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A review of largescale 3DCP: Material characteristics, mix design, printing process, and reinforcement strategies

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ABSTRACT

3D concrete printing (3DCP) is the additive manufacturing (AM) with the use of cementitious materials. It is a layer-by-layer new construction method which can provide design flexibility, minimize material waste, improve sustainability, decrease construction period, reduce labor requirements, increase site safety and significantly reduce the overall costs. In past 10 years, significant improvements have been made in developing concrete printers to transfer 3DCP from lab-scale to the real construction-scale. In this paper, the existing techniques that have been applied in construction of largescale 3DCP are presented. The recent literature is explored for new mix characteristics, printing process parameters, insight relations of flowability-extrudability-buildability, the hardened and mechanical properties of extrusion-based 3DPC. In addition, this paper investigated the different applied techniques for reinforcing of 3DPC structures in details, because to date, the largest challenge that faced 3DPC structures is the lack of appropriate methods of reinforcement. Overall, this work presents a comprehensive systematic review of 330 most recent publications in this field, with the focus on the last 3 years.

1. Introduction

Automation and digitalization can significantly contribute in upgrading construction methods, creating new jobs, increases in productivity, and compensate for unskilled labors. Largescale AM with the use of cementitious materials, usually referred as 3DCP, belongs to the new promising concrete construction technology for implementing digitally designed data from planning phase, to the actual automated construction on the project sites [1–5]. Generally, concrete shaping is done with formworks and shutters that are designed to support the fresh concrete pressure. The shuttering cost is usually about 50% of the total construction cost, and it could be 80–90% when the formwork is not standardized [6–8]. Over the past two decades innovative and novel techniques and various materials have been attempted for shaping of the cast concrete, and for reducing the need of the conventional formworks [9–12]. 3DCP have the potential to speed-up productivity and efficiency of construction from months to days and from days to hours, it enables a significant customization in design, without increase of construction costs. The combined performance of robotics and 3DP permits to reduce the waste, the material consumption by 30–60%, and boost the construction by 50–80% [13–15]. To 3D print a concrete structure, a digital model is created firstly either with a CAD like modeling software or 3D scanning of the object, after that a built-in algorithm can cut the designed model into 2D slices. Finally, a digitally controlled 3D printer builds the structures slice-by-slice based on the designed prototype [16–19]. With this technology, it is possible to rapidly construct very complex structures, or functionally graded structures with single or multiple materials layer-by-layer. 3DCP has been developed with the collaboration of software, structural, architectural, and mechanical engineering, with the material science [20–24].

Largescale cement-based 3DCP has rapidly developed in the last decade. The most common 3DCP technique is material extrusion [25–28], even though selective powder binding method have also been attempted [29–33]. Recently, the extrusion method has dominated 3DCP applications, in which, typically a well-designed cementitious mixture is pumped through a digitally controlled nozzle, mounted on a robotic arm. Based on the prototype, the printing head moves to extrude various concrete circular or rectangular filaments depending on the nozzle shape, with the printing speed of 50–500 mm/s. The mixture typically contains high ratio of powders, admixtures, with 2–3 mm aggregates, although recently even coarser aggregates have been attempted. Fig. 1 offers some examples of the 3D printed elements and

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