 ISSN: 2278-4632
Vol-11 Issue-01 2021

A Glance at Future Prospects of 4D Digital Printing and Its Imminent

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Abstract

Since its launch, 3D printing has become immensely popular. It applies in fields like prototyping, manufacturing and the medical sector, mostly because of its ability to translate digital 3D files rapidly and cost-effectively into real objects. 3D printing can print fixed structures that are static and not suitable for multifunctional use. In combining polymer composites, 3D printing and 4D printing was designed to work. 4D printing utilizes the fourth dimension of time to form 3D printed objects once exposed to stimuli usingthe 3D convertible printing technique and laser synchronization (LS). In response to stimuli like pH, moisture and temperature, 4D printed materials can activate 3D imported components without the need for electronics or engines. Much work has been conducted on intelligent materials that are capable of sensing and answering external stimuli. This paper examines 4D prints based on activation stimuli and explores the use of technology. 4D printing aims to simplify the design and production of various products and have the massive potential to create components that are automatically controlled to respond to their setting. 4D printing applications are in Nanocomposite materials, safety, patterned optical surfaces and multiple-directional structures.

Keywords: 4D printing, fused deposition modelling, laser synchronization smart materials, stimuli

1 Introduction

3D printing is a popular manufacturing additive technology that enables scientists, manufacturers and privately owned users to produce custom-made 3D objects through computer-aided design (CAD) software [1]. It has been used in various areas, including fashion jewellery production, print polymer textiles, super conductors, mechanical superconducting materials and sensors and organic hybrid robots, and tissue fabrics due to the extremely customizable design of 3D printing [2]. Many rapid prototyping devices have been introduced for mere inkjet and extruder printing processes and even some liquid deposition modelling, such as stereo lithographic (SL), digital light projection (DLP) and transparent inkjet and extruder print [3-5]. They allow complex, personalized and inter 3D microstructures to be manufactured at a lower cost in various applications, from fabric engineering to facing and skin-like sensors [6].

Presenting intelligent, externally stimulating materials has been used for the recovery of shapes, sensors and drives. 3D printing can be used to create static frameworks from the digital information that considers environmental influences; it's just the beginning, and then it soon sees changes as well [7]. For instance, intelligent design features can be found in intelligent textiles, robotics, drug development, and tissue engineering. The body's internal organs, such as tendrils, bracts, leaves, and flowers, may also exhibit complex dynamics regulated by microstructure and chemical composition[8-14]. All such botanical frameworks inspire 4D printing. In addition to offering new and unparalleled capabilities to convert digital knowledge from the virtual world in the physics of the material world, 4D printing has technological, environmental, geopolitical and policy implications of additive production. 4D printing corresponds to how objects can change shape and become intelligent, making smart materialsnecessary. This article presents an analysis of state of the art in 4D printing and offers predictions about its future potential.

2 4D Printing Fundamental concepts

3D printing technologies are used to create static structural elements in 3D co-ordinates from digital data. 4D printing adds to the idea of time shift, depending on external stimuli. The significant difference between 3D and 4D printing is intelligent design and smart materials, given that 4D prints can be shaped or operated. That involves completely programming the 4D printed structures by taking account for any time-dependent object distortion. Initially, 4D printing was implemented to manufacture 3D printed structures of time-sensitive, adjustable shapes and programmable properties or functionality by a research team of the Massachusetts Institute of Technology (MIT).

Smart materials can detect stimuli from the outside and provide a comprehensive answer. Smart materials can also be seen as a way to achieve an active, intelligent response in a product that otherwise would be missing and could produce a variety of improved capabilities and features. For 4D printing

ISSN: 2278-4632
Vol-11 Issue-01 2021

to take place, three prominent aspects must be met [15]. The first one uses composite stimuli mixed or combining multi-materials with different properties, which are sandwiched layer by layer. The second is the stimuli that are used to animate the object [16]. For example-heating, cooling, gravity, UV light, magnetic power, wind, and humidity. Simulation is the most important of stimuli of all. The last factor is that the simulation takes place, and the result is the change in the object's state.

The advancement of 4D printing research depends on intelligent materials. The ability to alter shape is not inherently essential for smart materials. In camouflage technology, signalling, detection of foreign substances and biomedical applications, materials with the ability to change colour, hardness or transparency are also essential [17-20]. Different types of stimuli may cause time-sensitive changes in form, property or functionality. Gladman et al. used water to cause 4D water-sensitive natural-inspired biomimetic structures. In 4-D printing, other stimuli such as heat, pH, heat and water combination, and heat and light, may also be used. These complex structures can evolve in scale employing regulated buckling, hydraulic transformation, governed creasing, photo-induced folding, stress-induced curing, thermal swelling through the use of composite form memory.

Table.1: 4D printing of typical intelligent materials

Material	**Input/Stimulus**	**Output/Response**	**Application**
Smart metal alloys	Temperature	Shape	Motor actuators
Polymer (e.g. thin film cellulose, ceramic)	Humidity change	Capacity /resistance change	Humidity sensor
Dielectric elastomers	Voltage	Strain	Robotics
Polymeric gal	pH change	Swelling or contracting	Artificial muscle
Electro-rheological fluid	Electrical signal	Viscosity change	Torsional steering or system damper
Pyro-electric material	Temperature	Electric signal	Personal sensor
Self-healing	materials Force	Force	Smartphone chassis
Ceramics (e.g.LA doped BaTiO3)	Current (or template)	Resistance	Thermistor/overcurrent protector

3 Motivations

4D printing opens up new operations where structures can be enabled by environmentally-free energy to be self-assembled, reconfigured and replicated. This technology has many benefits, including substantial storage volume reduction and transitions with a flat-pack 4D printed structure. Another example is the essential components of smart materials, which can be printed 3D first and then assembled to achieve the final, complex form instead of making complex structures directly using 3D printing. 4D printing can be widely categorized into three major categories: self-assembly, ease of processing and self-repair. The ability of 4D printed structures to assemble themselves and rehabilitate themselves opens up new possibilities of use, such as the production of minimally invasive surgical instruments inserted in human bodies through a small surgical implant and then integrated at the required location for surgery.

3.1 Self-assembly

In a broad and rigid ecosystem, a sensing mechanism can be applied. Individual pieces with small 3D printers can be printed and then automatically assembled into broader structures, such as antennae and satellites. Such capacity can be used to create transport systems to the space station for complex components. Additional applications usually involve self-assembled structures, particularly in conflict areas or outside areas, which can unite the elements to create a fully-formed structure with a minimal workforce. It also has the advantage that the use of 4D printing overcomes some of the construction limitations. Rigid materials and intelligent materials can be printed in 3D to produce unique components that act as joints and bending hinges. Raviv et al. argued that the construction of vast quantities of electricity, materials, cost, and construction resources must be improved and solved. These problems can be resolved with design programmes and software, which integrates data into materials that increase the material and construction accuracy. For every reason, self-assembling cannot be sufficient, involving various industries and applications that most benefit from self-assembly.

3.2 Self-adaptability

4D printing makes it possible to directly integrate sensing and motion control into such a material, makingexternal electromechanical systems redundant. It reduces the number of components per structure, manufacturing time, energy and material cost, along with the number of fault-prone devices linked to electromechanical systems. The technology can be used in self-adaptive four-dimensional printed and four-dimensional customized medical devices, including tracheal stems.

3.3 Self-Repair

The incorrect and self-repair capability of 4D materials demonstrate considerable biocompatibility and recycle advantages. Self-cure pipes and self-healing hydrogels are some of the possible 4D printing technologies. Self-healing in polymers could be accomplished by many forms of reactions, including covalent bond, supermolecular, H-bonding, ionic bond. Self-heating polymers also show that their capability to self-repair damage, from bulk cracks to surface rays, has the great potentials to produce softer actuators with enhanced durability. The use of additive production with self-healing hydrogels has proven effective.

3.4 Piezoelectric materials

Piezoelectric materials are the materials able to generate an electric response to applied mechanical stress. Electro-magneto rheological fluids do not always show shape changes, but they may also have important changes in their properties. Piezoelectric materials are intelligent materials that build up electric charge over the whole surface of the material under mechanical stress and alter the shape of the material.

3.5 Shape Memory Effect

A Shape memory material (SMM) can recover its original shape after a quasi-plastic deformation in the presence of the right stimulus. This is called the shape Model Memory Effect (SME). The Shape model Memory Polymers (SMMP) are capable of mechanically transiting between the imprinted form and a present form in response to external incentives. Xie et al. published a polymer shape memory via light curing, which changes when submerged in the water. A fascinating field for 4D printing is Hydrogels. The polymer chains generated by cross-linkage are usually 3D networks. The relations can be transient or irreversible through the formation of physical interactions or covalent connections. When submerged in water due to the network holes, these networks begin to swell. The hydrogels are biologically compatible and useful and make it a choice for 4D printing because of their ability to swells. The density of the location and the modification of the hydrogel particles' surface and dimension might influence the swelling. Raviv et al. synthesized vinyl caprolactam and poly-ethane, which can spread by around 200 percent underwater, as a means of mixing a hydrogel.

There are many significant disadvantages to tackle to apply hydrogels to change form in practical terms. In particular,their response rate is low to stimuli for large items as the swelling mechanism is inherently restricted by mass diffusion. Because

of instability and relatively brittle hydrogels, the actuated form may not be stable. It may suffer a mass loss in the water/dehydration cycle. The introduction of porosity into hydrogels could dramatically improve responsiveness and lead to resilient mechanical properties through novel molecular designs such as the double network.

SMMP is a substitute for hydrogenizes, which are more durable and have more mechanical properties to manufacture morphing structures. SMPs are distinguished from hydrogels by the basic programmability of the form shifting paths. The temporary shape identified by an outside deformation force can be established even during the programming procedure. The shapeshifts from this provisional shape to the original shape are synthesized or created. The related shapeshifting direction is also infinite as the original form can be fixed to various temporary forms by changing the external distortion power. This is not the case with the hydrogels that traditionally cannot be programmed, which implies that only two geometric forms can fit between, irrespective of their production sophistication.

3D multi-laterals, which change shape, are printed by a research group at the Massachusetts Institute of Technology (MIT) [21]. They have taken 2 types of porosities with water uptake capacities for printing the structures of biomaterials. On one side of these systems is a porous water absorption layer. On the other side, a solid, water-resistant material. The water absorption from both edges of the written material is immersed in water. The side which absorbed water raises its thickness, while on the other side, the movement toward the stiff side is unchanged, as seen in Figure 1.

ISSN: 2278-4632
Vol-11 Issue-01 2021

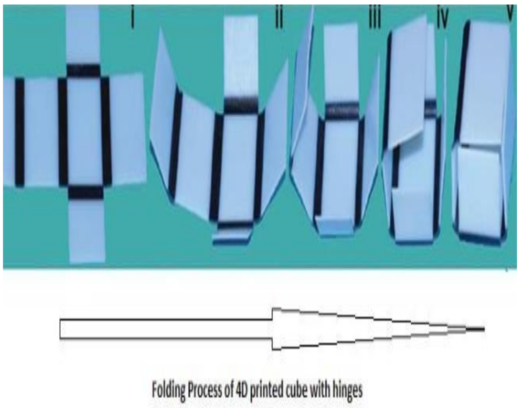
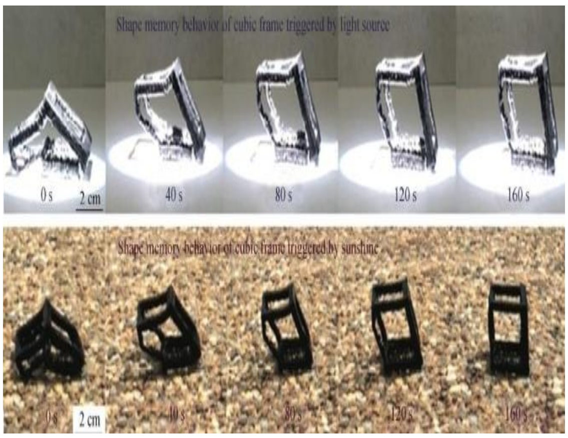


Figure 1. 1D to 3D Transformation of a structure with water absorption materials

In the design of composite hinge systems, Ge et al. created a model that considers various models. Their study aimed to characterise hinge behaviour as a function of geometric parameters, thermo-mechanical charging and programming parameters in terms of hinge bending angles. Ge et al. published a 4D printing technique for creating active printed composites that specifically print information fibres of the composite in an elastomeric matrix. When heat is applied beyond their glass transition temperatures, SMPs may restore their original form and scale. They demonstrated this experimentally by manufacturing the folding box seen in Fig 2 and 4D printed an aeroplane and pyramid. Tibbits and his collaborators present research on how 4D printed structures would assemble themselves. The matching strip of stiff material was printing a hydrophilic polymer band that extends by 150%.

Figure 2. Folding process of 4D printed cube with hinges



Yang et al. used poly-ethane memory thermoplastic form and a 3D structure-making printer Fused Deposition Model (FDM). The resin was introduced as a filler with carbon black, resulting in 3D morphing structures activated by photo-thermal mechanisms, as seen in Fig 3. In particular, thermoplastics perform poorly across certain thermosets, which restrict their ability for use. Modern thermoset SMPs remain chemically interlinked and cannot melt when crosslinks in a polymer network are formed.

Figure 3. Carbon and polyurethane extruded from an FDM printer onto a 3D printed object that reacts to a photographic memory [21]

The 3D printed structure printed with several SMPs, as seen in Figure 4. Multi-material grippers can act as the microscope for the capture and release of objects or medication suppliers. Figure 4 displays multi-material grippers of varying sizes with different styles. The 3D printed gripper is seen in Fig 4b as printed in its active system and compatibility if the artefacts are activated when heated. The representation of the gripper capturing an object is seen in Fig 4c, time-lapse. The time-dependent sequential form recovery can be designed by monitoring the dynamic properties of the various SMPs.

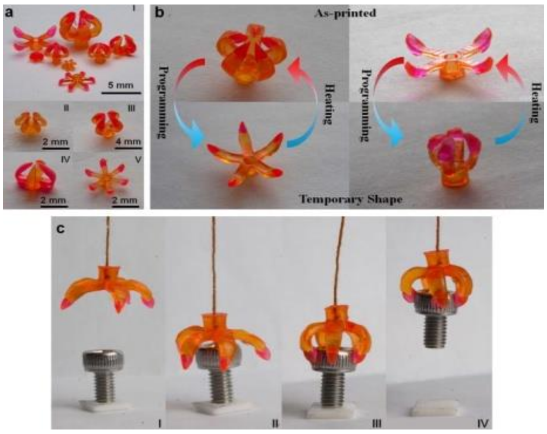
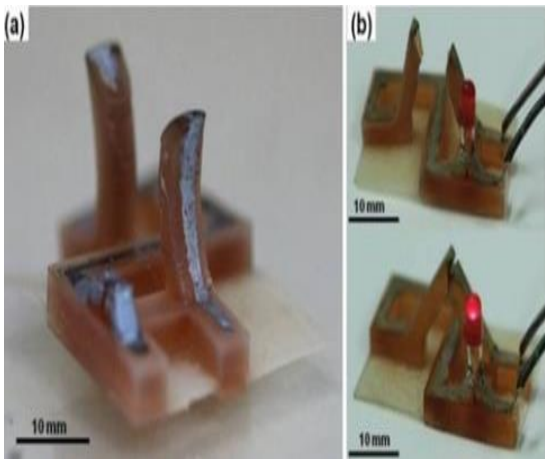


Figure 3. 4D printed gripper [21]

Zarek et al. were recently synthesized in 3D printing macromeres for shape memory artefacts. Such were used in compact electrical circuits, as demonstrated in Figure 5, an open electrical circuit. The circuit was closed whenever heated above T_m, and the LED was illuminated.



ISSN: 2278-4632
Vol-11 Issue-01 2021

Figure 4. Shape memory-based electrical device a) conductive ink printed on the shape memory construct b) fabricated Temperature sensor in its off state (top) and on the state (bottom)

The photopolymer was heated in a pan. The structures were created by a projection sintering laser (PSL) procedure. The inkjet printing was used to impress the conducting inks. 4D printing technique can also be used to produce soft robots, surgical equipment, sensors and wearable electronics based on this prototype since light is a rich, wireless and controllable activation technique for SMPs. In the aspect of self-systems, dynamic folding procedures and transformative surface deformations, light-activated SMPs can be used.

4 Composites in 4D printing

For printing active composite materials, Ge et al. used a 3D multiple material printer. A glassy polymer fibre embedded in an elastomeric resin comprised the printed active composite (PAC). The fibres had a memory effect via an estimated form fixity ratio of 80 percent. In contrast, the resin of the elastomer could not shape and had a fixation ratio of 0. Each laminate, consisting of pure elastomer and PAC Lamina, was printed, heated, spread, cooled, and implemented, with a specified fibre structure that includes the shape, scale and orientation. The laminate becomes a dynamic temporary type as the deformation stress was released by the incompatibility between the elastomer lamina and the PAC lamina memorizing form in the fixed ratio form. Complex 3D configurations, including square, bent, bent, twisted, and folded forms, are available according to the fibre properties. To construct active devices, this PAC laminate may be incorporated into other systems or practical elements. For example, the laminate PAC may be used as a means of constructing 3D structures.

Multi-material and multi-drop technologies could be required in 4D printing technologies, which are currently a constraint on 3D printing technologies. 4D printed parts are lighter, stronger, respond to different types of stimulus and offer different property changes in exploring various types of smart print materials. 4D printing can be applied by changing the form and the colouration of the text area of textiles and camouflage technologies. Textiles might respond to various weather elements stimuli and morph, enhancing the comfort of the wearer's improved ventilation or isolation. Self-healing polymers can improve the lifetime of the 3D printed components, as any damage to the material can be automatically repeated.

5 Conclusions

Additive production is indeed a thriving sector through its early years. The development and improvement of new technologies, printing processes, software and machinery are continual. In recent times, 4D printing has become more attentive because 4D printed materials can change shape or work in response to conditions such as heat, temperature, climate, water and light over time. 4D printing technology utilizes intelligent components, process prediction designs, and intelligent print in different areas, ranging from primary form shifts to organisms' bioprinting. 4D printing has been developed for multi-material 3D and smart materials. This modern technology offers a viable way of creating a lightweight structure that can be deployed. The core of 4D printing is smart materials.Intelligent materials could enable the self-assembly of 3D printed structures and save time and manufacturing costs if exposed to external stimuli.

- The use of intelligent materials also makes polymers to be self-healing. Intelligent materials can work as sensing and drive into the material and make external electromechanical systems redundant.
- By use of self-healing hydrogels may enable pipes to rehabilitate themselves if they produce a leak.
- This reduces the number of components in a system that include electromechanical actuators and electronics.

4D printing has different possible end applications that use shape change and other property such as polymer colour and texture. It may help intelligent textiles that react to a range of conditions, such as environmental elements and morphs, to allow improved ventilation or insulation for the wearers by changing the colour and texture of the texture.

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ISSN: 2278-4632
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