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4D Printing Technology: A Revolution Across Manufacturing

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Abstract: **The 3D printing technology is a well-known technology across the world and this is one of the most rapidly growing technology. This technology certainly offers us a great advances in many different fields in our life. Medicine, industrial buildings, education and the automotive sectors are just some of the areas where 3D printing technology promises a revolution. 4D printing technology is the method of 3D technology printing where the fourth dimension is the time. This paper presents a comprehensive study of the 4D printing technology and includes the practical concepts, the materials used a with a focus towards it applications in industry sector. Also, in this paper, the immediate future expectations of 4D printing technology were listed.**

Keywords: **3D printing, 4D Printing, Fourth dimension, Additive manufacturing.**

I. INTRODUCTION

Within the last five years, 3D printing technology has become far more well known. If you mention it at a dinner party, the likelihood is everyone will have at least some idea of what it is. However, mention 4D printing technology and you'll surely get some confused stares. In the past, there have been some deviations from 3D printing technology, such as CASIO's 2.5D printer. 4D printing, however, is an entirely different development. It is an upcoming form of the additive manufacturing, with some effects that continue beyond the print.[16]

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. currently, He teaches at the Massachusetts Institute of Technology, Department of Architecture where he has founded the Self-Assembly Laboratory. Also, Tibbits is the founder of SJET (a cross-disciplinary design firm in Boston, MA).[17].

Skylar Tibbits says the 4D printing technology is "the programming of biological and physical materials," and it is "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 changes as they are printed with materials that are programmed to change when exposed to a stimulus, such as through magnetics, heat, water, or other energy sources.

A definition of 4D printing could be: "The use of the 3D printing in the creation of objects which alter/change their shape when they are removed from the 3D printing. 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."

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. 4D printing technology is futuristic but has a very exciting future. 4D printing delivers the possibility to design any transformable shape, which can be made from a large selection material. These different materials will have different properties and a range of potential uses and applications and. There is a real opportunity for the creation of dynamic self-assembling objects which could transform and be used in a wide range of industrial processes and in a large number of applications.

4D printing can make dynamic structures with many adjustable shapes, properties, or functionality. This capability mainly relies on an appropriate combination of smart materials three-dimensional space [2]. Mathematical modeling is necessary for the design of the distribution of multiple materials in the structure. There are at least two stable states in 4D printed structures, and the structure can shift from one state to another under the corresponding stimulus. The main differences between 3D printing and 4D printing are shown in Figure 1.

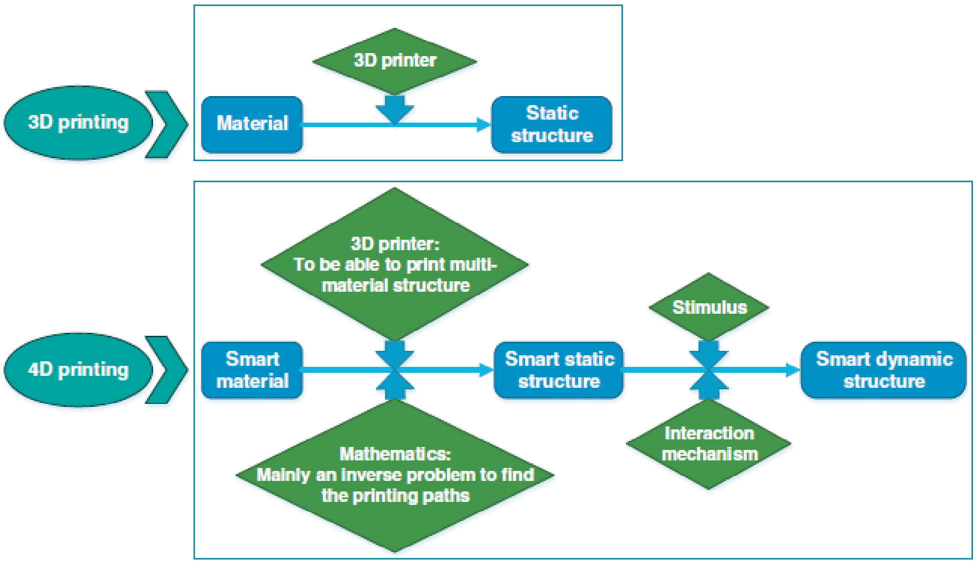


Figure 1: The differences between 3D printing technology and 4D printing technology.[2]

As obtained in Figure 2, the fundamental building blocks of 4D printing consists of a 3D printing facility, stimulus, stimulus-responsive material, interaction mechanism, and mathematical modeling.

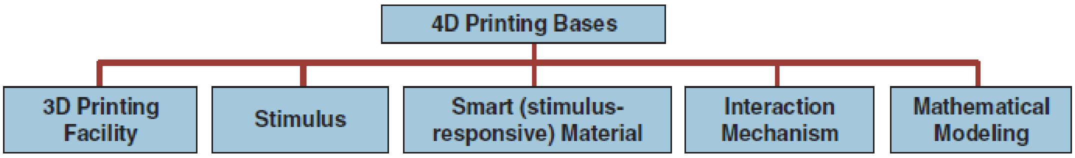


Figure 2: The bases of the 4D printing.[2]

II. 3D PRINTING AND 4D PRINTING PUBLICATIONS

The year-wise number of the publications of 3D and 4D printing technologies-related articles in the scientific journals and conferences. Figure 3 shows a growing interest in this field in the last few years.

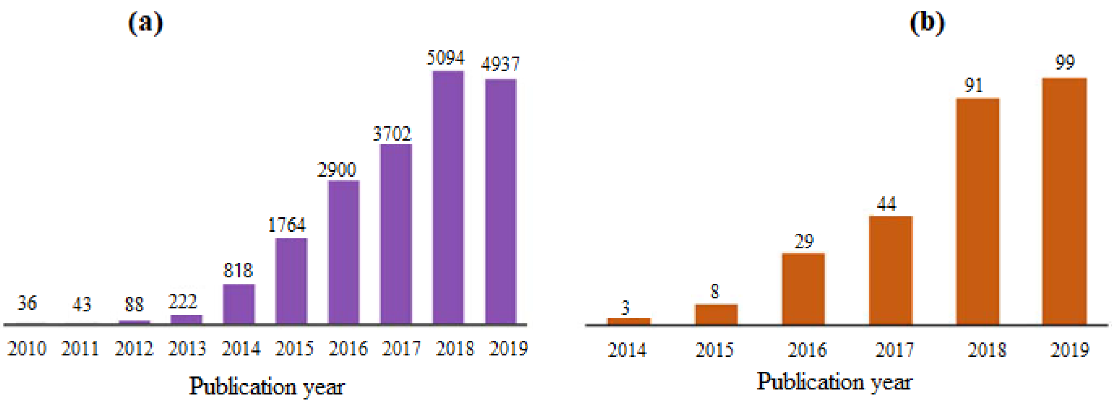


Figure 3: Number of publications on 3D and 4D printing as of September 30, 2019, (a): 3D printing and (b): 4D printing.[9]

III. MATERIALS USED IN 4D PRINTING

Recent developments in multi-material 3D printing technology have allowed to be more flexible and precise material placement, capabilities that are essential for 4D-printing technology. In this part of the paper, the classification of 4D-printing technology materials according to their environmental and/or temporal stimuli is shown in Figure 4. different stimuli will be discussed below including moisture, temperature, current, electricity, light, and magnetic field.[12]

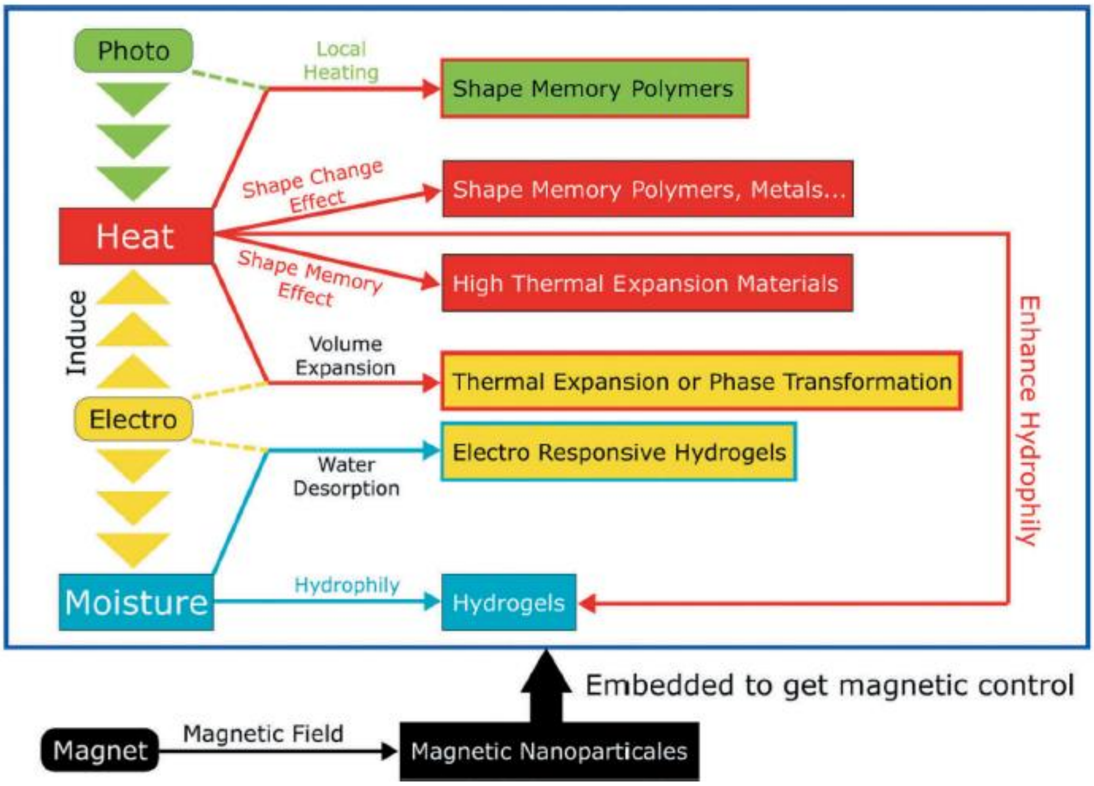


Figure 4: Classes of materials that can respond to various types of stimulus including heat, electricity, moisture, light, and magnetic field.[12]

1. Thermo-responsive

The deformation of thermo-responsive material is driven by one or two mechanisms: the shape memory effect (SME) or the shape change effect (SCE). Materials based on the SME are called shape-memory materials (SMM) which can be further divided into shape memory polymers (SMP), shape memory alloys (SMA), shape memory ceramics (SMC), shape memory hybrids (SMH), and shape memory gels (SMG).

2. Moisture-responsive

Water- or moisture-responsive material is of high interest owing to their ubiquitous stimulus and the broad range of applications. Hydrogels are extraordinary moisture responsive materials because their hydrophilic allows them to expand more than 200% of their original volume. Moreover, hydrogels as a class of polymer materials exhibit high printability. The main advantage of using hydrogels lies in their biocompatibility and easy of printing with direct ink writing.

3. Photo-responsive

Unlike moisture and heat, light is an indirect stimulus; an exposed area of a photo responsive material absorbs light as heat. Light power is absorbed by joints as heat where the rate is determined by colors of the joint and the light source**.**

4. Electro-responsive

Same the light, current can be used as an indirect stimulus in 4D-printing technology. some studies demonstrated a printed soft artificial muscle made from a mixture of ethanol and silicone elastomer. When a current is applied, the heat is generated due to resistive heating causing the evaporation of ethanol. This phase shift from liquid to gas greatly increases the ethanol’s volume and thus expands the whole matrix.

5. Magneto-responsive

Structures that are made using 4D printing that respond to magnetic fields are called magneto-responsive materials. J.C. Breger and his team incorporated magnetic nanoparticles into a microgripper printed from hydrogels and achieved remote control by applying the magnetic field [13]. The embedment is carried out in pre-processing where ferric oxide powders are mixed with the material solution. This technology has potential, also, in polymer printing and metal printing. One drawback is the restriction of the size of the print, which must be sufficiently lightweight to be affected by the magnetic field [12].

IV. MOTIVATIONS

4D printing technology opens many fields for application in which a structure can be activated for reconfiguration, self-assembly, and replication through environmental free energies. There are many advantages brought about by this technology such as a significant reduction in volume for storage, and transformations that can be achieved with a flat-pack 4D printed structures. Another example is instead of directly creating complex structures using 3D printing technology, simple components from smart materials can be made using 3D printing first and then self-assembled to reach the final complex shape [10]. The potential applications of the 4D printing technology can be broadly classified into three essential categories which include self-assembly, multi-functionality, and self-repair. The ability of 4D printed structures to self-assemble and self-repair opens new opportunities of application, such as the fabrication of minimally invasive surgery devices that can be placed in the human body through a little surgical incision and then assembled at the required position for surgical operations [14**].**

V. APPLICATIONS IN SECTORS

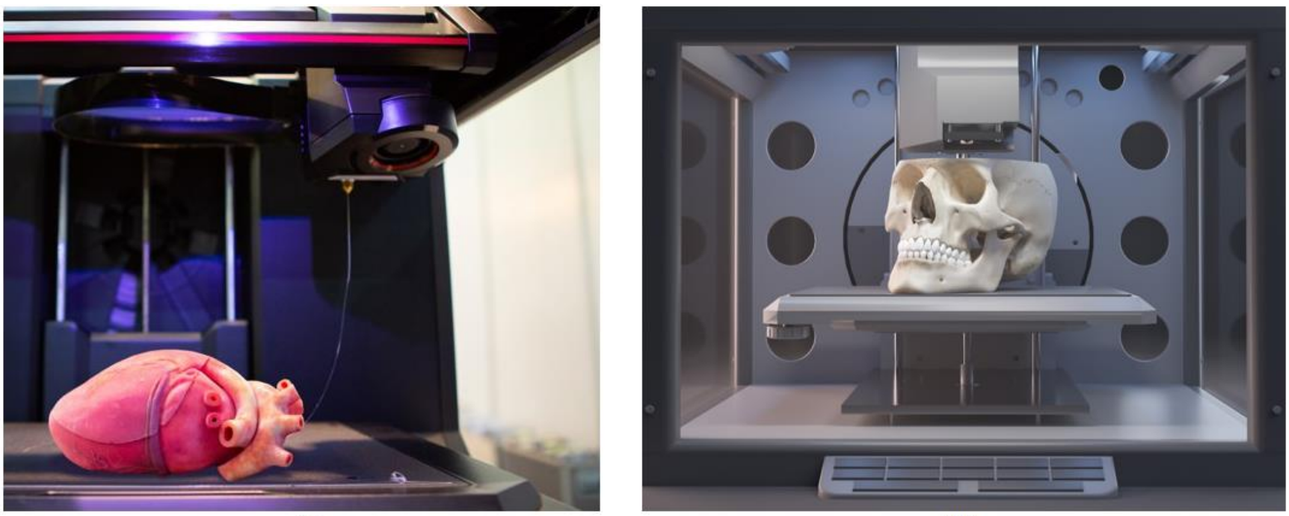
4D printing technology is destined to revolutionize the industrial world. These are some of its possible achievements and applications [18]:

1. Medicine and surgery

From five years ago, specifically in 2015, a medical team from Michigan University saved the lives of three babies with respiratory problems by inserting a 4D printed implant. This polycaprolactone device, designed to fit each patient, was designed to adapt its size to the child's growth and to dissolve itself when no longer necessary.

At present, the use of 4D printing technology in ultrasound scans allows, for example, to know more precisely the structural and functional development of the nervous system of the foetus.

In the future, vascular endoprosthesis (stents) or other 4D parts that react to body heat and expand to adapt to the patient, may be able to be printed.



(a) **(b)**

Figure 5: a: 4D-printed heart and b: 4D-printed skull.

2. Clothing and footwear

4D printing technology allows to the manufacture of clothing that adapts to the body's shape and movement. The USA military is testing, for example, uniforms that change color depending on the environment, or that regulate perspiration depending on the environment temperature or the soldier's pulse.

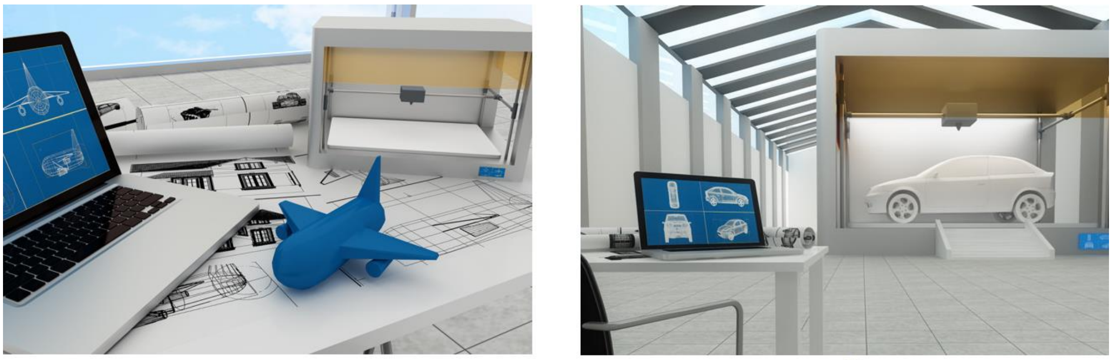
4D printed shoes will also be able to adapt to movement, impact, atmospheric pressure, and temperature.

(a) (b)

Figure 6: a: 4D-printed t-shirts and b: 4D-printed shoe.

3. Aeronautics and automotive

The NASA has developed an intelligent metallic fabric with 4D printing technology. This fabric which is already used for astronaut suits due to its insulating nature, could also be used to protect spacecraft and antennas against the impact of meteorites. Meanwhile Airbus is testing materials that react to heat to cool its aircraft engines. Thanks to 4D printing, intelligent airbags can be produced in the future that can anticipate any impact and reduce the risk of injury to the driver and passengers.



(a) (b)

Figure 6: a: 4D-printed plane and b: 4D-printed car.

VI. THE EXPECTED FUTURE OF 4D PRINTING

1. The next few years seem key to the development of this technology and will grow by 162 million dollars by an increase of 40% at a global level.

2. North America, Europe, and the Asia-Pacific region will dominate the markets.

3. The large manufacturing companies of 3D printers will lead the way.

4. 4D printing will have uses in automotive, construction, defense, aerospace, industry textile, health, etc.

5. Materials such as programmable fabrics, carbon fibres, and wood will be used.

6. The invention of new 4D printed products that benefit the consumers is planned.

7. The rise of sustainability and environmentalism will stimulate market growth.

8. 4D printing technology will reduce the energy expenditure resource and consumption in industry.

VII. CONCLUSION

Additive manufacturing (AM) is still growing industry still in its infancy stage. New printing methods, materials, machines, and software's are constantly being improved and developed. Recently 4D printing technology has been gaining attention because 4D printed products and structures have the capability to change in form as a function of time in response to stimuli such as temperature, pressure, wind, light, and water. 4D printing uses 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. Using multi-material 3D printing technology and smart materials, 4D printing has been improved. 4D printing provides a feasible method to fabricate compact deployable products structures. Smart materials used are the cornerstone for 4D printing technology. This new technology will reduce the energy expenditure resource and consumption in the industry**.**

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