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# A Review on 4D – Printing Design Materials

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## ABSTRACT

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Adding material layer by layer in successive way to create 3D component, after one more stimuli in the form of trigger heating, water submersion, current,uv light and others converts 4D printing. In this paper we conclude some results on printed master key both manufacturing and analysis. so many examples for material inputs ingredients which are thermally sensitive materials. Such materials are widely used in medicine,defense agriculture almost all fields. these will be future revolution .Here no need to make pattern directly takes exact size of path of key. After this giving strength.

**Keywords:** material synthesis, modeling, FEA, printer

## I. INTRODUCTION

There have been many advances in the area of additive manufacturing by 3D printing smart materials that react to external stimuli, which has led to the development of an exciting new technology. 4D printing is defined as using 3D printing technology to print smart materials that can actuate and change shape over time when exposed to external stimuli right off the print bed .Traditional rigid 3D printing materials (acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyvinyl alcohol (PVA), photo-resins, and photopolymers) can be printed in combination with the smart materials due to multi-material printing. This allows specific regions of the 3D printed product to be specified as smart material or rigid material with the help of 3D printing techniques, 3D modelling software, and the additive manufacturing machines.SEAS 4D printing system provides a method of creating 3D printed parts that change shape in water immersion using only a single material. Their modelling and simulation program allow designers to create products that can actuate and change shape based on material and printing properties: strand diameter, spacing between printing paths, and pathway orientation. The technique opens up the possibilities for 4D printing to access the biomedical market because of the biocompatible material. Cells could be seeded into more complex scaffold designs, better strategies for drug delivery systems, and improvement of minimally invasive medical devices.

The printed active composite (PAC) construction made up of a top layer of elastomeric material and a bottom layer of a combination of glassy polymer and elastomeric matrix material. (b) The process of

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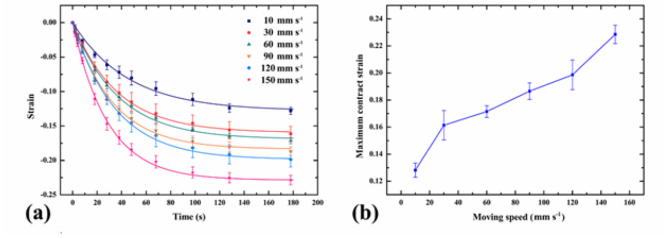
activating the PAC by heating the material, applying a load to the material, allowing it to cool, and releasing the stress to allow the material to bend. Reheating the PAC induces the material to return to its original flat shape.



Maximum contraction strains for PLA 3D printed at different building speeds and their theoretical curves. (b) The maximum contraction strain of the post printed PLA after it has been heated

## II. LAWS OF 4D PRINTING

F. Momeni and J. Ni devised three principles that control the shapeshifting behaviour of all 4D printed structures. These rules help us comprehend the mechanics behind 4D printed structures' capacity to change shape. These laws are as follows:

**First law**

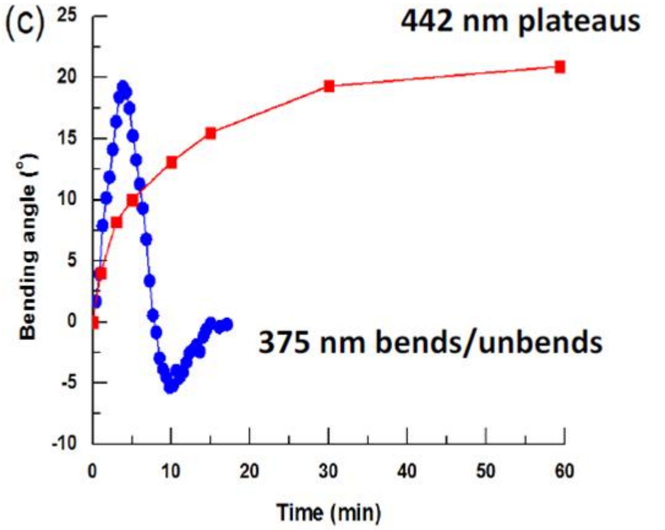
"All shapechanging behaviours of multimaterial 4D structures, such as coiling, curling, twisting, bending, and so on, are attributable to the relative expansion between active and passive materials," according to the first law.

**Second law**

Mass diffusion, thermal expansion, molecular transformation, and organic development are four physical processes behind the shape altering capabilities of all multimaterial 4D structures," according to the second law. All of these elements cause relative expansion of active and passive materials, resulting in shape morphing in response to a stimulus.

**Third law**

"Timedependent shapemorphing behaviour of practically all multimaterial 4D printed structures is governed by two "types" of time constants," according to the third law of 4D printing. Depending on the stimuli and material used for 4D printing, these constants can be equal, huge, or vanish with regard to others. A mathematical biexponential formula for the fourth dimension was also developed, which can be utilised to simulate 4D buildings in the future using software and hardware.



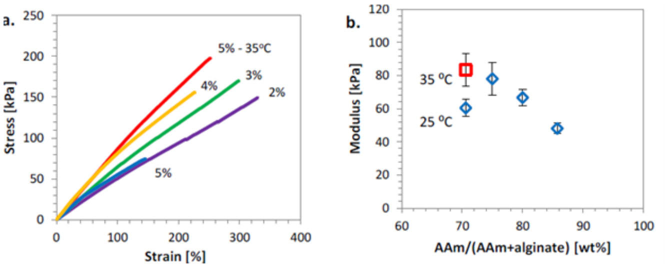


Fig.Typical tensile stress strain curves of printed ICE hydrogels. b. The effectof weight ratio of acrylamide to (acrylamide plus alginate), on the modulus of ICE hydrogels printed at 25 °C (diamonds) and at 35 °C (squares). All samples were printed with the same polyacrylamide content but with different concentrations of alginate: 2%, 3%, 4% and 5% corresponding to 85%, 80%, 75% and 70% AAm/(AAm + alginate) weight ratios the capability of 3D printing of simple fibre composites based on hydrogel materials. An example application was demonstrated by printing an artificial meniscus cartilage which mimicked the complex 3D shape and incorporated spatially varying fibre reinforcements.

Improvements in print resolution when matched to appropriate ink rheology and solidification methods offer the potential to print more complex composites structures, such as particulate reinforced, 3D reinforcement and cellular reinforcements, including honeycomb structures. Thefurther development of these 3D modelling techniques is expected to be useful for the fabrication of multi-component hydrogel structures or devices with multiple applications in micro-fluidics (pumps and valves), robotics (artificial muscles) and bionics (tissue scaffolds and artificial organs).Ultimately, we hope to be able to produce 3D printed versions of soft tissues like tendons, cartilage, skin and muscle where spatial variation in composition and properties is a major contributor to function

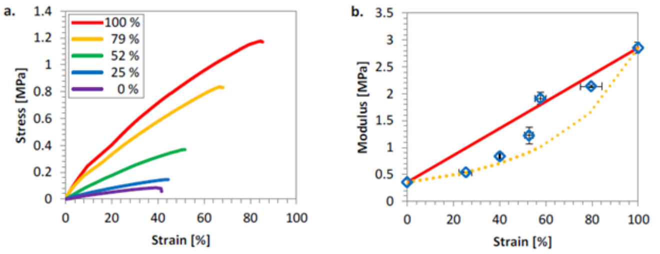


Figure 5:3 Typical stress-strain curves for printed composites with Emax volume fraction of 0, 25, 52, 79, and 100 %. b. Elastic modulus of the printed composites as a function of the Emax volume fraction. Solid and dotted lines represent the theoretical upper (evaluated using equation (4:2)) and lower (evaluated using equation (5:1)) bounds for elastic modulus, respectively

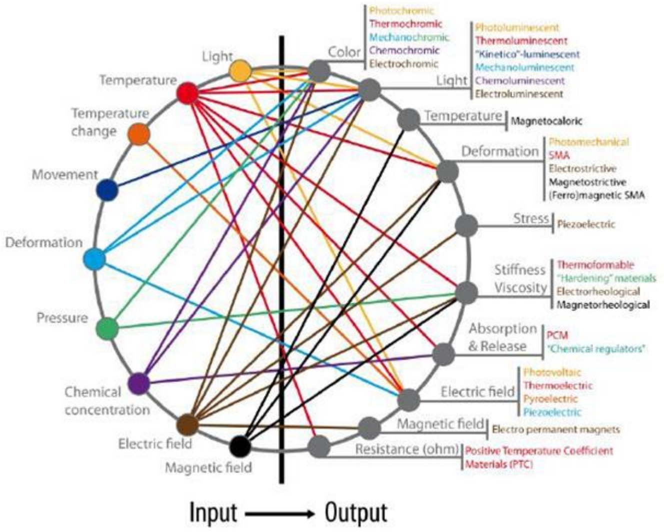
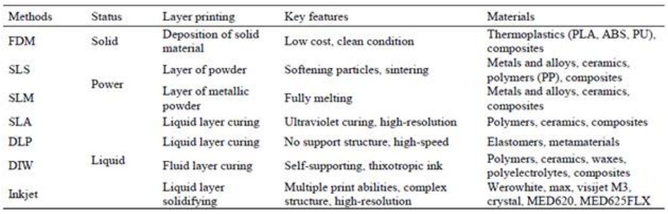
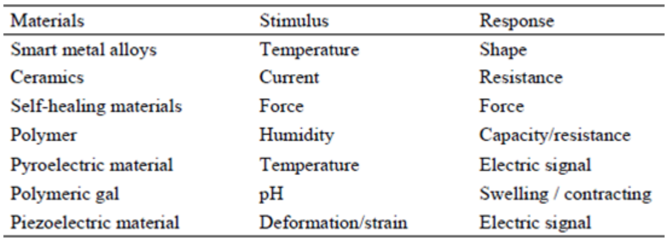


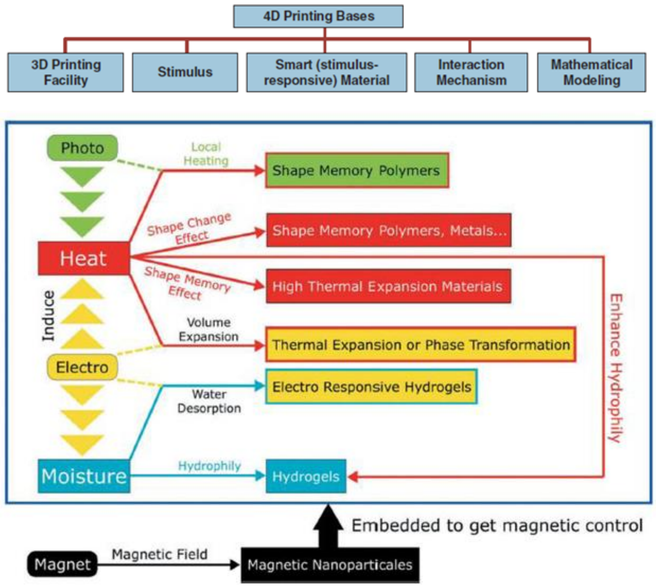
Fig. Material class



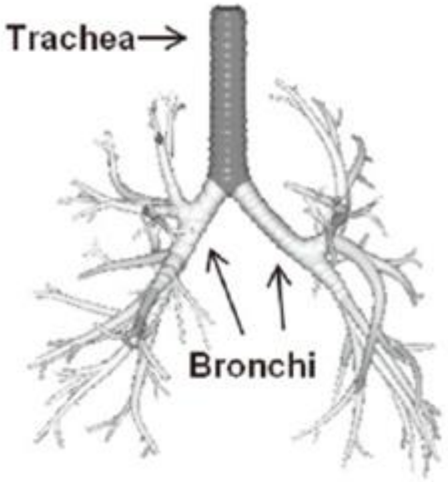
| Methods | Status | Layer printing | Key features | Materials |
|---|---|---|---|---|
| FDM | Solid | Deposition of solid material | Low cost, clean condition | Thermoplastics (PLA, ABS, PU), composites |
| SLS | Power | Layer of powder | Softening particles, sintering | Metals and alloys, ceramics, polymers (PP), composites |
| SLM | | Layer of metallic powder | Fully melting | Metals and alloys, ceramics, composites |
| SLA | Liquid | Liquid layer curing | Ultraviolet curing, high-resolution | Polymers, ceramics, composites |
| DLP | | Liquid layer curing | No support structure, high-speed | Elastomers, metamaterials |
| DIW | | Fluid layer curing | Self-supporting, thixotropic ink | Polymers, ceramics, waxes, polyelectrolytes, composites |
| Inkjet | | Liquid layer solidifying | Multiple print abilities, complex structure, high-resolution | Werowhite, max, visijet M3, crystal, MED620, MED625FLX |

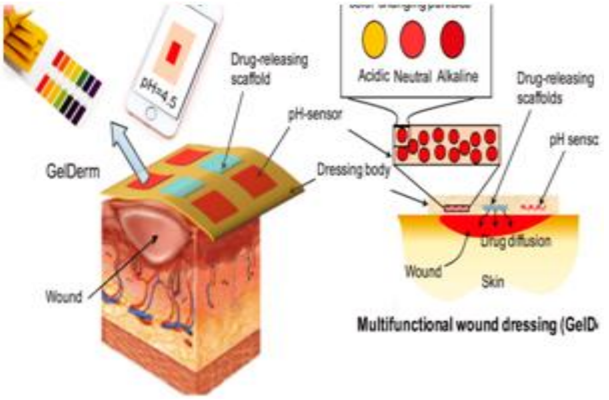


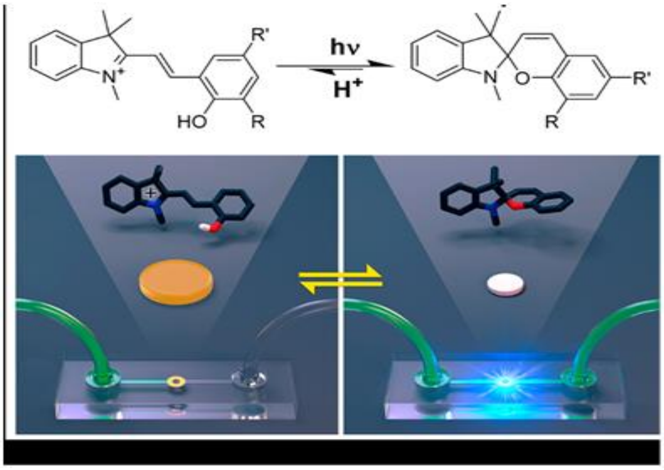
| Materials | Stimulus | Response |
|---|---|---|
| Smart metal alloys | Temperature | Shape |
| Ceramics | Current | Resistance |
| Self-healing materials | Force | Force |
| Polymer | Humidity | Capacity/resistance |
| Pyroelectric material | Temperature | Electric signal |
| Polymeric gal | pH | Swelling / contracting |
| Piezoelectric material | Deformation/strain | Electric signal |



**Applications fields& method for 4d**







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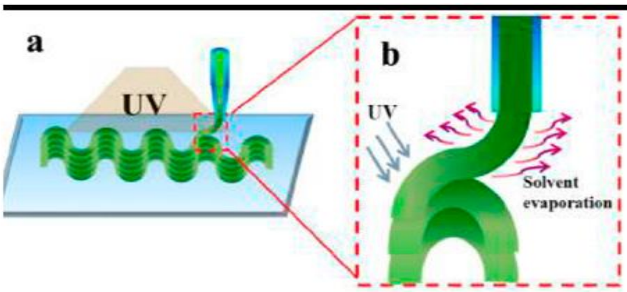

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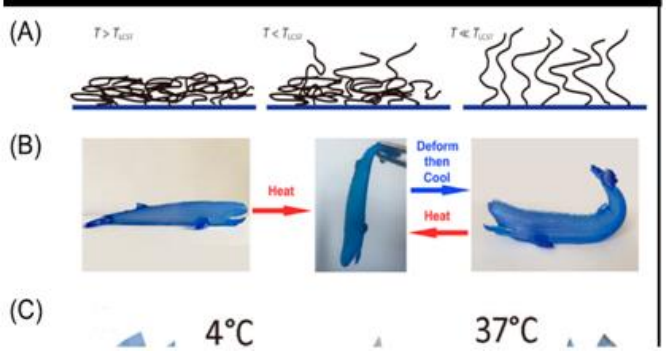

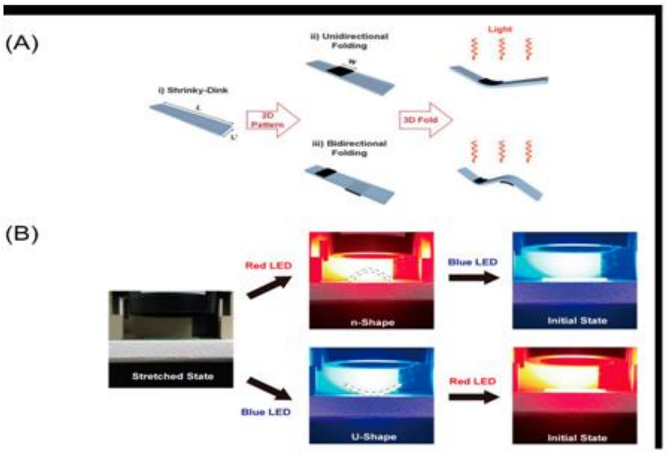

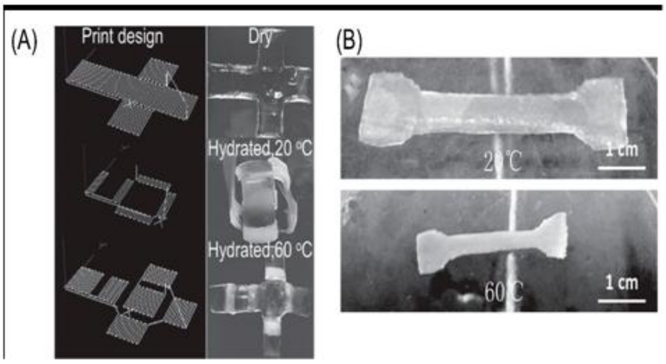

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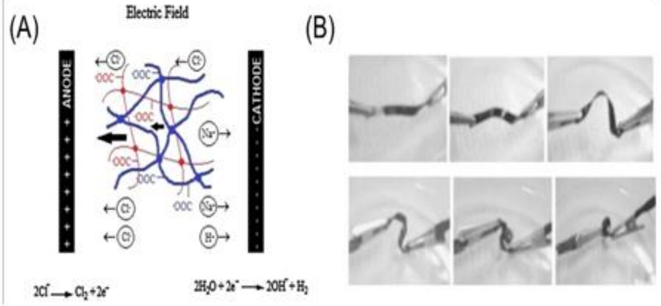
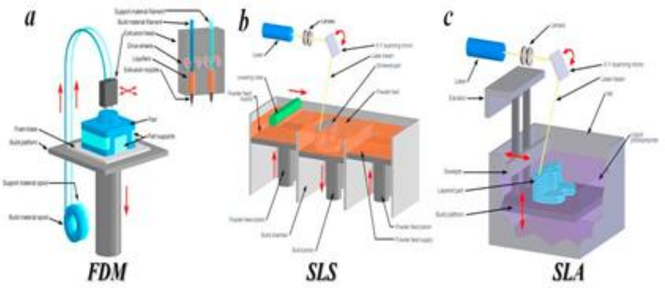
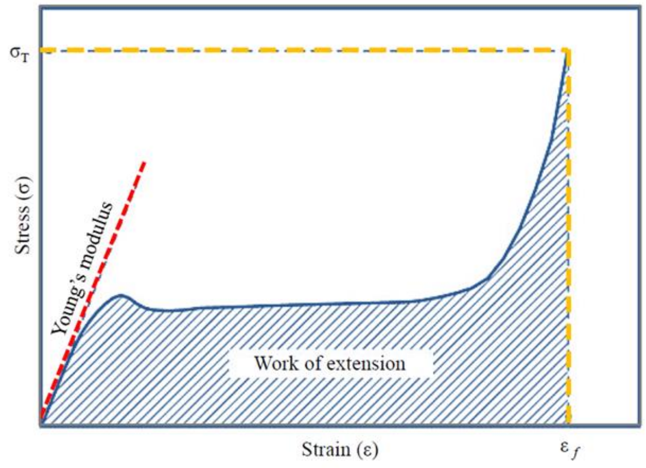
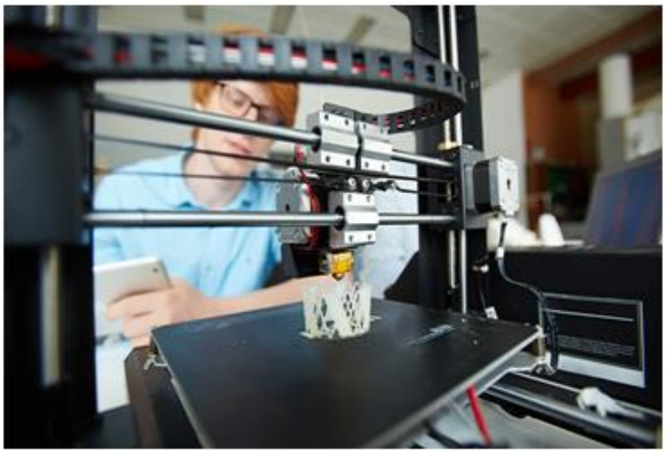




| Material | Input/Stimulus | Output/Response |
|---|---|---|
| Polymeric gal | pH change | Swelling or contracting |
| Electro-rheological fluid | Electrical signal | Viscosity change |
| Pyroelectric material | Temperature | Electric signal |
| Polymer (e.g thin film cellulose, ceramic) | Humidity change | Capacity/resistance change |
| Self-healing materials | Force | Force |
| Smart metal alloys | Temperature | Shape |
| Dielectric elastomers | Voltage | Strain |
| Ceramics (e.g Ladoped $BaTiO_3$) | Current (or template) | Resistance |
| Varistor (e.g Bidoped ZnO) | Voltage | Resistance |
| Piezoelectric material | Deformation/strain electric signal | Electric signal |

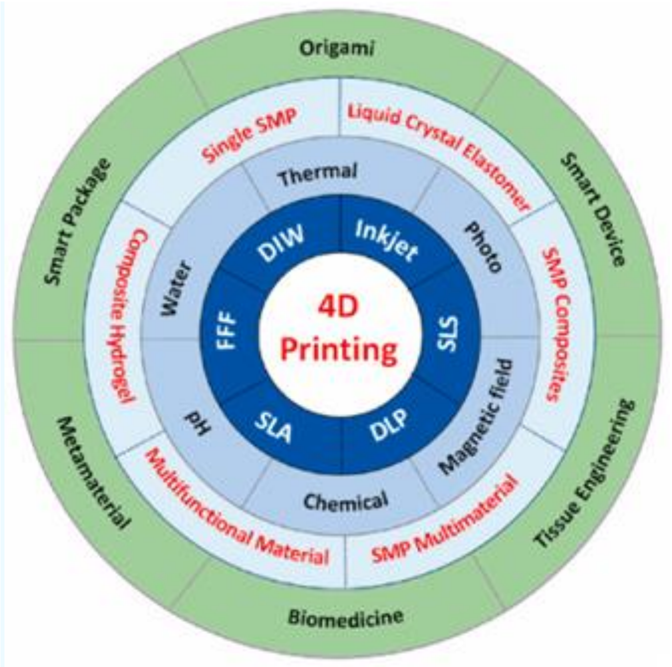


## 4D printers/4D printing machines



The research and development of 4D printing technology is still in its infancy. Currently, laboratories and prototyping facilities, as well as select architectural displays and art installations, are the only venues where 4Dprinted forms are likely to be found. The future is bright, and the list of potential applications, like that of 3D printing, is extensive. The usage of such intelligent materials has the potential to transform the world of materials as we know it.

Stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling (FDM), jet 3D printing (3DP), selective laser melting (SLM), direct ink writing (DIW), electron beammelting (EBM), and other AM processes are examples.



## III. FDM OR EXTRUSION-BASED PRINTING

The most prevalent and well-known printing process utilised by researchers for creating 4D structures is FDM printing, as mentioned earlier in the study. The rationale for this is that it is easy, inexpensive, and has a high printing speed when compared to the other approaches listed. The DIW is similar to FDM in that it is used for extrusion-based printing. The DIW has the advantage of being able to print a variety of materials. In all approaches, the setup is simple: the material (to be printed) extrudes from the nozzle and is immediately fixed. Then, layer by layer, additional material is added until the ultimate structure is achieved.

### DIW

Hydrogels can also be printed using printing. Gladman and his group's study has already been addressed in this paper's earlier part (hydrogels). They developed a composite hydrogel ink with an acrylamide matrix and cellulose fibrils incorporated in it. After that, the ink was successfully printed into a complex structure with various shapes and geometries.

### Stereolithography apparatus (SLA),

Photopolymerization is a vatbased and early accepted AM technique that works on the process of 3D printing by solidifying photocurable resin by photopolymerization began by absorbing light. Photopolymerization is a method for propagating a chain polymerization process that results in photocrosslinking of preexisting macromolecules using light rays. A crosslinker is a component or material that forms a covalent or ionic bond between two polymer chains. The photopolymerization process causes a pattern to solidify inside the resin layer, which helps to hold the subsequent layers in place. To transform photolytic energy into reactive species (radical or cation) that can drive chain formation via radical or cationic mechanisms, a photoinitiator or photoinitiator system is required.

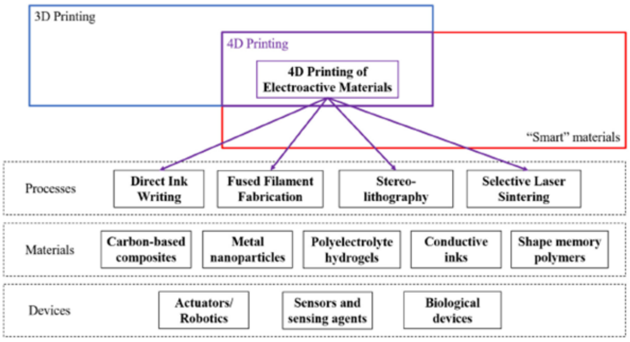
### SLS

Design for Additive Manufacture (DfAM) has the capacity to build not only static shapes, but also ones with dynamic performance and the ability to transform. This powerful trait can be used to boost production and consequently value in your additively made parts, as well as to create parts that have functional behaviour.This form of design is frequently referred to as 4D printing, which, while catchy, just adds to the mystique surrounding AM design. In actuality, this is just DfAM combined with a knowledge of SLS's dynamic material properties in order to make objects perform. Advanced SLS can provide design advice on when and how to employ this technique to maximise the function, productivity, and value of your system.

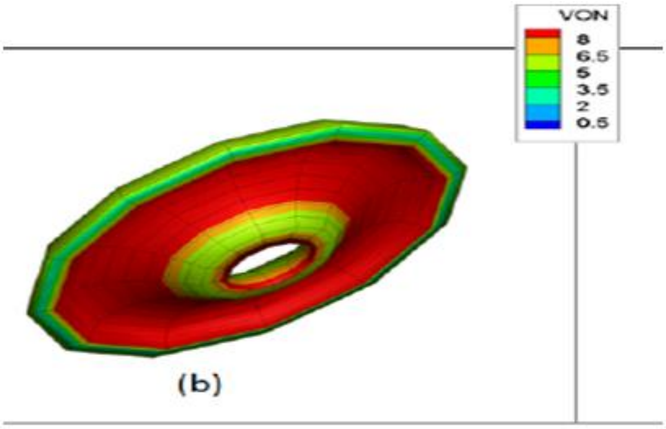
### Digital Light Processing (DLP)

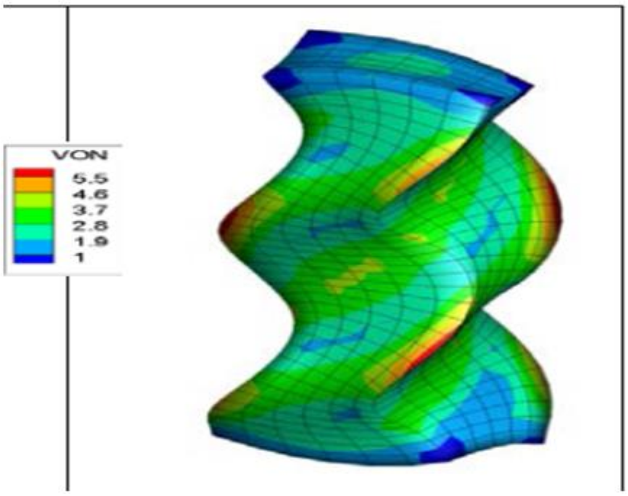
It's a highresolution, highspeed additive manufacturing technique that creates 3D items by layerbylayer curing of photopolymerizable resins. Researchers employed numerous switchable resin vats to create multicolor DLP printing. These approaches, on the other hand, necessitate complicated vat switching mechanisms and cleaning procedures, resulting in low efficiency. As a result, achieving effective multicolor DLP 3D printing remains a difficulty.

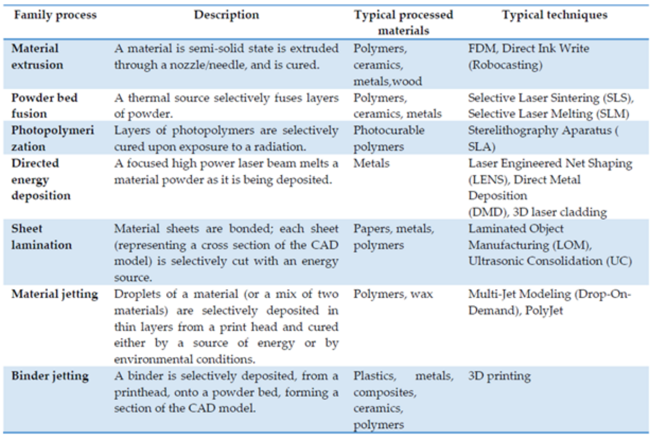
Using an anthraquinone- based dye, Qi and his collaborators create a single-vat multi-color DLP 3D printing system. Under UV light, the dye can be oxidized by free radicals generated by photoinitiators, changing the color from blue to yellow. By regulating the light dose, this colorchanging mechanism allows for a graded range of colors as concomitants of the photopolymerization process during DLP printing without the use of additional vats or devices. Multicolor demos, such as engineering stress simulation results in 3D and multicolor vases, were successfully built to demonstrate the adaptability and efficiency of our multicolor DLP. This unique method can be applied to sensitive dyes of various hues to broaden the color palette and find uses in the 3D printing sector.Single-vat



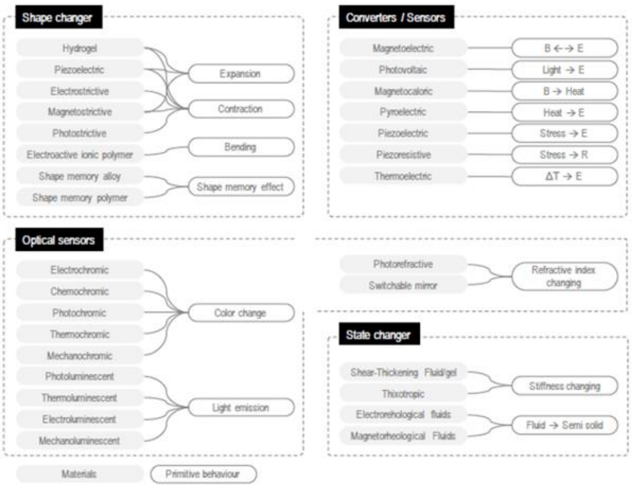
## FEA Analysis report







| Family process | Description | Typical processed materials | Typical techniques |
|---|---|---|---|
| **Material extrusion** | A material is semi-solid state is extruded through a nozzle/needle, and is cured. | Polymers, ceramics, metals,wood | FDM, Direct Ink Write (Robocasting) |
| **Powder bed fusion** | A thermal source selectively fuses layers of powder. | Polymers, ceramics, metals | Selective Laser Sintering (SLS), Selective Laser Melting (SLM) |
| **Photopolymerization** | Layers of photopolymers are selectively cured upon exposure to a radiation. | Photocurable polymers | Sterelithography Aparatus ( SLA) |
| **Directed energy deposition** | A focused high power laser beam melts a material powder as it is being deposited. | Metals | Laser Engineered Net Shaping (LENS), Direct Metal Deposition (DMD), 3D laser cladding |
| **Sheet lamination** | Material sheets are bonded; each sheet (representing a cross section of the CAD model) is selectively cut with an energy source. | Papers, metals, polymers | Laminated Object Manufacturing (LOM), Ultrasonic Consolidation (UC) |
| **Material jetting** | Droplets of a material (or a mix of two materials) are selectively deposited in thin layers from a print head and cured either by a source of energy or by environmental conditions. | Polymers, wax | Multi-Jet Modeling (Drop-On-Demand), PolyJet |
| **Binder jetting** | A binder is selectively deposited, from a printhead, onto a powder bed, forming a section of the CAD model. | Plastics, metals, composites, ceramics, polymers | 3D printing |



These resins offer strong adherence to a variety of substrates and are soft when cured. They are viscous (the viscosity of honey is in the range of 210 Pa.s), making them suited for our LDM equipment. They cure in seconds when exposed to UV radiation in layers as thin as a few millimetres thick. Because of their form memory effect, they were utilised in our machine.

Gcode generation and machine controls with that Gcodeshowing the printing zone are part of the software component of the developed machine. In order to make the printing of material distributions generated easier in the future. This addon can create Gcode for FDM, DLP, inkjet, and syringebased printing, among other AM processes. The process for creating G-code is pretty simple.

Printing volume domain box, layer height, printing pressure, printing speed, wall count, and filling ratio are among the options. The rule of thumb for printing height has been half of the nozzle diameter. The printing speed has been tuned to the speed of the resin at the needle's tip in order to ensure proper deposition (no gaps in the deposited lines or overextrusion). The resin viscosity causes the flow to be laminar in the needle, hence only straight needles were employed. The difference in pressure between the top of the needle (where the controller's pressure is up to 7 bars) and the needle's tip at atmospheric pressure causes the flow. In this case, the flow follows a Hagen-Poiseuille pattern.

The resin's speed at the tip can then be derived from the Hagen-Poiseuille law fiving the flow rate:

$V = D^2 \Delta P/(16\eta L)$

Where D –needle of diameter

$\Delta P$- pressure diameter

$\eta$- resin dynamic viscosity

L- length of needle

The so generated G-code has been somewhat tweaked to suit our LDM machine's needs. As such the G-code only provides commands for the printing head motions but no control over the dispensing system controller nor over the UV curing light. We elected to keep the UV light on during printing. The G-code was only tweaked for the dispensing system controller. This latter is plugged to the spindle relay output of the breakout board. So the G-code commands M04 (*spindle on*, that is, *deposition*) and M05 (*spindle off*, that is, *no deposition*) have to be inserted. Some of the lines of the initial G-code are for travel motions while others correspond to printing. The difference between these two states is the federate (the motion speed). This difference has been used to insert the M04 and M05 command at the right lines. Technically a short Matlab script was written to read the code generated from Xylinus and to modify it accordingly.

The so modified G-code is then saved in a .tap format and loaded into the Mach3 software from which commands are sent to the machine. The Mach3 software that can control the breakout board can only work on a desktop computer running Windows XP as operating system. This requires thus the G-code to be transferred to another computer connected to the breakout board

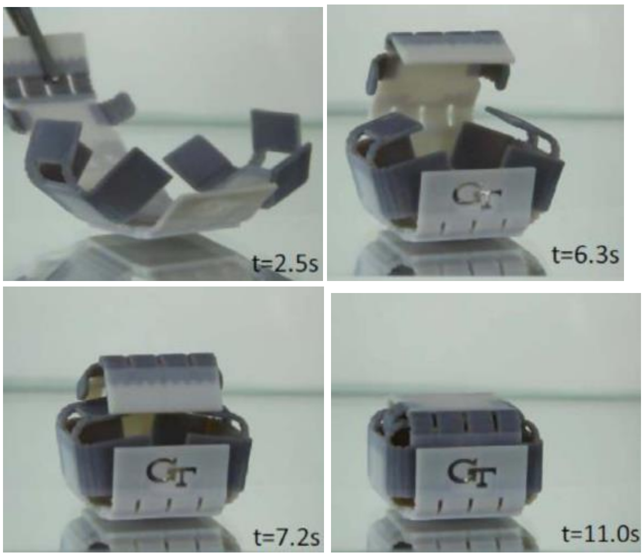


Fig Gautomatic locking system

**Applications of 4d**

**Medical applications:**

Organ printing, Smart multi-material printing, Dyspnea (Breathing problem), Smart medical implants and tissue engineering

Application in soft robotics: soft robots may be also used in autonomous surgeries, laparoscopy, and endoscopy,soft robots during manufacturing,

**Application as self-evolving structures:**

Application as active origami

Application in aerospace: to manufacture aerospace components that rely on aesthetics over function, such as door handles and light housings to control wheels and full interior dashboard designs

Application in sensors and flexible electronics:**3D printed circuit boards,3D-printed supercapacitors,3D-printed sensors,4D-printed sensors3D- and 4D-printed actuators,Printed photovoltaics,**

## IV. CONCLUSION

1. From CAD package files we can print 4d layers
2. These 4d printed materials are gel type ones
3. Assembly and dismantle are peculiar 4d printed layers
4. These 4d materials are least stress carrying ones
5. 4th dimension plays vital role in 4d materials usually stimuli
6. Pattern can make use of 4d materials
7. Almost every sector can use 4d materials
8. Most benefit in medical field is skin, tissue, organ implantation is widely applicable

## V. REFERENCES

[1]. BerkayErgene and B. Yalçın, A Review on 4d printing technology and applications, 5th international conference on advances in mechanical engineering, December 2019, Istanbul, Turkey.

[2]. Guanyun Wang, Ye Tao, OzgucBertugCapunaman, Humphrey Yang, and Lining Yao. 2019. A-line: 4D Printing Morphing Linear Composite Structures. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.

[3]. FarhangMomeni, SeyedM.MehdiHassani.N, Xun Liu, and Jun Ni, A review of 4D printing, Materials and Design 122 (2017) 42–79.

[4]. Haleem A, Javaid M, 4D printing applications in dentistry, Current Medicine Research and Practice, https://doi.org/10.1016/j.cmrp.2018.12.005.

[5]. Pei, E. (2014) "4D printing – Revolution or Fad?", Assembly Automation, 34(2) DOI: http://dx.doi.org/10.1108/AA-02-2014-014.

[6]. Bi, Z. (2011) "Revisiting system paradigms from the viewpoint of manufacturing sustainability" Sustainability 3 (9): 1323-1340.

[7]. Yap, Y. and W. Yeong. (2014) "Additive manufacture of fashion and jewellery products: A mini review: This paper provides an insight into the future of 3d printing industries for fashion and jewellery products" Virtual and Physical Prototyping 9 (3): 195-201.

[8]. Pei, E., J. Shen, and J. Watling. E. (2015) "Direct 3D printing of polymers onto textiles: experimental studies and applications" Rapid Prototyping Journal 21 (5): 556-571.

[9]. MacCurdy, R., Katzschmann, R., Kim, Y., and Rus. D. (2016) "Printable hydraulics: A method for fabricating robots by 3D co-printing solids and liquids" 2016 IEEE International Conference on Robotics and Automation (ICRA).

[10]. Holmes, B. Zhu. W. Li, D. Lee, J and Zhang, L. G. (2014) "Development of novel three-dimensional printed scaffolds for osteochondral regeneration" Tissue Engineering Part A21 (1-2): 403-415.

[11]. Mu, X., Bertron, T., Dunn, C., Qiao, H., Wu, J., Zhao, Z., and Qi, H. J (2017) "Porous polymeric materials by 3D printing of photocurable resin" Materials Horizons 4(3): 442-449.

[12]. O'Donnell, J., Ahmadkhanlou, F., Yoon, H. S., & Washington, G. (2014) "All-printed smart structures: a viable option?" Active and Passive Smart Structures and Integrated Systems International Society for Optics and Photonics.

[13]. Reissman, T., MacCurdy, R. B., Garcia, E., &Nejhad, M. G. (2011) "Active and Passive Smart Structures and Integrated Systems" Proceedings of SPIE 79-77.

[14]. Chua, C. K. and K. F. Leong (2014) 3D Printing and Additive Manufacturing: Principles and Applications (with Companion Media Pack) of Rapid Prototyping Fourth Edition. World Scientific Publishing Company

[15]. Frazier, W.E. (2014) "Metal additive manufacturing: a review" Journal of Materials Engineering and Performance 23 (6): 1917-1928.

[16]. Bogers, M., R. Hadar, and A. Bilberg (2016) "Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing" Technological Forecasting and Social Change 102: 225-239.

[17]. Conner, B. P., Manogharan, G. P., Martof, A. N., Rodomsky, L. M., Rodomsky, C. M., Jordan, D. C., &Limperos, J. W. (2014) "Making sense of 3-D printing: Creating a map of additive manufacturing products and services" Additive Manufacturing 1: 64-76.

[18]. Rayna, T. and L. Striukova (2016) "From rapid prototyping to home fabrication: How 3D printing is changing business model innovation" Technological Forecasting and Social Change 102: 214-224.

[19]. Breger, J. C., Yoon, C., Xiao, R., Kwag, H. R., Wang, M. O., Fisher, J. P., ... & Gracias, D. H. (2015) "Self-folding thermo-magnetically responsive soft microgrippers" ACS applied materials & interfaces 7 (5): 3398-3405.

[20]. Momeni, F., X. Liu, and J. Ni F. (2017) "A review of 4D printing" Materials & design 122: 42-79.

[21]. Hager, M. D., Greil, P., Leyens, C., van der Zwaag, S., & Schubert, U. S. (2010) "Self-healing materials" Advanced Materials 22 (47): 5424-5430.