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Latest trend in building construction: three-dimensional printing

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Abstract. Today world is looking towards additive manufacturing as a solution for sustainability in the construction business, one of which is three-dimensional printing that involves creating a three-dimensional (3-D) object by printing layer by layer developed digitally. Nowadays, 3-D printers have evolved so much that they can create a whole house from pin. This technology is not only cost and time effective but also speeds up the construction rate with reduced power, material consumption, and hence reduced waste in building construction. The scope, elements, and classification of 3D printing has been discussed to highlight the work done by past researchers. This paper reviews the elements, merits, and demerits of using 3D printing in construction and evaluates it as a promising technique for sustainable development.

Keywords: 3D printing, sustainable development, fast construction, additive manufacturing.

1. Introduction

In the past three decades, three-dimensional printing (additive manufacturing) has paved its roads in the different fields of science and specifically in the construction field. It is now possible to use 3D printing in the construction of buildings as it is faster, economical, trustworthy, eco-friendly, and accurate. Since there is no restriction presented by the limited presence of materials. This developing technology will be used up to its potential in the future. Although the use of 3D printing in the field of aerospace and manufacturing set itself an example of a solution that saves time, energy, and reduction of waste and yet it is not widely used [1,2]. Presently the construction process is simpler and structured, requiring 2D drawing, a scale model of buildings, skilled and unskilled labor but the construction worker's health, work-related injuries style, and mortality are high as compared to other fields [3]. These issues could be eliminated by introducing 3D printing technology in the field of construction. The making of complex and customized structures will be simple as well as less time-consuming. 3D printing technology has been used in numerous fields which includes biomedical, aerospace, manufacturing, etc. [4,5]. Conventionally, different types of manufacturing processes and techniques have been used to manufacture parts [6–12]. Traditional parts have been processed subtractive machining methods and material joining techniques [13–24]. 3D printing technology eliminates the need of machining which is required for achieving final shape in conventional methods [25–29]. Many researchers believe that with the use of this technology the global CO₂ emissions will be reduced as well as there will be a 40% reduction in the total concrete budget of the building with the possibility to complete the project before the timeline. There is a need to motivate and promote these innovative construction technologies that can pave its way towards sustainability. In this direction, this paper reviews different types of 3D printing techniques its advantages, challenges, and limitations of 3D printing in the building construction industry. Figure 1 shows the brief of three-dimensional (3-D) printing in building construction.



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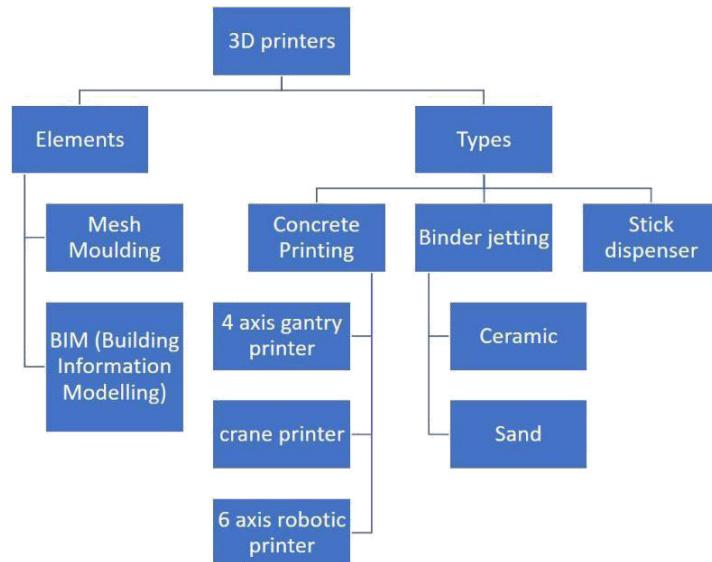


Figure 1. Brief of three-dimensional (3-D) printing in building construction.

2. Scope of 3D printing

3D printing is a process of creating three-dimensional objects using a digital file and additive process. In this process, the object is sliced into very thin horizontally cross-section layers of the object which is layered down repeatedly until the object is created. It is the opposite of subtractive manufacturing which is hollowing or cutting out of the metal or plastic with the help of a milling or CNC machine. 3D printing allows us to make complex and highly finished objects in lesser time and material than contemporary traditional methods. A 3D model is scanned and using a 3D modeling software a virtual model is created with the required dimensions. Research and Development of the 3D printer have made them capable of printing a wall, house, or a complex structure used in the construction of a building. Some techniques frequently used are Building Information Modelling (BIM), Contour Crafting (CC), Binder Jetting, Concrete Printing, and Mesh Molding.

3. Elements of 3D printing

3.1. Building Information Modelling (BIM)

The concept of BIM started in the 1970s and became an agreed term in early 2000. The basics of international standards ISO-19650 of BIM launched in January 2019 were developed since 2007 in the United Kingdom. The development and adoption of BIM have been different in different countries. Figure 2 shows the illustration of the Building Information Modelling (BIM) cycle process.

In India, it is also known as virtual design and construction (VDC). The construction industry which has always been criticized for its lack of productivity, collaboration, and innovation, BIM proved to be the solution to the various, problem construction industry face. The program inputs data such as geometrical data, materials, equipment, and manufacturing data. This requires information about geographical surroundings, material, and equipment available. These inputs lay a base for 3D printing and design and help in faster and simpler project execution and also lay a base for 3D printing techniques and designs to be used. BIM's experimentation and implementation are on a large scale in India as compared to other developed counties. BIM's experimentation and implementation are on a large scale as compared to other counties. Through it is widely recognized by new generations of architects and engineers, it is still very unpopular in the eastern region. Also, there is no market leader

so far with no success stories to tell. Recently, the United Kingdom has reorganized this technology to help reduce capital as well as a carbon footprint to 20% and started a project using this technology.

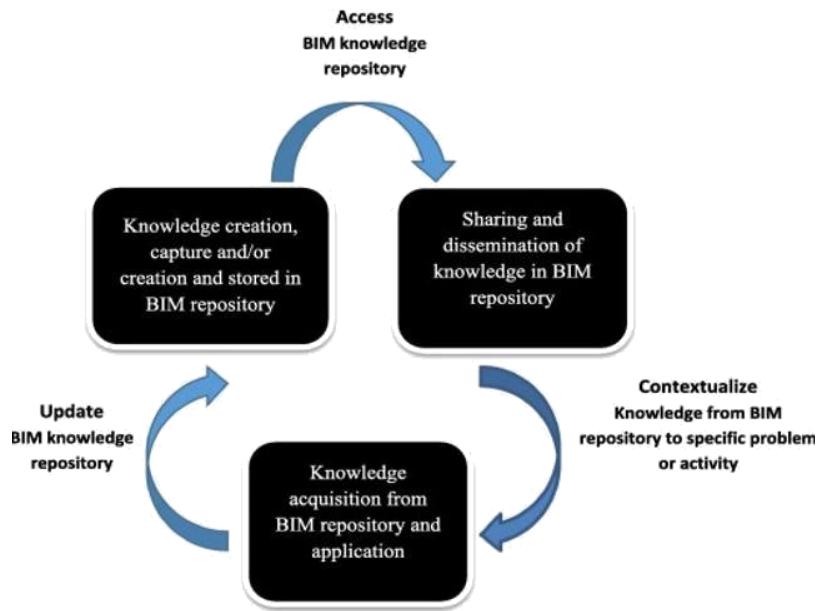


Figure 2. Building Information Modelling (BIM) cycle [30].

3.2. Mesh Moulding

This technique converts thermoplastic polymers to print structures in space using a large six-axis robot. Pressurized air is used at the nozzle for the pinpoint cooling and high level of control that helps to weave a framework efficiently and accurately. The concrete is poured over the framework. The thermoplastic polymers act as a reinforcement framework for the concrete later the concrete is trowelled by manual labour to smoothen the surface finish. Fig 3(a) shows the printing process and Figure 3(b) represents the mesh moulding used as reinforcement, and Figure 3(c) illustrates the different type arrays of mesh mould. Using this methodology, it is easier and faster to make a complex structure and is feasible for large-scale projects or structures. This technique uses interface and software because of which it accommodates design changes fast and concerning convectional method and mesh can be printed in different ways of arrays of forces according to the structure.

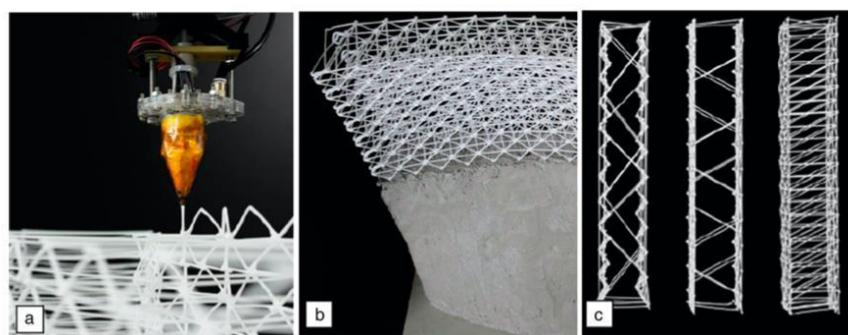


Figure 3. (a) Printing process (b) Mesh moulding used as reinforcement (c) Different type arrays of mesh mould [31,32].

4. Classification of 3D printing in the Construction Industry

4.1 Contour Crafting

Contour crafting has great potential in the construction business. This building technology which prints building in layers uses a computer-aided crane or gantry to build fast and efficient structures with substantially less manual labor. A concrete-like quick settling substance has also been used layer by layer which forms the wall of the building until it reaches its height of roof upon which a prefabricated roof is installed. The space for structural components, plumbing, wiring, and utilities are made side by side of the process of layering. Figure 4 shows the contour crafting process and the wall made up by the process of contour crafting.

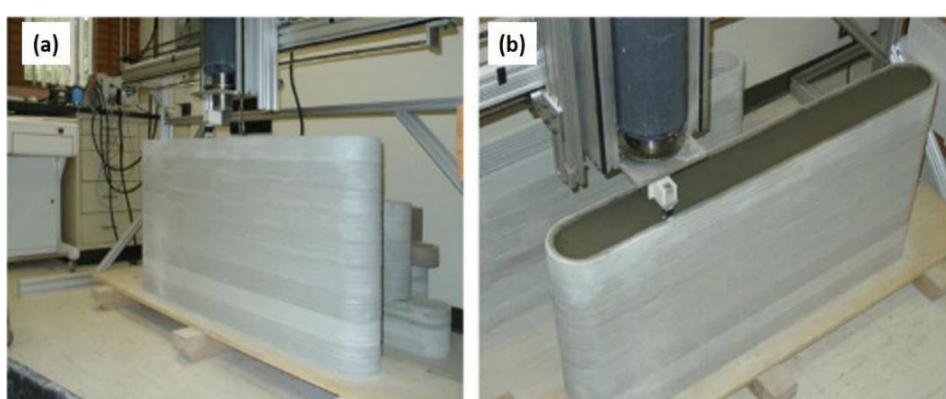


Figure 4. Contour crafting process (a) side view. (b) top view [33].

The process involves two trowels that help in the movement of the nozzle attached below the material feed barrel. The trowel help in the movement of the nozzle to create a very fine and accurate surface. The nozzle sprays a thick liquid concrete layer, one at a time so as to give it time to settle and harden and to support the weight of the new layer of concrete to be sprayed. It is different from other 3D printing methods as it uses two trowels to lay smooth and accurate layers. Using this technology, it is now possible to make a square foot of the wall in about 20 seconds, a whole room in an hour, and a 200sq meter single-story house in a day. This technology can be used to make homes for the economically weaker section and emergency shelters in case of a disaster. Fig 4(b) shows a wall made from contour crafting. Extensive research at NASA is going on to use this technology to make space colonies. Contour crafting also uses BMI technology to plan and execute the process more efficiently and smoothly.

4.2. Binder Jetting

Developed by MIT in 1993, binder jetting is also known as bed and inkjet or drop on power printing. It is a fast prototyping and additive manufacturing technology that uses digital inputs like CAD files to make an object. This 3D printing process involves the selective deposition of layers of the binder layers across a powder bed. Droplets are dropped from the binder onto a thin layer of powder material which is spread on top of a build tray. These 2D cross-sections layers are bound together to form a desirable object. Fig 5(a) shows the process of binder jetting, and Fig 5(b) depicts the Egg shape structure using the binder jetting technique.

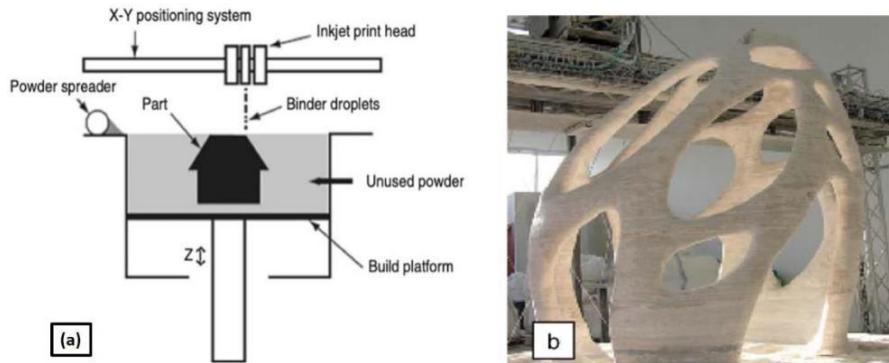


Figure 5. (a) Process of binder jetting (b) Egg shape structure using of binder jetting technique [34].

The cycle goes on repeating until the product is complete. During the process, unglued parts of the object can be removed from the bed using a vacuum which can be recycled to make new objects. The method is used to make complex geometrical designs with high resolution and a good surface finishing because of minimal distance layers. In the past, starch-based material with water as a binder was used but now a day's plaster-based calcium sulphate hemihydrate is used for making 3D objects with its limitation of using this technique for on-site applications and structures are highly weathered sensitive.

4.3. Concrete Printing

This technology was developed by Loughborough University, the United Kingdom similar to that of contour printing that involves the layering of concrete layers as per the digital input given to it, within the dimensions of a $5.4 \times 4.4 \times 5.4$ m gantry printer. A Four-axis gantry printer which has a printing dimension of 11m x 6m x 4m was developed by the Technical University of Eindhoven, Netherlands. In January 2015, Winsun built multiple houses, a five-story apartment block, and an 1100 m^2 mansion using concrete printing. Sometimes, reinforcements are done manually between the layers of concrete. The concrete printer can either be OVER-PRINTING or UNDER-PRINTING upon the flow of concrete. Fig 6 (a) represents the 4-axis gantry printer; Fig 6 (b) shows the 6-axis robotic printer, and Fig 6 (c) presented the crane printer.

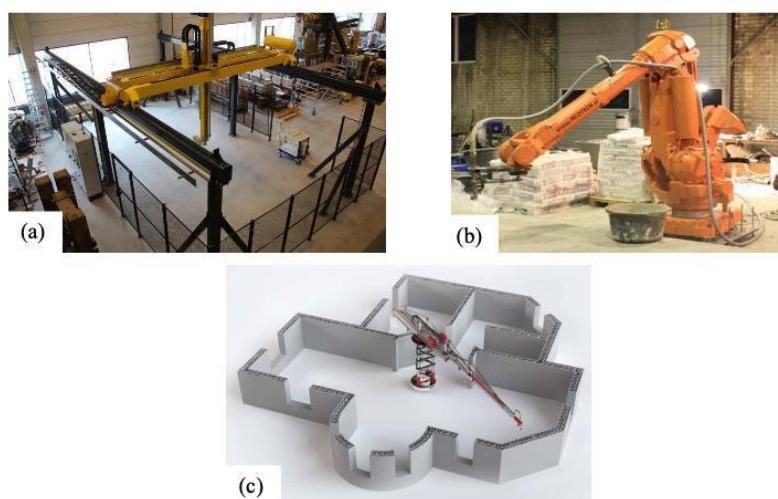


Figure 6. (a) 4 Axis gantry printer (b) 6 axis robotic printer (c) Crane printer [35].

These problems can be troubleshooted by fine-tuning the parameters of the machine or modifying the tool path according to the material used. A Russian company named ApisCor has developed a crane type concrete printing machine that can print area up to $58m^2$ with no height limitations. The dimensions of filament layers are dependent on the printer head. For example, a fixed nozzle that sprays the concrete at a slower speed will deposit more than the required material increasing its breadth and vice versa.

5. Discussion and future directions

3D printers in the construction industry can lead to efficient use of resources as it is based on additive manufacturing and the printers can be powered by solar energy making this technology eco-friendly, affordable, and efficient. 3D printers are the solution to the complex figures as we can easily design and print complex structures. While printing is cheap, the set-up cost of printers is very much high and some advanced printers can cost up to a million dollars. The 3D printers are in the developing stage and are not capable of printing the whole building wiring plumbing and windows frame are installed manually and also lack certification and safety laws as the technology is not so common and the certificates and laws are made on the traditional methods of construction. There is a whole population of daily wages and skilled workers based on the traditional method of construction, projects involving 3D printers replace them thus creating unemployment. Future directions involve metal 3D printing side, there is tremendous potential to replace traditional metal parts. Different companies have been working to develop next generation technologies to produce higher volume of parts with tight control on dimensional tolerances. Different state-of-the-art designing software's have been developed for additive manufacturing which ease the manufacturing of intricate parts. 3D printing has been evolving as an alternative solution for dental implants, crowns, and surgical guides. Smart 3D printing is another concept in which machine learning and sensors plays a significant role. In this way, 3D printing has huge potential in various fields such as mechanical, biomedical, aerospace, construction, and automotive industries.

6. Conclusion

Emerging as the key growing printing technology, 3D printing holds a promising future to construct cost and time-efficient not only housing solutions but also magnificent structures that challenge engineering. It is not only cost and time-efficient but also sustainable in terms of usage of natural resources. Numerous space research and development agencies such as Indian Space Research Organization and National Aeronautics and Space Administration etc. are looking forward to this technology to explore and seek shelters in space. However, traditional construction of a building is a lively hood for many people who are being used in this process of construction and using 3D printers in construction can cause unemployment of people in this sector.

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