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A Novel of 3D Printer Types and Sizes in the Construction Industry

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This study provides a comprehensive review of 3D printer types and sizes utilized in the construction industry, examining their applications, capabilities, and impacts on modern construction processes. With 3D printing revolutionizing construction through enhanced design flexibility, reduced material waste, and labor efficiency, it is essential to understand the distinct roles of different printer types and scales. The construction sector has begun adopting various printer types, such as robotic arms (stationary and mobile robotic arms) and gantry-based systems. Each type offers distinct benefits for specific construction needs, from creating detailed prototypes and specialized components to printing structural elements and entire buildings. Small-scale 3D printers provide greater precision and flexibility, are suitable for intricate designs and component-level production, and are often used in rapid prototyping or for custom architectural details. In contrast, large-scale 3D printers are primarily used for constructing full-size structures, utilizing substantial material volumes to achieve stability and durability. These printers, often fixed or semi-mobile, enable efficient production of large sections but may lack the fine detail achievable by smaller systems. This review aims to provide a comprehensive understanding of these 3D printer types and sizes, assessing their efficiency in construction for both industrial and institutional use.

Key Words: 3D printing, 3D printers, Robotic arm, Gantry, Construction.

Introduction

Although knowledge and technology have advanced, construction techniques have mostly stayed the same for a long time. This has led to a high environmental impact, continued dependence on labor during periods of labor shortages, and substantial time and financial investments. Consequently, residential housing costs have risen to meet the demands of a growing population (Malaeb et al. 2019).

As additive manufacturing (AM) technology advances in several sectors, its utilization is also simultaneously growing. The ideas that allowed engineers to develop contemporary 3D printing technology are one of the main factors contributing to this technology's growing accessibility in the construction industry. Recent developments and usage of technology in construction have shown evidence to reduce the cost of 3D printers, making them more widely used in places like institutions, homes, hospitals, and labs (Ko, C., 2022).

The adoption of functional architecture and pre-assembly, along with the design and fabrication of complex geometries, are among the significant advantages of 3D printing. These benefits include enhanced productivity, reduced labor requirements, improved labor safety, sustainability, and energy efficiency, and a decrease in construction and demolition waste (Robayo-Salazar et al. 2023).

The emergence of 3D printing and additive manufacturing (AM) has introduced innovative and rapid production methods in the construction industry (Strohle et al, 2023). Up until recently, the aerospace and biomedical industries were the only ones using additive manufacturing (AM) processes. This was mainly because the fundamental materials required for these processes were quite expensive (Gosselin et al., 2016).

Large-scale 3D printing has developed over the past ten years in industries including design, building, and architecture, employing a variety of materials like polymers, metals, and cementitious materials (Gosselin et al., 2016). In 2017 Tay's team mentioned that full-scale building components printed using 3D technology are still in infancy, but they are gaining popularity as an alternative to traditional construction techniques (Tay et al., 2017).

Although previously limited to high-value industries due to their cost, advancements in technology have made it increasingly feasible to utilize additive manufacturing techniques in design, building, and architecture using a diverse range of materials at a more affordable price point. This has presented numerous opportunities for cost-effective implementation of technology in the construction sector (Strohle et al, 2023).

There are two common types of printers in the construction industry: Robotic arms and Gantry Robotic systems. Both are extrusion-based printing systems that use a pump-pipe-nozzle system to deposit the material layer by layer. In this paper, we are focusing on using these two types in the construction field for both institutional and industrial purposes. Also, we are discussing their sizes in terms of small-scale and large-scale.

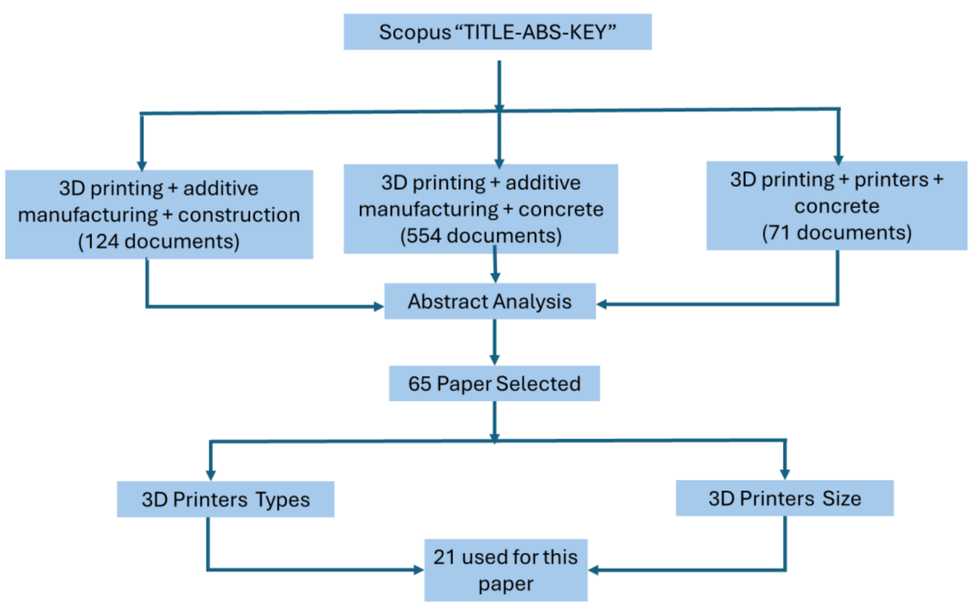

Figure 1. A schematic of the data selection methodology

Methodology

This study aims to comprehensively assess the latest advancements in 3D printing equipment within the construction field. A systematic search was conducted on Scopus using the TITLE-ABS-KEY function, employing various permutations and combinations of keywords, including “3D printing,” “concrete,” “additive manufacturing,” “printers,” and “construction.” A total of 65 relevant papers were selected depending on the abstract analysis, then 21 papers were identified and categorized into groups, including review papers and papers discussing printer types and sizes, as shown in Figure 1.

Literature Review

Types of Printers Technique in Construction

Robotic Arm System

A robotic arm system is a robotic arm equipped with a concrete extrusion nozzle, which deposits material layer by layer to create a structure. It is flexible and can move in multi-axes freely (Puzatova et al. 2022) and (Lim et al. 2020). Figure 2 shows a robotic arm printing system. Robotic concrete pouring in accordance with a generated 3D model is known as 3D printing in concrete (Malaeb et al, 2019). It is used to print structural elements since it is limited to the length of the arm.

Figure 2. The robotic arm of 3D concrete printing, created by AI

To overcome the limitations of the robotic arm and to address the need for printing large-scale elements and on-site printing of whole structures, the idea of a 3D crane printer system or giant robotic arm emerged. Figure 3 shows a 3D crane printer/giant robotic arm printing system.

Mechtcherine et al. investigated how the CONPrint3D printer could allow for the on-site fabrication of large-scale concrete structures. CONPrint3D recommends transforming current devices—like portable concrete pumps—into 3D printers, the concrete conveyor is affixed to the vehicle, and the boom functions as a robotic arm guided by the printing algorithm [Mechtcherine et al. 2019]. While other companies like ICON improved the robotic arm by increasing the length of the arm. That has an impact on the industry since it helps to print multi-story structures.

Figure 3. Giant Robotic arm or Crane system 3D printer with concrete conveyor, created by AI

Gantry System

A gantry printer is a large, frame-based robotic structure that supports and guides the movement of the printing nozzle across multiple axes (X, Y, and Z) to deposit concrete layer by layer, as shown in Figure 4.

This system provides precise control, stability, and scalability, enabling the construction of large structures. It is commonly used for printing building components. The con of this system is limited by the fixed size of the gantry frame, which represents the maximum dimensions of the printed structure [Xiao et al, 2021].

The technique of fabricating an object or component from a 3D computer-aided design (CAD) file using a layer-by-layer method is known as additive manufacturing, according to the ASTM Committee F42. The benefits of self-compacting concrete and spray concrete are merged in 3D printed concrete, a special mixture of concrete that can be used for construction solely by using a 3D printer and does not require the conventional process of erecting formworks and vibrating the concrete. The capability of 3D printing to create a variety of forms without the use of formwork is one of its key selling advantages. This has several benefits over traditional building methods (Zhang et al, 2019).

The development of 3D-printed concrete requires a multidisciplinary effort involving materials science, robotics, computing, architecture, and design. The building is finished once all the printing layers have been assembled (Zhang et al, 2019). In addition to minimizing construction times and waste generation, this makes it possible to print components with complicated geometries without the need for molds and with little work (Khan et al, 2020). Sahin & Aghabaglou explain in brief the process of 3D printing in concrete. The printing procedure for 3DPC mixes mainly entails three steps: (i) G Code development followed by, (ii) material mixture preparation and transportation to the printer, and the final stage of (iii) printing. A 3D CAD file is used to construct a 3D model initially. From the prepared model, a file in STL (Stereolithography), a typical format for the 3D printing industry, is produced. Any slicing program is then used to process the 3D model and generate the G Code. Transferring the resulting G code to the memory completes model construction. The printing process's next phase requires combining cementitious ingredients. The printing is done using the nozzle system while the materials are being prepared (Şahin et al, 2022 & Wang et al, 2021). Incorporating design principles inspired by nature into 3D concrete printing technology can enhance the structural properties of finished products, reduce material consumption, and open possibilities for innovative architectural forms. While 3D printing still faces certain material and procedural limitations, ongoing research is pushing the boundaries to unlock its full potential. By applying biomimicry and bio-inspired approaches, 3D concrete printing has the potential to create custom structures with improved mechanical properties, greater sustainability, and reduced human intervention, establishing it as an exciting advancement in construction methods. (du Plessis et al., 2021).

Figure 4. Gantry system of 3D concrete printer, created by AI

Although there are other kinds of building techniques utilized for 3DCP, extrusion-based printing is the most often employed method. Similarly, Fused Deposition Melting (FDM) or Inkjet printing techniques use a pump-pipe-nozzle system as well. The type of printed material is where 3DCP and inkjet or FDM differ most. In extrusion-based printing, a layer of carefully sliced shape is created by selectively depositing the significant material (Khan, Shoukat Alim & Koç, 2022).

These two printing techniques were among the first few that laid the groundwork for understanding 3D printing and its potential applications in the building sector. Modern 3D printing has evolved over the years, and it is anticipated to combine technology with more traditional construction techniques eventually. Further, we'll look more closely at contemporary 3D printing technologies that are scalable in size and reasonably simple to use. Following that are some current instances of 3D printing being used in building on various platforms.

Types of Printers Sizes in Construction

In addition to the two printer technologies, this research has briefly classified printers according to the size of printed components. Nowadays, several researchers are doing printer tests using both large-scale printing and small-scale 3DCP (Gosselin et al., 2016).

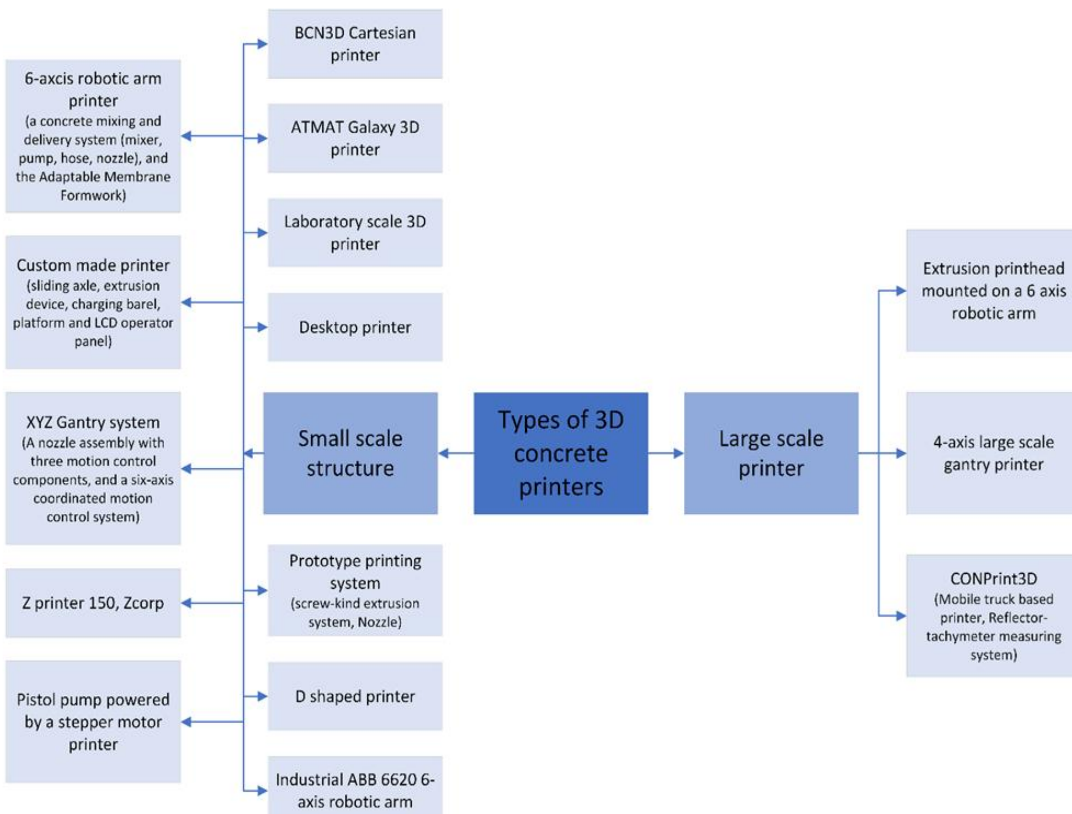

Figure 5. Types of 3D concrete printers for small- and large-scale printing

Currently, there are two different kinds of printer sizes being utilized for 3D printing in concrete: small-scale printers and large-scale printers. Each category's available printers are depicted in Figure 5. Researchers employ a variety of small-scale 3D printers to test the printability of concrete mixes. It has been thoroughly explored how to run these printers, which are mostly extrusion-based. Print volumes

for small-scale printers typically range from a few cubic centimeters to several cubic meters, making them ideal for printing little to medium-sized things. Small-scale printers are frequently used for research, training, quick prototyping, and finding optimum mixtures. These printers are reasonably priced, portable, and even adjustable for use in laboratories because of their small size.
Large-scale printers, on the other hand, are made to print considerably larger items, such as complete structures or infrastructure parts. These printers generally have a volume range of several hundred to several thousand cubic meters for the items they can produce. Large-scale printers are often more expensive than small-scale printers and need a lot more room to operate (Alonso-Canon, et al., 2022 & Robayo-Salazar et al., 2023).

Table 1. Types of small- and large-scale 3D concrete printer

No.	3D Concrete Printer	Filament sizes (F) / Nozzle sizes (N)
	Small Scale Printer	
1	Desktop printer	35mm, 5mm (F)
2	Prototype printer	25mm Dia (N)
3	Laboratory-scale 3D printer	20mm (N)
4	3DCP system – sliding axle, extrusion device, charging barrel, platform & LCD operator panel	25mm (F)
5	A piston pump powered by a stepper motor	30 x 30 mm (N)
6	BCN3D Cartesian printer	3-6mm (F)
7	(ATMAT, Kraków, Poland)	15mm (N)
8	Zprinter® 150, Z-Corp, USA	0.1-1000/ um
	Large Scale Printer	
9	XYZ Gantry Printer	25mm Dia (N)
10	Extrusion mounted on robotic arm 6 axis	
11	Gantry printer	10cm (N), 15mm(F), 20cm Dia (F)
12	CONPrint3D, Mobile truck-based printer, Reflector-tachymeter measuring system	151 × 50 mm2 (F)
13	6-axis robotic arm, mixer & delivery system (mixer, pump, hose, nozzle), & the Adaptable Membrane Formwork	10 mm (F)
14	A constant displacement type screw pump	50 x 20 mm (N)
15	D-shape printer	9mm (F)

For producing large-scale 3D-printed structures, Gosselin et al. studied the use of a 6-axis robot arm with an extrusion printer mounted on it. The related 3D printing method is based on a Fused Deposition Melting methodology and involves an extrusion printhead coupled to a 6-axis robotic arm to deposit material layer by layer. Later, the mechanical qualities, like the strength of 3D printed structures, are evaluated (Gosselin et al., 2016). Panda & Tan used a 4-axis large-scale gantry printer to evaluate the effects of adding micro silica (SF) to HVFA mortar, which is suitable for concrete printed applications (Panda et al, 2019).

The study team's six-axis coordinated motion control system, or "3D printer," was tested by Alonso Canon et al. The system can manufacture a specimen with a 77-centimeter wall and potentially different structural forms by moving on all three axes (Alonso-Canon et al., 2022). One of the most important parts of the printer, the printing nozzle, was created to enhance the concrete extrusion procedure. Robayo-Salazar et al. evaluated printability according to the following standards: Extrudability is the first need, followed by buildability of the layered printed shape using a desktop printer (Robayo-Salazar et al., 2023). To address the needs of the construction sector, the evaluation looks at the current cutting-edge technology and introduces the CONPrint3D idea created at the TU Dresden for on-site, monolithic 3D printing. The CONPrint3D idea has been particularly created to accommodate the needs and restrictions of construction practice, adhere to accepted architectural standards and design guidelines, and consider existing concrete classes and financial restraints (Mechtcherine et al., 2019).

Table 1 outlines the diverse printers featured in the examined papers, categorizing them based on their scale, as large scale and small scale, and the size of their nozzles (N) and/or filaments (F). This presentation offers a comprehensive insight into the dimensions & components characterizing each printer.

Small-scale printers are used for printing smaller components, prototypes, or complicated architectural designs. Large-scale printers are used for printing full-size structural elements, such as walls, columns, or even entire buildings.

Conclusion

Despite extensive research and progress in the field of 3D concrete printing, much work is needed to improve the accuracy, capability, and printability of the printer equipment and the materials to fit this need.

This study is an analytical review of two main types of 3D printing technologies: robotic arms and gantry systems. Both systems are important and essential in advancing 3D printing in construction, with robotic arms providing versatility for more complicated and innovative designs, and gantry systems prioritizing scale and stability.

Robotic arm systems use a multi-axis robotic arm with an attached extrusion nozzle, offering greater flexibility and range of motion for printing complex, curved, or intricate designs. These systems are adaptable to confined or irregular spaces but are limited by the reach of the arm, which constrains the structure size in a single setup.

The innovation of mobile robotic arms overcame many limitations of stationary robotic arms since they can move around the construction site, such as printing larger structures in one setup, improving efficiency, and reducing downtime associated with repositioning stationary equipment.

Then, crane systems or giant robotic arms were developed to ease using 3D printers for multi-story buildings since they can reach higher levels and farther distances without the need to move the equipment. That helps in saving re-setup time as well.

Gantry systems consist of a fixed or semi-fixed frame with horizontal and vertical beams, providing stability and precision by guiding the nozzle across the X, Y, and Z axes. They are ideal for large-scale construction, like walls or foundations, but are limited by the size of the frame, which restricts the maximum dimensions of the printed structure. Large-area structures and multistory structures are achievable with large frames.

Also, in this article, we classified these two printer types depending on their size, small scale, and large scale, according to the researchers who used them in their papers. Small-scale and large-scale 3D printers in construction serve different purposes and offer distinct advantages and limitations based on the size and complexity of the project.

Any type of robotic arm or gantry can be used in large-scale or small-scale projects. Depending on the size of the project, if small or medium size, the cost of large-scale printers is higher than that of small-scale printers. While for big projects, large-scale printers may save more cost by reducing the relocation and setup times of smaller-scale printers. Small-scale printers excel in detail-oriented, customizable, and experimental projects. Large-scale printers are ideal for projects requiring significant durability, size, and stability.

Many institutes and companies are still experimenting with discovering the optimal technique and mixtures for constructing stable, durable 3D-printed structures. It is crucial to save costs by embracing 3D concrete printing in the construction industry and establishing standardized practices.

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