objects can however then change over time, which is called the fourth dimension. The aim is that objects made self-assemble when being exposed to heat, air or water, this is caused by chemical reactions due to the materials utilized in the manufacturing processes.

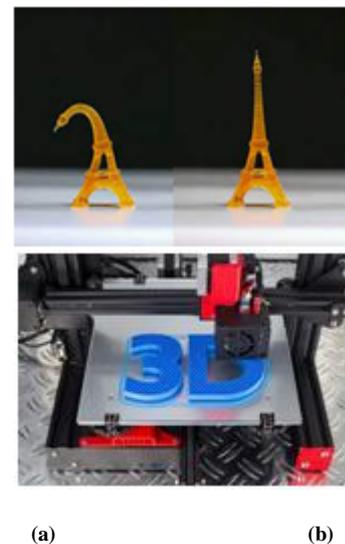


Figure 1: (a) 4D Printing and (b) 3D Printing

AM is a method that creates 3D objects by layering on material; formerly, this material was typically plastic, metal, or ceramic, but more recently, "smart" materials have been used. Today, the phrase "3D Printing" is frequently used to refer to computer-aided additive manufacturing. AM supplies benefits of comfortable design, more flexibility, and decreased manufacturing cycle time. Despite the limitations of 3D printing technology, its benefits are enormous. To overcome the challenges of 3D printing, it is necessary to move to a novel technology known as 4D printing. 4D printing means "AM of objects able to self-transform, in form or function,

when they are exposed to a predetermined stimulus, including osmotic pressure, heat, current, ultraviolet light, or other energy sources. This technology was employed in the medical, industrial, educational, and car industries. Skylar Tibbitts, Research Scientist & Director, Self-Assembly Lab, MIT, upgraded 3D printing to 4D printing technology by adding the fourth-dimension time, heat, temperature, light, and electronic to 3D objects. This technology has numerous uses in the medical field, business world, field of education, and automotive industries. We examine the objectives of this review of 4D printing technology, emphasizing its industrial applications; Industrial materials offer excellent potential for tissue and organ regeneration as well as present and future uses.

1.1 Smart Materials

Due to the use of smart materials in 4D printing, the objects can possess the following features: self-assembly, self-disassembly, self-sensing, self-folding, self-repairing, and self-adaptability. For instance, this innovative technology can manufacture a bone as part utilizing stimuli-responsive materials, and this bone can extend in the human body over time. So, 4D printing novel technology satisfies miscellaneous standards due to the use of smart materials and the fabrication of flexible parts. Self-progress materials are an additional instance of 4d-printed multi-materials. Exposition of water, while they shift into their pre-built shape, and these materials are prepared with hydrophilic polymers that absorb water to swell, possibly twice the size of the original volume. Active origami is another illustration of 4d-printed multi-materials. These materials promote the deployment of large objects into small volumes, such as airbags in automobiles, and photovoltaic solar cells in the panels due to its ability to change the shape.

1.2 Difference between 3D-Printing and 4D-Printing

The difference between 4D and 3D printing: Think of 4D printing technology as the same as 3D printing technology with the addition of the time as a fourth dimension. By adding the time to 3D printing the connotation of 4D printing is born. This enables objects to be pre-programmed in different ways to react to a range of different stimuli.

Table 1: Major Difference between 3D Printing And 4D Printing

Parameter	3D Printing	4D Printing
Design Properties	Does Not Change	Color, Shape, Function, Etc., Changes
Raw Material	Metals & Alloys Nanomaterials Thermoplastics	Shape Memory Polymers Shape Memory Alloys Self-Assembled Materials
Dynamic Shape Change	No	Change In Color, Shape, Function, Etc.
Printing Facility	3D Printer - SLA	3D Printer – SLA

	FDM SLS	Multi-Material 3D Printers
Product Flexibility	No	Yes, After Printing In Shape, Color, Various Functions And Other Condition
Equipment Cost	Low	High
Market Outlook	Medium	Medium-High

II. MATERIALS USED IN 4D PRINTING

More precise and flexible material placement is now possible because to recent advancements in multi-material 3D printing technology, which are crucial for 4D printing. The classification of materials for 4D printing technology according to their environmental and/or temporal stimuli is covered in this section of the article. The many stimuli, such as moisture, temperature, current, electricity, light, and magnetic field, will be addressed in more detail below.

1. *Thermoresponsive*: The Shape Memory Effect (SME) or the Shape Change Effect (SCE) are the two mechanisms that cause thermos-responsive materials to deform SCE. Shape-Memory Materials (SMM) are substances based on the SME and include Shape Memory Gels (SMG), Shape Memory Hybrids (SMH), and Shape Memory Ceramics and gels (SMC), (SMG). additionally broken down into Shape Memory Polymers (SMP), Shape Memory Alloys (SMA).

2. *Water- or moisture*: Responsive material: Due to their pervasive stimulation and wide range of applications, water- or moisture-responsive material is of significant interest. Because they can expand by more than 200% of their original volume due to their hydrophilic properties, hydrogels are exceptionally moisture responsive materials.

3. *Photo-responsive*: Light is an indirect stimulus, unlike moisture and heat, and exposed areas of photo-responsive materials absorb light as heat. The rate at which light power is absorbed as heat by joints is influenced by the colors of the joint and the light source.

4. *Electro-responsive*: Similar to light, 4D printing technology can use current as an indirect trigger. Resistive heating causes heat to be produced when a current is delivered, which causes ethanol to evaporate. The ethanol's volume significantly increases as a result of the matrix's transition from liquid to gas.

2.1 Applications in Sectors

1. *Medicine and Surgery*: Five years ago, specifically in 2015, a Michigan University medical team used a 4D printed implant to save the lives of three infants who had breathing issues. This polycaprolactone appliance, made to fit each

patient, was made to grow with the child and dissolve on its own when no longer required. In the future, it might be possible to print vascular end prosthesis (stents) or other 4D parts that react to body heat and expand to fit the patient.

2. *Clothes and Footwear:* 4D printing technology enables the production of clothes that conforms to the contour and motion of the body. Additionally, 4D printed shoes will be able to adjust to changes in temperature, pressure, movement, and impact.



Figure 2: Clothes and Footwear

3. *Tissue and Organ Regeneration:* A viable solution to the severe tissue and organ shortages is offered by 3D printing, which has shown a significant promise for designing functional tissues or organs to cure or replace defective and necrotic tissues or organs. A breakthrough in bio manufacturing technology is 3D printing. Based on all the cutting-edge features of 3D printing, 4D printing adds a time-dependent dynamic process in the fabrication design, which is thought to further revolution, is existing platforms for generating tissue and organs.

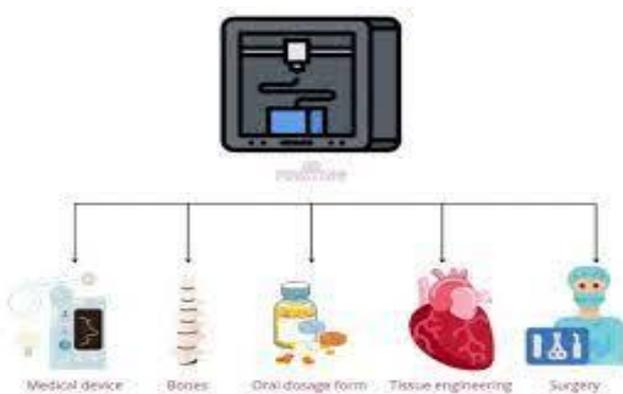


Figure 3: 4D printing applications in medical field

4. *In the Biomedical Industry:* 4D bio-printing has recently benefited from an increasing number of inventive and intriguing ideas. It is possible to print human organs directly from cells with the aid of modern technology.

5. *When Creating Stents:* A stent is a tiny, inflatable tube that is placed into a hollow artery, vein, or other structure, such as the tube that carries urine (ureter). Stents aid in maintaining an open framework. Stents in the beginning were made of bare

metal. Despite nearly eliminating the risk of the artery collapsing, they only reduced the risk of re-narrowing.

6. *Bone Tissue Engineering:* Tissue engineering strives to maintain and improve the capabilities of damaged tissues while also repairing or replacing them. Through the process of tissue engineering, tissues that are later transplanted in human bodies are shaped using a combination of purified cells and scaffolds. Instead of using standard surgery, intrusive advances can deliver SMPs to the injured location. It will change shape when stimulated, either by heat or moisture-based stimuli, and the precise configuration can be determined before production. Recently, a unique SMP for the treatment of cranio-maxillofacial deformities was also developed.

7. *Soft Robotics* is a field that primarily examines how living things adapt to their surroundings. One of the study areas for 4D printing applications that encompasses advancements in practical materials, manufacturing, displaying, and performance control with a focus on soft object applications is soft robotics. Another exciting new topic for 4D printing is field-assisted meta materials, which may adapt to a changing structure when exposed to a field, such the magnetic field.

8. *Automotive Sector:* Due to the emergence of numerous technologies, the automotive industry requires systems and subsystems that are affordable, lightweight, and sustainable. The automotive industry offers a variety of automobile applications where 4D printing technology can be used, while some of the uses, including shape memory and self-healing materials, are more common than others. Applications for healthcare also.

9. *Automotive and Aerospace:* Using 4D printing technology, NASA has created an intelligent metallic fabric. This insulating material, which is already used for astronaut suits, might be utilized to shield spacecraft and antennas from meteorite impacts. To cool the aero plane engines, Airbus is researching materials that respond to heat. Future intelligent airbags that can predict impacts and lower the risk of injury to the driver and passengers are now possible thanks to 4D printing.

10. *In the biomedical industry:* 4D bio-printing has recently benefited from an increasing number of original and intriguing ideas. It is possible to print human organs directly from cells with the aid of modern technology.

11. *When creating stents:* A stent is a tiny, inflatable tube that is placed into a hollow artery, vein, or other structure, such as the tube that carries urine (ureter). Stents aid in maintaining an open framework. Stents in the beginning were made of bare metal. Although they almost completely eliminated the risk of

the artery collapsing, they only significantly reduced the risk of re-narrowing.

The 4d printing technology increases day by day as shown in the below Figure 4.

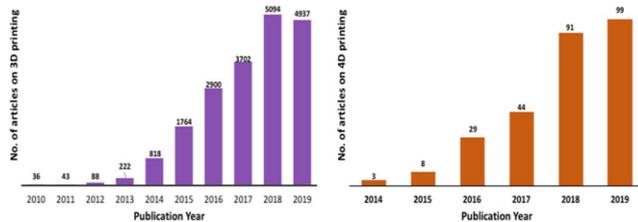


Figure 4: Number of articles publishing on 3D and 4D printing

III. RESULTS AND DISCUSSIONS

Design is used in 4D printing to anticipate changes in workflows and intelligent materials. Smart printing has numerous applications, ranging from straightforward shape alterations to bio printing of living things. 4D printing has been enhanced using multi-material 3D printing technology and smart materials. The industry's resource and energy usage will decline thanks to this innovative technology.

The field of additive manufacturing (AM) is currently in its early stages of development. The development of new printing techniques, materials, tools, and software is ongoing. Because 4D printed goods and structures may vary in shape over time in reaction to stimuli including temperature, pressure, wind, light, and water, the technology has recently attracted attention.

IV. CONCLUSION

As per the above Journal Publications we concluded that, 4D printing technology will reduce the energy expenditure resource and consumption in the industry. It will use designs to forecast change processes and smart materials. Smart printing can be applied to many fields from simple changes of shape to bio printing for organisms, biomedical field and practical industrial applications, continuous progress should be made to overcome the current challenges because it is driven by the rapid deployment of the technology across the manufacturing sector and only then this technology will bring out its best features for the future world.

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Citation of this Article:

Gudipudi Bhargav Sai, Vallabhaneni Lakshmi Venkata Chaithanya, Kandikuppa Navendra, Nuvvula Maniraj, Vallabhaneni Shyam Sundar, R. Vijay Krishna, "A Review on the Advancements in Additive Manufacturing – 4D Printing", published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 6, Issue 8, pp 135-139, August 2022. Article DOI <https://doi.org/10.47001/IRJIET/2022.608018>
