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Advancements and Application of 4D Printing in the Medical Field : A Comprehensive Review

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Abstract*: 4D printing is an innovative and quickly expanding technology that combines the concepts of 3D printing with the adition of shape –shifting and self adaptable capabilities. The review paper investigates the advancement application of 4 D printing with the medical industry .we describe the fundamental concepts of 4D printing stressing its potential in the production of personalised patient –specific medical equipment tissue engineering drug delivery system and surgical tools. Additionally we evaluate the challenges and future possibility of 4D printing in healthcare.*

Keywords: 4D printing

I. INTRODUCTION

According to an appraisal of the literature, 4D printing is a more sophisticated version of 3D printing. Here, changes in a 3D-printed product's functionality, features, and shape are a function of time. Itappears to be capable of achieving self-assembly, self-repair, and numerous capabilities. As a result, 4D printing can generate dynamic structures, adjustable shapes, and things with diverse functionality. In order to do this, the 3D printing technology takes use of intelligent material and uses mathematical modeling to the development of a structure. The technology of 4D printing is identical to that of 3D printing. The printed product adapts to environmental elements like temperature, humidity, and others to vary its form over time, providing another level of metamorphosis. It is a cutting-edge technology that is fast growing because tothe study of. This is why 3D printing technology is growing across several sectors, including engineering, medicine, material science, chemistry, basic sciences, and computer science. The concepts of stereolithography serve as the foundation for this technology.wherein the printing process involves the layer-by-layer drying of a material utilising ultraviolet radiation (UV).It is a speedy and precise manufacturing technique.a procedure for creating soft structures to order. It incorporates specific materials with self-deformation properties that scientists use for study

The medical profession is facing a tremendous transformation thanks to 4D printing technology. It has greater uses in chemotherapy, tissue engineering, and self-assembling biomaterials for human scale. Now, there is a transition from 3D to 4D medical devices, such as the fabrication of biomedical splints, stents, and bioprinting.surgery. Doctors might apply a self-deforming component on a patient's body to fix any defects.

The development of medical implants and equipment that grow with the patient is required in the medical industry. This technology can effectively meet this condition since it uses smart materials to make implants that can shift shape over time as the human body develops. In this method, patient data is obtained utilising scanning technologies like computer tomography (CT), magnetic resonance imaging (MRI), and others that are easily printable using specialized machining procedures that layer by layer produce intelligent medical material. This technology can produce unique implant-making techniques and materials.

II. SMART MATERIALS USEDFOR 4DP

Smart materials	Description	Applications	References
Thermo-responsive smart materials	These involve the shape-memory effectwhich means the object regains its original shape after deformation and the shape-change effect. These materials are responsive to heat or temperature	Used widely in the medical field for the release of drugs and biomedical engineering	Sponchioni et al. (2019)
Photoresponsive smart materials	Light works as an indirect stimulus and when it is converted to heat it shows a response to light	Self-folding polymer sheets, self-assembled nanoparticles	Behl and Lendlein (2007), Habault et al. (2013), Liu et al. (2023b)
Moisture-responsive smart materials	These materials either release or absorb moisture with the change in relative humidity and cause deformation in the structure. Example- Hydrogels (it has high printability, and biocompatibility and are used as moisture- induced shape memory materials	Different varieties of hydrogels like natural and synthetic polymeric hydrogels and peptide hydrogels are applied in the 4DP	Osada and Matsuda (1995), Kopeček and Yang (2012), Shiblee et al. (2018), Erol et al. (2019)
Electro-responsive smart materials	Materials are responsive to electrical energy. Current is an indirect stimulus to show electro-responsive nature	For medical purposes, electro-simulative gels can be used, such as artificial muscle, sensors, actuators, and lenses, and as biomedical and soft materials	Ali et al. (2019)
Magneto-responsive materials	Materials responsive to magnetic energy are polymeric networks; functionalized chemically or physically with the magnetic nanoparticles including ferromagnetic and paramagnetic particles like iron, cobalt, nickel or their oxides. The first time the motion generation of austenite-martensite interfaces due to magnetic effect was reported where Fe (33.5)-Ni alloy was applied as an actuator and was justified by energy	Used in printed hydrogels micro-gripper. It also acts as a remote control for the magnetic material by applying a magnetic field Huge potential in material and polymer printing is also used to manipulate printed structures in a rapid manner	Ullakko (1996), Nichterwitz et al. (2021)
pH-responsive materials	Due to the unique properties of these types of smart materials to work at different pHs of the organs in the body can be used as triggers in the drug delivery system	These types of smart materials have many biomedical applications in drug delivery, actuators and soft robots, valves, biocatalysts and stabilization of colloids	Jeong and Gutowska (2002), Soppimath et al. (2002), Schmaljohann (2006), Dai et al. (2008), Ali et al. (2019), Modi et al. (2023a)
Piezoelectric materials	These are other special properties of smart substances; such substances are sensitive to mechanical stress	Piezoelectric smart materials can be deformed under the influence of a mechanical force, therefore can also be utilized for the 4DP.	Nadgorny et al. (2016), Grinberg et al. (2019)

TABLE 1 Different variety of smart materials and important applications.

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III. ADVANCEMENT IN 4D PRINTING TECHNOLOGY

In 2013, SkyalarTibbits exhibited 4D printing with a structure that folded with a simple 90-degree transformation and triggered when the printed specimen was submerged in water. Similar research involving the stretching of composite printed materials in response to heat activation, light activation, and electrical activation were presented. As theWhile progress is always being made, more needs to be done to make folding from one shape to another universal. To acquire control of autonomous transformation rather than a human-guided energy source, further innovation is required. The design structure of 4D printing technology, which incorporates both hardware and software components, provides major obstacles. It is vital to take additional precautions while developing hardware components. Because this asks for detailed and advanced material programming, accurate multi-material printing, and designingThe contemporary 3D printing technology known as Fused Deposition Modelling (FDM) was initially introduced in 1989 by Scot Crump, a co-founder of Stratasys Inc. EOS was established in Germany the same year. Direct Metal Laser Sintering (DMLS) pioneered by EOS and supplier of incredibly effective Numerous additive 3D printing technologies have been devised, including Three Dimensional Printing (3DP), Laminated Object Manufacturing (LOM), Solid Ground Curing (SGC), and Ballistic Particle Manufacturing (BPM). Technology has mostly been committed to the development of industrial manufacturing processes.

IV. APPLICATION IN THE MEDICAL FIELDS

The existing business climate could transform thanks to 4D printing technologies. Future growth of this mechanism depends on a variety of skills and will continue to do so. For instance, the current approach enables 4D printed buildings to expand when exposed to water, and when they are left to dry, they tend to unfold and resume their original shape. But in circumstances where similar .The process is repeated repeatedly, the material deteriorates over time, and the repetitions are restricted. More research and development are required to regulate directionality and reversibility processes. This trend shows that science and education will alter in the future. Existing self-changing structures and models can be investigated to enable new experiments with novel material features and functional behaviors.

Robotics and Aeronautics

Airbus' Emerging Technology and Concept team and MIT Research Scientist Skylar Tibbits worked together to build a new air inlet component. This partnership with Airbus generated a new air intake that automatically alters to control air flow.This keeps the engine cool. Because the air intakes for ventilation are static, air flow changes with flight speed. 2016 (Group A) Researchers from MIT and Harvard University constructed reconfigurable robots called origami robots, which are capable of folding into any shape and crawling away. The entire prototype robot was created using printed components.2014's Hardesty.

Applications in the Military

The military sector will have a wide range of applications for programmable matter.The US Army and Navy are constructing programmable elements that can be constructed into full buildings with all the critical components, as well as three-dimensional printed spare parts for use in the field.components include plumbing, electricity, and other technological building pieces.Researchers from Harvard's School of Engineering and Applied Science, the University of Illinois, and the University of Pittsburgh Swanson School of Engineering earned $heUS Army Research Office in 2013.

Biomaterials and Smart Materials

The variety of smart materials suitable for printing has risen in recent years as the sector has evolved. In 4D printing, smart materials play a crucial role in receiving, transmitting, and evaluating the applied stimuli. The materials react by undergoing actuation, which entails shape-morphing or functional alteration, resulting in a structural change. The physical features of the printing materials may be exploited to produce a desired stimulus-response in the final printed structure. As a result, the smart material (or a mix of materials) that is picked is fully reliant on the intended application of the final printed item. Biocompatibility, for example, is a crucial concern in the manufacture of biomedical

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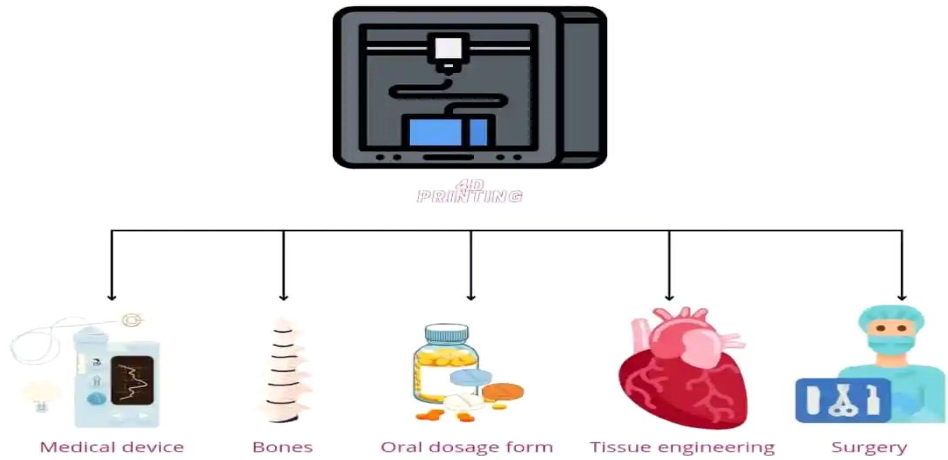
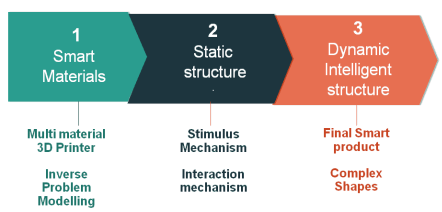
equipment. Fabrication of high-resolution structures that stay stable in both temporary and permanent spatial configurations is another area of increasing study.



Hydrogels

Cross-linking polymer chains comprised of hydrophilic monomers produce a hydrogel. Hydrogels' capacity to absorb huge volumes of water without dissolving is owing to the chains' arrangement in a three-dimensional network. They differ from dry-state polymers in that they expand greatly when exposed to water and then shrink back to their original size once dried .

Soft hydrogels' viscous matrix and high water content enable them to respond to environmental stimuli such as temperature, light, pH, etc. Hydrogels also have self healing properties.



Working heart model is 3D printed using 4D flow MRI images

Technicians and doctors in Colorado, are integrating 4D magnetic resonance images of blood flow with 3D printers to produce a multicolored working heart model 4D flow scans give doctors with a straightforward approach to visualize exactly where abnormalities are located as blood goes through each area of the heart during a cardiac cycle, from the conclusion of one heartbeat to the beginning of the next, by color-coding the velocity at which blood flows through the heart. This allows them to spot specific abnormalities and schedule suitable surgery. The printed model is based on a Stratasys digital anatomy solution, which comprises a suite of novel materials that, according to the company, more accurately match true tissue density than a rigid model. "This is more about trying to replicate native tissue," said Scott Drikakis, Stratasys' medical segment leader. He went on to claim that the platform enables greater and more efficient blending to better imitate an organ's various physical qualities. It evolves from a purely visual model to a functional model for surgical planning.

Magnetically activated system for drug delivery

To develop a 4D printed device, magneto-restrictive materials operated by an external magnetic field can be used, which could aid with targeted medications and appropriate dosing. Li et al., built a micro-robot utilising a hydrogel bilayer using a typical lithographic process. There was one layer that altered shape when exposed to specific pH levels, which helped in drug release This was made possible by employing an Iron Oxide coating on the device that allowed it to be magnetically steered and ensured site-specific drug delivery. As a result of this discovery, targeted delivery of anti-cancer drugs can be made possible. Tumor tissue with a low partial pressure of oxygen and a certain pH can cause drug release. So-called "drug delivery devices" can administer the maximum quantity of effective medicinal therapy while minimizing any undesired side effects. Before its commercialization, however, further research must be done on this technique.

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REFERENCES

[1]. Greenberg S. 4D Printing in Healthcare. Blog.bccresearch.com. https://blog.bccresearch.com/4d-printing-in-healthcare. Published 2021. Accessed September 1, 2021.

[2]. Quanjin M, Rejab M, Idris M, Kumar N, Abdullah M, Reddy G. Recent 3D and 4D intelligent printing technologies: A comparative review and future perspective. *Procedia Comput Sci*. 2020;167:1210-1219. doi:10.1016/j.procs.2020.03.434

[3]. Bajpai A, Baigent A, Raghav S, Brádaigh C, Koutsos V, Radacsi N. 4D Printing: Materials, Technologies, and Future Applications in the Biomedical Field. *Sustainability*. 2020;12(24):10628. doi:10.3390/su122410628

[4]. 4D printing promises biomedical applications – ASME. Asme.org. https://www.asme.org/topics-resources/content/biotechnology-anticipates-4d-printing. Published 2021. Accessed September 13, 2021.

[5]. Li H, Go G, Ko S, Park J, Park S. Magnetic actuated pH-responsive hydrogel-based soft micro-robot for targeted drug delivery. *Smart Materials and Structures*. 2016;25(2):027001. doi:10.1088/0964-1726/25/2/027001

[6]. https://www.marketsandmarkets.com/Market-Reports/4d-printing-healthcare-market-196612645.html. Published 2021. Accessed September 13, 2021.

[7]. Zhang, F., Wang, L., Zheng, Z., Liu, Y., and Leng, J. (2019a). Magnetic programming of 4D printed shape memory composite structures. *Compos Part A Appl. Sci. Manuf.* 125, 105571. doi:10.1016/j.compositesa.2019.105571

[8]. Zhang, Z., Demir, K. G., and Gu, G. X. (2019b). Developments in 4D-printing: a review on current smart materials, technologies, and applications. *Int. J. Smart Nano Mater* 10, 205–224. doi:10.1080/19475411.2019.1591541

[9]. Zhang, Z., Wang, L., Zheng, W., Yin, L., Hu, R., and Yang, B. (2022). Endoscope image mosaic based on pyramid ORB. *Biomed. Signal Process Control* 71, 103261. doi:10.1016/j.bspc.2021.103261

[10]. Zhao, Q., Li, C., Shum, H. C., and Du, X. (2020). Shape-adaptable biodevices for wearable and implantable applications. *Lab. Chip* 20, 4321–4341. doi:10.1039/ D0LC00569J

[11]. Zhu, W., Holmes, B., Glazer, R. I., and Zhang, L. G. (2016). 3D printed nanocomposite matrix for the study of breast cancer bone metastasis. *Nanomedicine* 12, 69–79. doi:10.1016/j.nano.2015.09.010