International Journal of Civil Engineering and Construction

E-ISSN: 2707-8337
P-ISSN: 2707-8329
IJCEC 2022; 1(1): 13-16
Received: 02-01-2022
Accepted: 06-02-2022

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Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing

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DOI: https://doi.org/10.22271/27078329.2022.v1.i1a.4

Abstract
Additive Manufacturing (AM) of raw materials like concrete, appeared as one of the most effective emerging technologies in the construction sector. The primary aim of this technology centralized over the minimization of supply chain difficulties, as the adoption of the technology made the construction industry autonomous in the area of building material production, directly by the aid of the digital models. The world population is exceedingly growing which exerts pressure on various sectors including construction.

The AM-based 3D printing of the Concrete utilized the designing on digital platforms, which developed the aspect of high customizability with infinite boundaries. Digital designing made the development of the structure possible that fulfilled the requirement of the situation or the client. The technology is bespoke without any additional resources or machinery. The study work will elaborate on the dimension of AM of concrete in the construction sector and illustrate the potential and challenges.

3D printing of the concrete is associated with the development of the structures and shapes, on-site construction leading towards the decentralization of manufacturing, followed by the construction and construction. 3D Printable concrete is one of the emerging trends in the construction sector. This trend developed on the core of Additive Manufacturing (AM), under which the concrete is designed by pumping through a nozzle connected to a "Gantry Grider" The movement of the nozzle is directed by the user or manufacturer, leading towards the development of the 3D Concrete model. The development of 3D Printable Concrete is a major potential and benefits discussed in the research studies about the AM of Concrete or 3D printable concrete.

Keywords: 3D concreting, construction, additive manufacturing, emerging technology

1. Introduction
Construction material is associated with a major role in the domain of construction because the material directly associates with the quality of the final product and the durability of the construction projects relies heavily upon the quality of the construction materials. The material used in the construction, signified the structural existence, hence the practicability of the constructional project critically associate with the raw material. In this context, the Additive Manufacturing (AM) of raw materials like concrete, appeared as one of the most effective emerging technology in the construction sector. The primary aim of this technology centralized over the minimization of supply chain difficulties, as the adoption of this technology made the construction sector autonomous in the area of building material production, directly by the aid of the digital models and the adoption of this digitalized model not required any complex framework or human influence and interventions (Paolini *et al*., 2019) [10]. In recent years, significant development observed in the context of additive manufacturing in the construction sector and many printing methods for the replacement of OPC blocks of cement and concrete adopted during practical construction project development. This practical application of additive manufacturing developed the ground for the future aspects of Additive Manufacturing (Liu *et al*., 2022) [6]. The current study work will elaborate on the dimension of AM of concrete in the construction sector and will illustrate the potential and challenges involved in 3D concrete printing.

2. Synopsis
2.1 3D Concrete Printing
The world population exceedingly growing which exerts pressure on various sectors including the construction sector. According to the United Nations, the population of the world is expected to reach the figure of 9.6 Billion by the year 2025 (Cao *et al*., 2022) [1]. This excessive increase in the population with a significant growth rate developed the need for more construction projects for accommodation in a quick time.

The supply chain network and the current trends following in the construction sector found it difficult with an old set of technologies to cater for the need of such a huge segment and the rise of population. This pressure guided the construction sector towards the adoption of rapid and new technologies that enhanced the rate of production in the sector accompanying the elements of enhanced rate of production with minimal wastage and proper resource utilization (Chen *et al*., 2021) [2]. 3D Printable concrete is one of the emerging trends in the construction sector, this trend developed on the core of Additive Manufacturing (AM), under which the concrete is designed by pumping through a nozzle connected to a "Gantry Grider" (Figure 1). The movement of the nozzle is directed by the user or manufacturer, leading towards the development of the 3D Concrete model, and large-scale adoption of this principle used in the development of houses and other constructional projects. The passing of the concrete from a narrow nozzle is associated with the minimal wastage of the raw materials while the wastage recorded doubles in the traditional constructional practices (Nair *et al*., 2020) [9]. There were some major potentials and benefits discussed in the research studies about the AM of Concrete or 3D printable concrete.

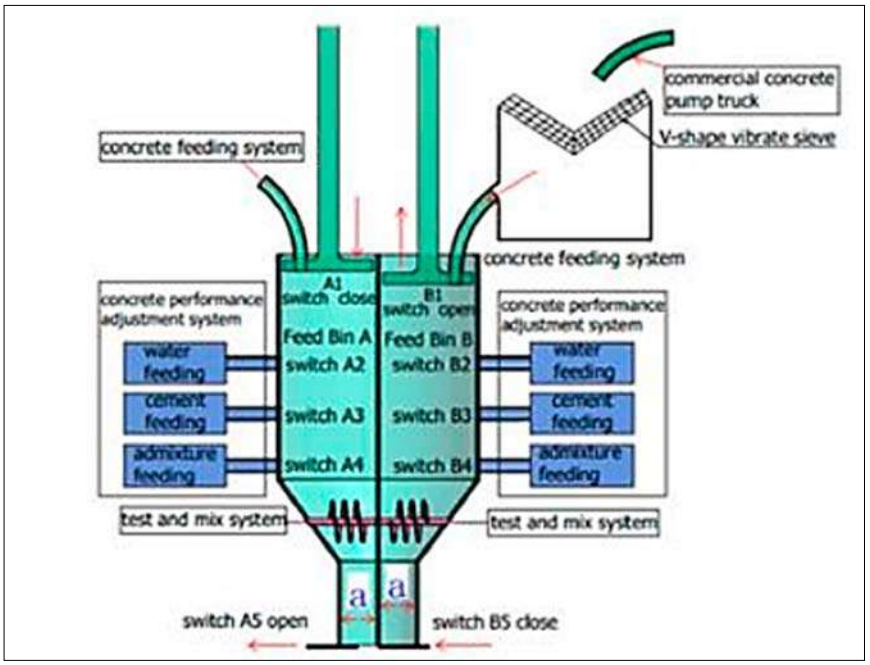

Fig 1: Double Aides Nozzle

2.2 Potentials of 3D Concrete Printing

There were certain benefits involved in the utilization of 3D Concrete Printing in the construction sector;

2.2.1 Design Freedom

Conventional concrete manufacturing is associated with the use of certain frames and molds that limit the involvement and range of shapes and designs in the concrete. However in the case of 3D Printable Concrete, there was an element of three-dimensional freedom is involved, under this core, the additive manufacturing of the concrete provided the development of complex yet attractive forms of concrete (Figure 2). The fact was reported the AM of concrete developed the complex lines and curves structures without any additional resources and costs (Vantyghem *et al*., 2018) [11]. Hence the element of design freedom is one of the major potentials associated with AM-based 3D printing of concrete.

Fig 2: Design Variations-AM based 3D concrete printing

2.2.2 Decentralization
The AM-based 3D printing of the concrete is associated with the development of the structures and shapes, on-site construction leading towards the decentralization of manufacturing, followed by designing and construction. This element also catered for the aspect of the supply chain, under which the complex structure was developed in the facilities and then transported to the construction site. The elimination of this transportation also asserted effects on the cost reduction in the aspect of logistics and supply chain network. Furthermore, this also made the entire design and fabrication connected, as the designing can be done in any part of the world and fabricated by the 3D printer at a completely different part (Zareiyan and Korjani, 2018) [12]. Hence, decentralization is also one of the key potentials of this technology.

2.2.3 Bespoke and Small Batch
The AM-based 3D printing of the Concrete utilized the designing on digital platforms, which developed the aspect of high customizability with infinite boundaries. This aspect of the technology made the trend effective perfectly bespoke and small batch production based on the involvement of 3D printing. Digital designing made the development of the structure possible that fulfilled the requirement of the situation or the client. The most major potential associated with this aspect, the technology is Bespoke without any additional resources or machinery (Jipa *et al*., 2019) [5]. Hence in the construction sector this potential of 3D concrete printing, made it very effective in the alignment with complex construction requirements.

2.2.4 Rapid and Fiscally Effective
The construction of any project small or huge, required a long duration of time and financial cores, as traditional construction required a complex set of tools and equipment followed by many other raw materials, besides this intensive labor is also required in this domain. The reports developed the fact that AM-based 3D printing of concrete is very cheap and rapid, as the 3D printers involved in it possessed the capacity to perform operations round the clock. Under this context, the fact was highlighted that the adoption of AM-based concrete 3D printing, served 50% cost reduction in the alignment with cost-cutting of labor charges (De Schutter *et al*., 2018) [3]. Thus the cost-effective and enhanced speed potential of 3D printing of concrete made it one of the valuable prospects for the future of the construction sector.

2.3 Challenges
Despite the effective utilization of this technology in the field of the construction sector, certain challenges are highlighted in the domain of AM-based concrete 3D Printing, as the technology is yet in the phase of development and very minimal core literature is available on it (Nair *et al*., 2020) [9]. Some of the major challenges are;

2.3.1 Pumpability
Concrete Pumpability is referred to as "its ability to flow through a pipe using a pump and also the ability of confined concrete to flow under pressure while maintaining its initial properties", and the Pumpability index served as its measure. The 3D concrete printing involved the element of low slump-flow values that lead towards the lower Pumpability index tending the cracks in the alignment of having rough texture on the surface. Moreover, in the case of higher flow values, congestion occurred leading towards poor printable properties (Mohan *et al*., 2020) [7]. Hence the creation of a balance of the Pumpability index is one of the major challenges in the adoption of this technology.

2.3.2 Buildability
Buildability is also a major prospect of concrete and is referred to as the "concrete layer's ability to hold the successive layers above it without subsiding. The concrete must also have a certain compressive strength". The fact was reported that there was relatively low strength and stiffness appeared in the printed filament of concrete arise Buildability problems, and the cavity developed over a course of time (Muthukrishnan *et al*., 2021) [8]. Thus this is one of the most problematic challenges that needed to be catered to in the aspect of AM-based 3D printing of Concrete.

2.3.3 Extrudability
In the concrete element, extrusion is one of the vital processes and defined as "a process in which a rigid paste is forced to pass through a rigid die with a high shear, resulting in a liquid behavior". The size of the nozzle involved asserted the influence on Extrudability, as the larger diameter of the nozzle influenced the strength of the concrete arising the problems of Buildability while the smaller nozzle diameter messed with the separation of components involved in concrete (Jayathilakage *et al*., 2020) [4]. Thus for adequate Extrudability, the nozzle diameter needed to be very precise, and it is one of the challenging aspects of the technological trend in the construction sector.

3. Summary
The review of the articles in the domain of Additive manufacturing (AM) of construction material established the importance of this technology on future grounds. This study review highlighted the fact that the pressure of excessive population directed the sector towards the adoption of this technological advancement. There were certain potential benefits like; Decentralization, Cost-Effectiveness, Design Freedom and Bespoke while some of the major challenges like Buildability, Extrudability and Pumpability revolved in the space of AM-based concrete 3D printing. Thus the future of the construction sector, rely upon the hand of technologies like Artificial Manufacturing.

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