



A Review on Application of 3D Printing Principles in Infrastructure Industry and its Impact on Evolution of the Industry

K. Avinash Varma ¹, Kaushik S Chundury ^{1,*}, B. Narendra Kumar ¹

¹ Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad- 500090, India

* Corresponding author email: kaushikchundury@gmail.com

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Abstract: As 3D printing emerging to be a much-matured technology, its range of uses are now seemed to be infinite. 3D printing is now beyond the stage where it was only observed as a prototyping solution. From a simple artwork and playing toys to ready to live in buildings and also transplantable organs, the technology could potentially last until our imaginations die. From automobile to consumer goods manufacturing industries, organizations across various industries are trying to observe the advantages 3D printing has got to offer for production. With such acknowledgements, organizations are now trying to find their ways to incorporate this technology in their respective industries, whose applications could potentially extend from tooling to spare/replacement parts and sometimes till a full-fledged end-use ready product. While 3D printing looks like a most exciting new normal for organizations who are planning to streamline their prototyping technology, its prospects for the non-tech consumer world is also evolving rapidly. Additive Manufacturing in construction can be seen as an option that could contribute towards complete automation in the infrastructure industry. The method offers advantages in the aspects of design, sustainability and also efficiency. This work scopes for a comprehensive approach to advance the technology in construction and proposes research potentials, challenges, and future scope. The potential of 3dcp for automation advances all other practices in prospects like exclusion of form work, precise design execution, waste reduction and extremely low consumption of time. The real-time status and futuristic approaches to be adopted are briefed in the paper and also the scope for sustainability over other practices are detailed in the paper.

Keywords: 3D Printing, Technology, Prototyping Solution, Transplantable Organs, Tooling, Sustainability.

About the Authors



K. Avinash Varma is currently pursuing his B. Tech. degree in the department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad. With having a primary agenda of driving the Construction & Infrastructure field towards sustainability yet sophisticative, research about new potential technologies are his major interests.



B. Narendra Kumar is currently working as an Associate Professor in Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad. He received his B.Tech in Civil Engineering, M.Tech in Structural Engineering and is pursuing his PhD at JNTU, Hyderabad. His research interests are SCC, special concretes and concrete mix designs.



Kaushik S Chundury is currently pursuing his B. Tech. degree in the Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad. He actively participates in all co-curricular and non-scholastic activities, while having exceptional zeal for the advancement in the field of Civil Engineering and upcoming technologies.

1. Introduction

Additive manufacturing or 3D printing a process of giving a solid form in reality by a mechanised process using a digitally drawn file. It is a process of layering in sequence of a mixture of materials in order to create 3D shapes using a computer-controlled mechanism [1]. The 3D printing technology when compared to other conventional methods can be considered as an environmentally friendly option giving numerous

prospects for complex geometrical realizations. It can be used in various industries like construction, automobile, medicine, Aerospace, manufacturing etc. It has got many advantages of technology, just like reduction in costs and time, rapid prototyping, printing on demand, lightweight materials, fast design, minimising waste and many more. This technology has grown so much in recent years that it can also be used to build or construct structures in outer space. In this research, we will be focusing more on the usage of 3D printing in the construction and infrastructure field [2].

This technology was first developed in the 1980s, but during that time it was a difficult and expensive operation, so it had very less applications. It is since 2000 that it has become relatively straightforward and affordable technology that it has become viable for a wide range of uses including product design, component and tool manufacture, plastics, aerospace engineering, plastics, metalworking, dental and medical applications, footwear and construction.

3D printing (also referred as Additive Manufacturing) is the computer-controlled sequential layering of a mixture of materials to create three-dimensional shapes. 'Construction 3D Printers' are few exclusively developed systems to potentially meet the appropriate needs of technology in the construction

industry [3]. A 3D model of the required object is designed, either by computer-aided design (CAD) or using a 3D scanner. The printer then reads the design made and lays down accordingly in successive layers of printing medium like concrete, cement mortar, geopolymer or any other binding agent to obtain the desired structure as shown in figure 1.

3D printing in construction may allow quicker and more precise structures of complex structures and it avails lower labour costs, less wastage of materials, less cost, time etc. It can be used to construct in any environment with suitable technologies [3].

2. Types of 3D printing in construction

There are two major types in 3D printing.

2.1. Extrusion based printing

Figure 2 depicts the mechanism used for Extrusion Based printing. In this process, usually feedstock materials are nothing but mixture of a binder and an essential compound in form of a fine grain solid powder of metal or ceramic materials the concrete is cast or printed layer-by-layer through an automated process. One of the major advantages of this printing technique can be attributed to less or no use of formwork [4].

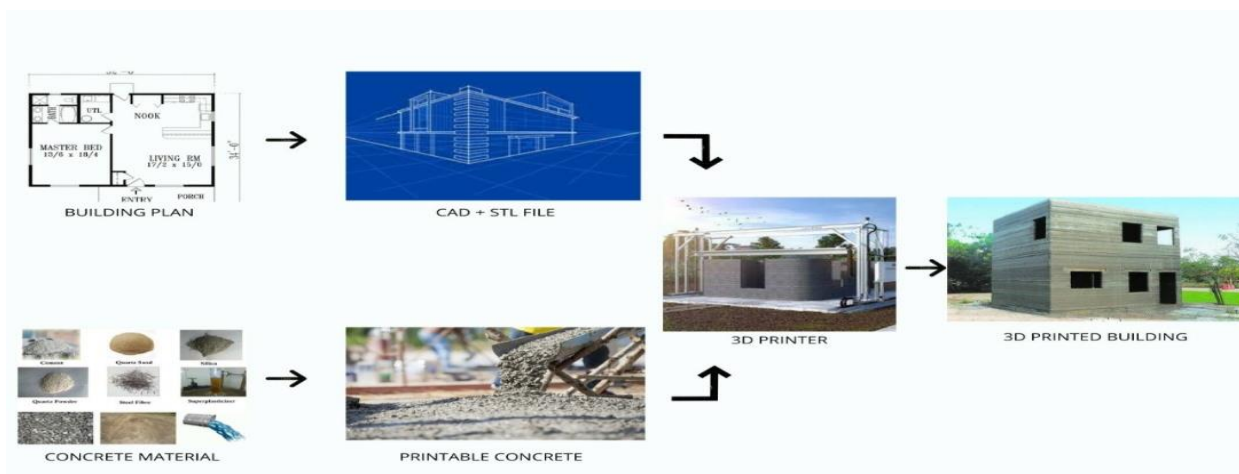


Figure 1. Basic Outline of 3D Printing Construction Process [9]

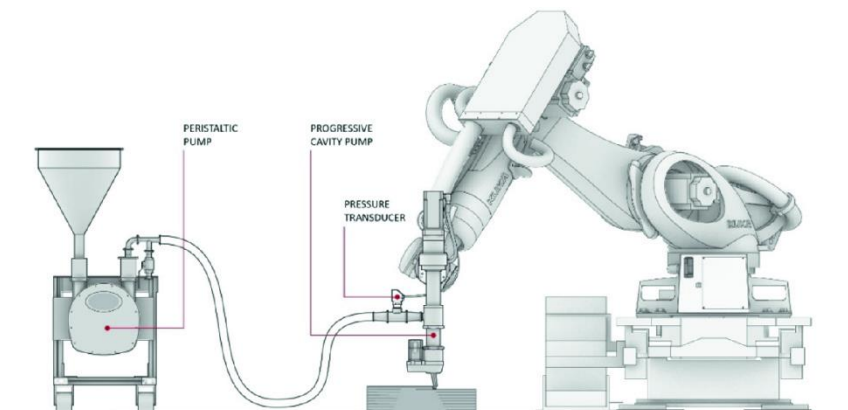


Figure 2. Extrusion based 3D Printing Type Mechanism [5]

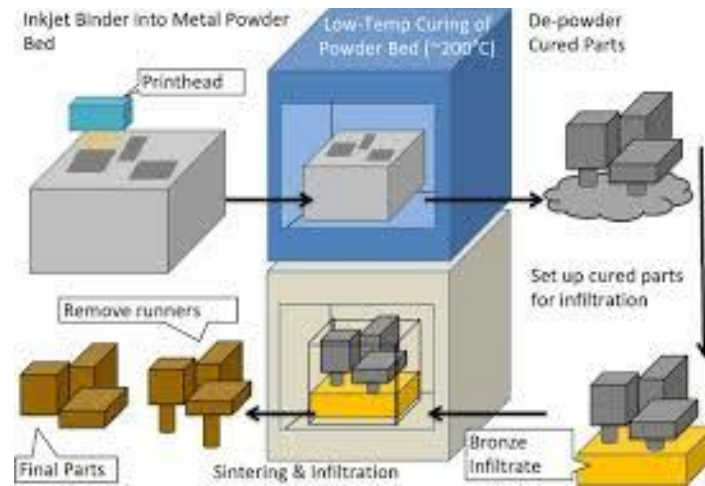


Figure 3. Binder Jetting Type Mechanism [5]

2.2. Binder jetting

Is another technology used in 3D printing. The construction is done by ejecting/spraying binders like droplets on the top of a build tray with a carrier material like sand or cement [4]. The figure 3 shows the mechanism used for Binder jetting process.

3. Materials

The Materials used for 3D printing play a major role in construction (Table 1). 3D printing structures can be made using different components, such as, the material mixture of concrete, fibre, sand and geopolymers. All these mixtures can be fed into a hopper from which they are sent to the extrusion pipe and layered into the designated shapes or patterns. In recent times, 3D printing structures have also been constructed using biodegradable materials such as soil, rice husk, mud etc.

Additives can be used to modify the characteristics of fresh or hard-set mortar. During the compounding of mortar, uniform extrusion of concrete should be considered, as the used materials should blend adequately for proper consistency and workability [6]. The principal properties of hard-set concrete are compression strength and bending strength. The various additives that could be used are: GGBS, fly ash, silica fume, and rock powders such as, limestone and quartz [7].

Fly ash – is a derivative of coal which is obtained by burning pulverized coal in electric power generating plants. Its wide application is determined by its high fineness, chemical and phase composition as well as pozzolanic activity. Its spherical shape creates a ball bearing effect to the mixture, which increases the workability without the need for excess water. It improves the permeability of concrete which decreases the total volume occupied by capillary pores by lowering the water to cement ratio. Additional advantages of

using fly ash content in concrete mix enlist its opposing nature to resist concrete reinforcement corrosion, attack led by the Alkali-silica reaction, acids, salt attack and sulphate attacks.

Ground granulated blast furnace slag is high quality, low CO₂ material that is procured by the quenching process of molten iron slag which again is a derivative of steel making and iron from a blast furnace in water or steam. It is later dried and powdered to produce a fine granular product. GGBS can replace 60-70% of PPC in a concrete mix. It is highly sustainable, durable and gives an aesthetic finish.

Silica fume is a derivative obtained from silicon metal or ferrosilicon alloys. It has an average particle size of 120-150 nm, which seals the microstructure of concrete by filling the space between the cement grains [7]. Because of their fine particle size and large SiO₂ content, silica fume is yet another reactive pozzolan which can be helpful for concrete. 2-3% of silica dust is added to the concrete as an admixture, which improves the workability parameter of mixture and also provides enhanced viscosity. The raw materials used for the production are wood chips, quartz and coal.

Synthetic resins which give negative charge to the cementitious grains depend upon superplasticizer, which expedites the formation of the water layer between the cementitious grains. Because of which, the interaction in between molecules due to electrical forces, increases the workability of the mixture [7].

Admixtures are usually incorporated to accelerate the dynamics of mortar gaining strength over a period of time. The early strength of the mix is accelerated, with no degrading effects on the resulting mortar at the end. While extruding the subsequent layers of the structure, the early strength of the mortar is very vital to avoid delamination and disintegration of the printed structure [8].

Table 1 Materials used for 3D printing by leading companies [6]

Company Name	Materials Used
COBOD	Concrete mixture with major constituents as cement, sand and other additives [5]
WASP	Natural raw material mixture consists of ,40% straw, 25% of soil and rice husk each, and 10% of hydraulic lime.
TVASTA	Concrete mix design based on Portland cement, but with low water-cement ratio and consisting of cement, and other additives.
APIS CORE	Concrete mix design made up of cement, geopolymer, sand and other additives.
WINSEN	Concrete mix design made up of cement, fibre, sand and other additives.

The various materials used for 3D printing by leading companies are listed in table 1. Retarding admixtures are normally used for the process of printing as the transportation of the 3D concrete mixture will take a large amount of time as it is important to commission proper bonding in the mortar layers. Lowering the rate of bond formation between layers helps to retain the liquidity natural for the transported mixture for a prolonged time period, which is a boon for the printing process and the pumping of mortar. Concrete with a retarder admixture indicates slower hardening and lower initial strength [7].

Viscosity enhancing admixtures are specifically designed to enhance the parameter of the mortars, excluding major adjustments in consistency. Usually they are incorporated to avoid the segregation effect in self-compacting mixes. Proper planning and design should be used for the process of feeding the concrete mixture in to the 3D printer, as pumping of mixture with high viscosity needs a relatively greater pumping pressure.

4. Procedure

In the field of construction, the procedure for 3D printing technology can be mainly divided into two parts as shown in figure 4, the software part and the other hardware part. The first part is related to the planning and design stage where the designers can use 3D software's such as SolidWorks or AutoCAD to design the 3D model of the structure. By using a specific software (depending upon the type of 3D printer), the design is sliced to determine the size of each concrete layer and simultaneously it is converted to a G-code format which is the ML language recognised by the 3D printer under use. The hardware part is the construction phase where it comprises an extrusion-based system, which extrudes the concrete layer by layer to build large scale buildings [6].

Majority of the concrete 3D printers consist of a robotic arm, which is connected to a storage system, and

operated by using a specified software [6]. A hose pipe is used to connect the nozzle and the storage unit where the concrete mix is stored. A pumping system is utilized to transport the mix to the nozzle from the mixer, and the concrete is laid layer by layer as per the specified design (Figure 5).

For a huge scaled cement-based 3D printing system, the placing, solidifying and the volume of concrete mix in layers is controlled by a computer. This printing methodology includes 3 major steps:

4.1 Data presentation

A variety of methods are used for the data preparation. The usual method is to place the 3D shape in form of thin layers with a uniform thickness of each layer which are to be laid one over the other. Each layer consists of a filling pattern and contour line. [10]

4.2 Material preparation

This includes the mix design of the concrete or any other binder material which is going to be used for printing as the raw material. Once the material is filled inside a container, it will then be passed from the nozzle to extrude the structure – layer by layer. [10]

4.3 Control system

These are of two types: Robotic arm system and gantry system. The gantry system guides an operator attached to an overhead to identify the position of print nozzle in XYZ Cartesian coordinates while the robotic arms can offer large range of freedom to the mixture pumping nozzle, allowing the system to be more precise while printing the design just like printing using a continuous tangential method [10].

The four major characteristics in 3D printing to keep in mind are Pumpability, extrudability, buildability and open time.

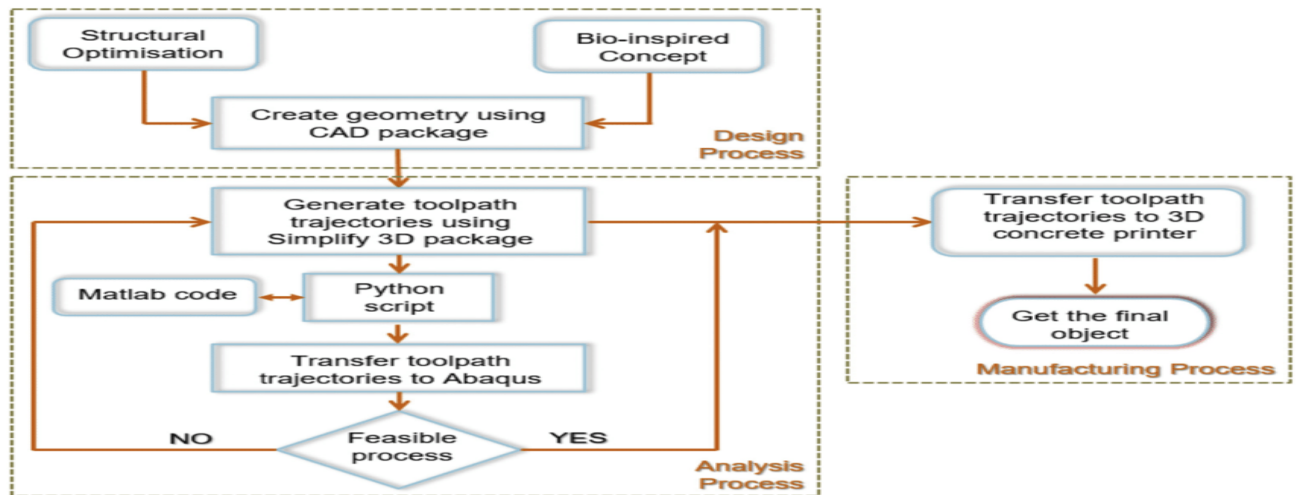


Figure 4. Complete Flow Chart of 3D Printing Construction Procedure [6]



Figure 5. Layering of 3D Printable Concrete [9]

1. **Pumpability:** the ease of transport of material through the system i.e., mixer/container to nozzle.
 2. **Extrudability:** is the ease of extruding concrete through the nozzle at a given rate.
 3. **Buildability:** the ability of the printed concrete to retain the imposed loads of subsequent layers without deformation.
 4. **Open time:** it refers to the time during which concrete retains its necessary fresh properties
- 3D printers reduce human error and also reduce labour costs up to 50-70%.
 - Cheaper construction: once 3D printers are adapted, constant use of 3D printers will result in cheaper construction.
 - Construction will be faster and more accurate.
 - By using 3D printers, the potential health and safety risks are reduced to a greater extent as the dangerous parts of the construction that are otherwise important can be avoided by humans.

5. Benefits

- About 60% - 70% of the time is saved in construction when compared to the conventional method.
- Reduces wastes: 3D printers use a precise number of materials which leads to less wastage of resources and saves about 30% - 60% of materials.
- Design freedom: allows us to design highly complex designs that are otherwise almost impossible to be given a real form with conventional methodologies.

6. Challenges

- Transportation of printers from site to site may be challenging.
- There will be less demand for labour which might lead to unemployment.
- Skilled labour will be required to operate the machine.
- Technicians should always be available on sight.
- 3D printers are very expensive and require high maintenance.

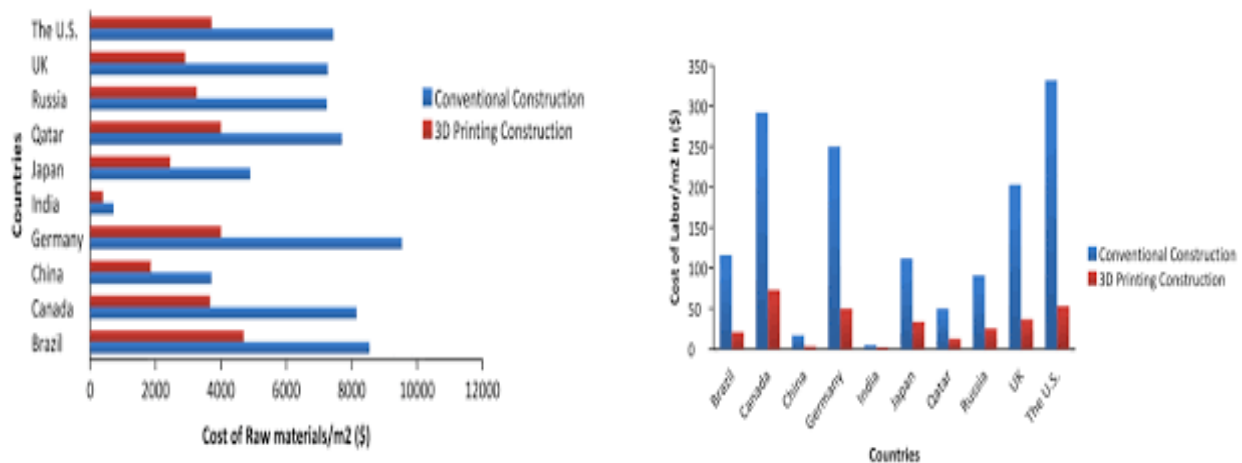


Figure 6a. Figure 6 (a) . Comparison in Cost of materials **6b** Comparison in Cost of labour [11]

7. Discussion and Conclusion

It is clearly evident that the use of 3D printers in construction provides a lot of benefits. The first 3D printed wall was built in 2004, and since then, this innovation has exploded and become one of the greatest technologies in the construction industry. A structure can be built within hours with high strength and quality, low costs and wastage, faster construction speed and even complex structures can be built with ease. It is also suitable for construction in dangerous and harsh environments which are not suitable for humans such as space. With the recent arrival of building information modelling (BIM) in the industry, it may facilitate greater use of 3D printing.

Construction companies have realised the potential of 3D printers in the field and it is estimated that the 3D printing market could reach \$60m by 2022 and \$30 billion by 2027 [8].

3D printing in the construction industry helps save a lot of effort, material, time and most importantly money when compared to the conventional method of construction as shown in figure 6(a) and figure 6(b). But it should be noted that, as of today, a fully functional house cannot be constructed using a 3D printer. Elements such as plumbing, electricity, doors, windows etc. have to be installed separately.

Though the 3D printing process in construction provides so many benefits and has such a high potential in the construction industry, many professionals are cautious of the effect that 3D printing could have on their businesses. Increased mechanisation and automation have always been challenging to the fidgety labour markets in the past and also the present [8].

3D printing promises many opportunities to the construction industry to become cost effective, greener, safer and many more, but, like everything else in the world, this too has two sides of the same coin and only

time can tell us where this technology is going to lead the many facets of the construction industry [11].

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Conflict of interest

The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

Does this article screened for similarity?

Yes

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