

Additive Manufacturing in Civil Engineering



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Submission: July 03, 2017; **Published:** August 04, 2017

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Abstract

Additive Manufacturing (AM) is well-established technology in the field of mechanical engineering. It is widely appreciated due to its functioning and seamless transformation of the virtual model into a physical prototype. Utilizing the benefits of AM in construction technology can aid in reducing the project duration. Some AM process for building construction has been developed, but they are in the very initial stage. The design of deposition mechanism and development of suitable material for AM are the two major research gaps in this area.

Keywords: Civil engineering; Additive manufacturing; Rapid prototyping; 3D-Printing; Building construction

Introduction

Research in additive manufacturing is going on since last three [1,2] decades. Researchers have been developed different materials [3], tool path [4] and methods of AM. Initially, AM was used for fabrication of prototypes [5-10], but now functional machine parts [11,12] are also produced. Due to its ability to process different kinds of materials AM is now utilized in various other sectors like food printing, chocolate printing, glass and ceramic printing, bio printing, scaffold fabrication [7,13-17], etc. In the modern era of industrializations, there is need to fabricate custom design products of the short life cycle to transform the traditional design of products. Designers have the potential to design new products which are aesthetically and functionally better than existing one. However, some time subtractive manufacturing techniques were not able to fabricate part of complex geometry, which was a major gap between design and manufacturing conceptualization.

The fabrication of complex shape and geometry becomes possible with AM technique. In AM computer aided design (CAD) model is tessellated and then sliced into thin layers of same thickness [18-21]. In next step path for laser scanning or material, deposition is generated and stored in CLI file. And then CLI file will send to machine for part fabrication with very less human intervention. AM is well-established technology for metal and polymer part fabrication with high fabrication speed, repeatability, and accuracy. Available commercial systems of Rapid Prototyping (RP) can directly transform CAD files into physical models without difficulty [22]. This seamless technology

is now becoming major part of transforming the world and able to fabricate critical functioning parts like aerospace propulsion components [23].

Construction technologies are well developed in various aspects of customer satisfaction like design novelty, reliability, robustness, but the construction industry is still criticized for its time-consuming operations. Construction time will directly affect the cost and price of civil structure. Use of AM in civil and architectural engineering can lend wings the present construction scenario. AM in civil engineering can be utilized in the fabrication of building prototype, architectural building ornaments and for building construction. A review of existing works on the integration of AM and building construction along with the challenges and opportunity is discussed in this article.

AM for Building Construction

The principle of AM is to build the structures by adding material in layered manner that is why it also known as layered manufacturing. By construction technique AM can be divided into two groups i.e. binder jetting and material deposition methods [24].

Binder Jetting

This process was suggested by Dini [25], for structural construction. Binder jetting for construction is based on the principle of inkjet 3D printing [26]. In this technique, a liquid binder is sprayed over the thin film of material using a printing head. Head follows the contour as per the slice geometry. Over

hanged feature of structure can easily be a print by this method without using support structure. In 3D printing techniques surface finish and build time of the part depends on the slice height of material deposition. Large slice height will reduce build time but increase the surface roughness of inclined and freeform structure [27] and vice versa. In the case of binder jetting the slice, height depends on the binder penetration capability. Binder penetration capability is significantly low, that is why the slice height is also very less with respect to other AM process used for construction. Minimal slice (5mm) high of binder jetting provide comparatively good surface quality (Figure 1) [25].

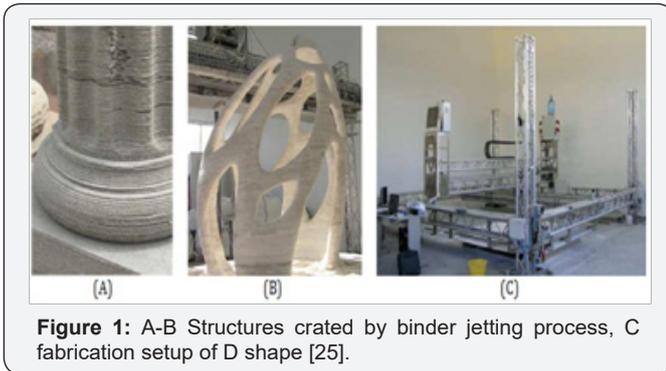


Figure 1: A-B Structures crated by binder jetting process, C fabrication setup of D shape [25].

Material Deposition Techniques

Material deposition techniques for construction are similar to fused deposition modeling (FDM) method. In material deposition technique, the building material deposited on successive layers, by following the nozzle path stored in CLI file. Deposited material must be able to get sintered to support the weight of consecutive layers. Several techniques based on MD principle has been developed for building construction i.e. stick dispenser, contour crafting, concrete printing, flow based fabrication, contour crafting, minibuilders and mesh mould [24].

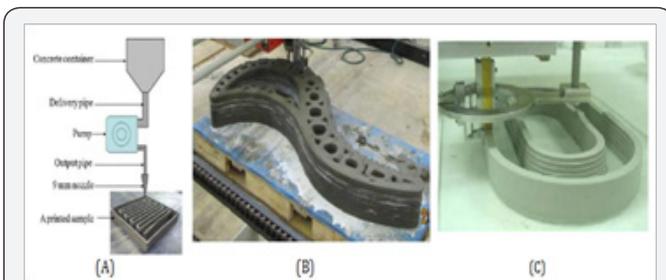


Figure 2: (A) Schematic of Material Dispenser of material deposition technique [28], (B) Material deposition Modelling process [28], (C) contour crafting process [29].

Material deposition system is supported by a gantry crane or by robotic arm which hold the material dispenser (Extruder) [28]. Material dispenser (MD) can move in X, Y and Z direction. The material was deposited as per the contour layer information in XY direction. Then after deposition of a layer, MD move upward as per the slice height and again deposit material for next contour. This process will continuously carry out until the

end of construction. Concrete printing and counter crafting are similar processes, and both use a gantry crane to support the MD. The only difference is the trowel which is connected with the MD, in the case of contour crafting. In CC the attached trowel significantly improve the surface finish and reduce build time by increasing the slice height [29] (Figure 2).

Flow-based fabrication (FBF), Minibuilders, Digital construction platform and mesh mould are used robot(s) to hold and move MD in three dimensions. FBF system extrudes water based polysaccharide gel along with natural composites using syringe based extrusion system. This extruder was attached as end effectors of 6 axes robotic arm. This technique can fabricate low weight structure with high stiffness and water resistivity [30] (Figure 3).

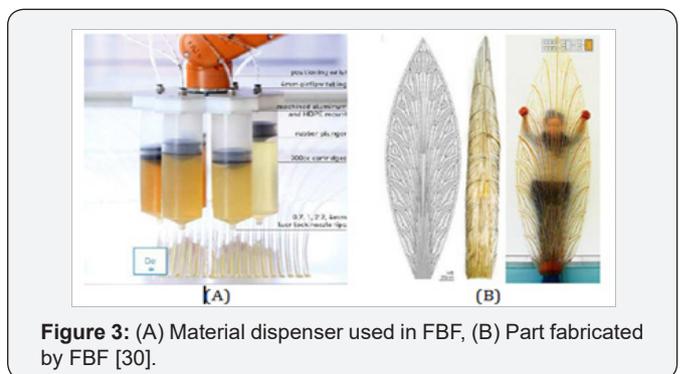


Figure 3: (A) Material dispenser used in FBF, (B) Part fabricated by FBF [30].

Minibuilders is resin deposition system developed by Nan [31]. MD was supported by simultaneously controlled three robotic systems. Foundation and grip robot deposit layers in the horizontal plane whereas vacuum robot moves in vertical direction by creating vacuum between its grippers and surface of structure [31]. Digital construction platform uses a six-axis KUKA robotic arm mounted to a 5-axis Altec hydraulic boom arm. The whole system was equipped with reference sensors and accelerometer for closed loop positioning system. Due to fast curing time and high insulation capacity, polyurethane foam was used as material (Figure 4) [32].

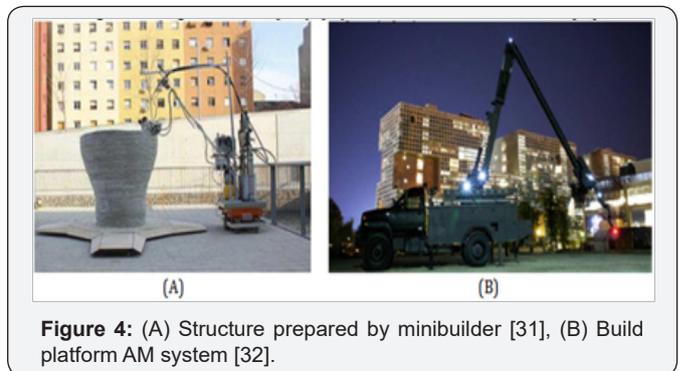


Figure 4: (A) Structure prepared by minibuilder [31], (B) Build platform AM system [32].

Mesh mould method was developed by Hack et al. [33]. Basically it is the extension of fused deposition modeling

process. It contains an extruder similar to FDM machine fitted on the six axes robotic arm. Mesh mould method is used to fabricate the three-dimensional mesh of acrylic butadiene styrene (ABS). These meshes are filled with concrete to get a rigid structure. The constructed structure was reinforced by ABS mesh [33]. Stick dispenser a handheld device and used for deposition of chopstick material composition. Glue coated chopsticks were deposited randomly. A camera and projector associated with stick dispenser was guide the operator to identify the next place for stick deposition. Fabricated structure doesn't have enough strength to bear any load, but it can be used to build complex structures (Figure 5) [34].

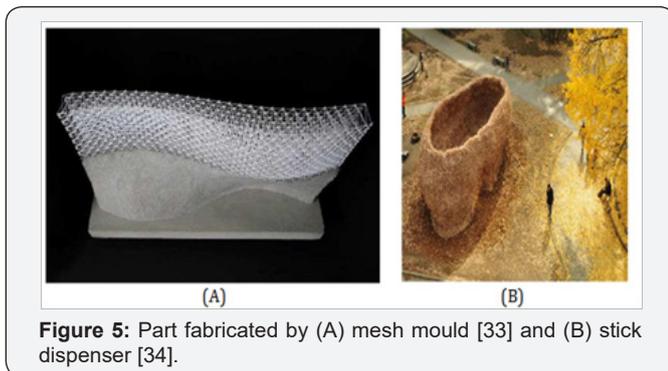


Figure 5: Part fabricated by (A) mesh mould [33] and (B) stick dispenser [34].

AM for Architectural Prototype and Product

Apart from construction technology AM is contributing to fabricate architectural prototypes and sculptures. Several commercial AM systems with adique accuracy and precision are available for prototype fabrication. CAD model of the building can be translated into a scaled prototype for demonstration of the building plan. The fabricated physical prototype will contain all complex and small design features as per the virtual model. Surface finish and build time of parts depending on the build orientation and slice height. Parts fabricated by AM required some post processing for support removal and to get the good surface finish. Similarly, fabrication of architectural sculptures and model is become possible by using rapid tooling. In direct rapid tooling, the mould of sculpture fabricated by AM is used for sculpture casting while in indirect rapid tooling the physical model of sculpture fabricated by AM is used as the pattern to make a mould for sculpture casting.

Conclusion

AM in highly appreciated technique for fabrication of small parts. However, in the case of building construction, it is still in developing phase. MD technique seems promising among all the other methods of construction. But suitable availability material is still a big challenge for researchers. Use of AM technique in building construction will enhance the productivity of construction industry, but before its commercial application, it required developments and experimental validation.

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DOI: [10.19080/CERJ.2017.01.555559](https://doi.org/10.19080/CERJ.2017.01.555559)

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