

From Concept to Reality: Transforming Architectural Visions with 3D Printed Concrete

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Abstract: As global societies face profound environmental and economic challenges, the construction sector is focusing on the integration of smart technologies and the conceptualization of resilient infrastructures. Currently, low-carbon 3D printing concrete technology stands as a key innovation in the field of concrete, promising to reduce carbon emissions and enhance labor productivity. This study aims to explore the feasibility of using low-carbon 3D printing concrete technology as a channel for promoting intelligent and sustainable development in civil engineering. This paper will introduce 3D printing concrete from the aspects of printing methods, production materials, and mechanical properties. Additionally, it will discuss the current and future applications of 3D printing concrete and explore its potential use in building a smart and resilient future.

Keywords: Green-sustainable development, 3D printing concrete technology, Construction practices, Low carbon.

1. Introduction

The construction sector is responsible for nearly 40 percent of solid waste, 45 percent of energy consumption, 12 percent of water consumption and 37 percent of greenhouse gas emissions. With the continuous reduction of resources and the increasing environmental damage, the innovation of the construction industry is inevitable. Compared to traditional concrete technologies, 3D printing concrete technology has obvious advantages in terms of higher construction efficiency, lower labour costs and less environmental pollution.

Currently, the civil engineering industry is exploring the economic feasibility and environmental sustainability of applying 3D printing concrete technology to engineering practices. The prevailing methods for producing 3D printed concrete in society today are extrusion processes and powder-based techniques. The raw materials used in 3D printed concrete are innovative, as they can recycle a significant amount of construction waste and incorporate different chemicals to enhance the concrete's properties. The improvement and reinforcement of the mechanical properties of concrete are also key areas of ongoing research and exploration.

This study will explore the advantages of 3D printed concrete in building engineering applications from three perspectives: printing methods, raw materials, and mechanical properties.

2. 3D Printing Methods

To produce concrete through 3D printing, there are a variety of technologies that have been applied to it, such as the extrusion process, contour crafting, and powder-based methods. Extrusion process is most widely used due to its advantages of large-scale production and relatively fast production rates. The method of constructing the entire structure using extrusion is to extrude the material layer by layer using a hopper system with various nozzle sizes and shapes. Civil engineers usually use a gantry-type extrusion-based 3D printer, which was equipped with an auger extruder with a 20mm circular nozzle. (see Fig. 1). These specific applications of the extrusion method are instructive for future

research on improving methods of 3D printing concrete technology.

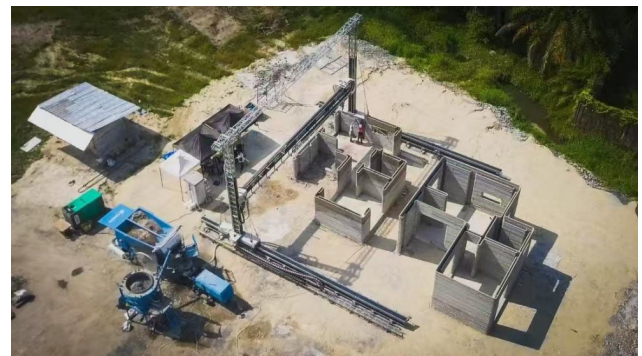


Figure 1. Extrusion based 3D printer



Figure 2. The robotic arm set up for printing

Powder 3D printing technology was initially developed by Sachs et al. at the Massachusetts Institute of Technology (MIT) in 1993. This technology uses a combination of printing powder and a binder (referred to as "ink"), where the "ink" is selectively sprayed layer by layer onto the powder surface to bond it, thus automatically constructing the digital model and designing complex three-dimensional structures. Compared to contour crafting and concrete printing techniques, powder 3D printing technology offers higher forming precision, making it suitable for printing complex 3D structures and

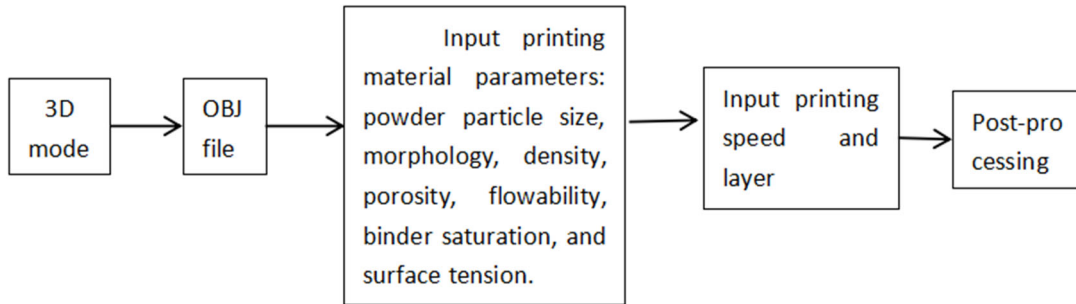


Figure 3. Powder-based 3D concrete printing process.

3. The Raw Materials for 3D Printing Concrete

According to the working characteristics of extrusion method, sufficient fluidity of 3D printing concrete raw material is needed to effectively squeeze and form qualified cement products to meet the process requirements. To address practical application difficulties, exploring suitable 3D printing raw materials is crucial for 3D concrete technology. Among them, there is an alkali-activated materials(AAMs), also called geopolymers, which can be used to improve the strength, fire resistance, salt resistance, acid resistance and other properties of concrete, and at the same time, geopolymers can also reduce carbon dioxide emissions in the production of concrete. Many factors can affect the

performance of geopolymers, such as temperature, humidity, mixing method. and the geometric and physical properties of the material itself. The properties of 3D printing materials will directly affect the printing results, the properties of concrete, and their applications. Geopolymers are based on natural materials or waste products as the primary source. One of the advantages of this 3D printed concrete mixture is to apply recycled and waste materials to the raw materials. And the main raw materials include fly ash, silica fume, ground granulated blast furnace slag, and metakaolin. Geopolymers synthesis method also has a certain experimental basis, it will be solid aluminosilicate material and alkali activator mixed with a certain temperature treatment, in the addition of specific additives, and water, the reaction can generate the geopolymers (see Fig.4).

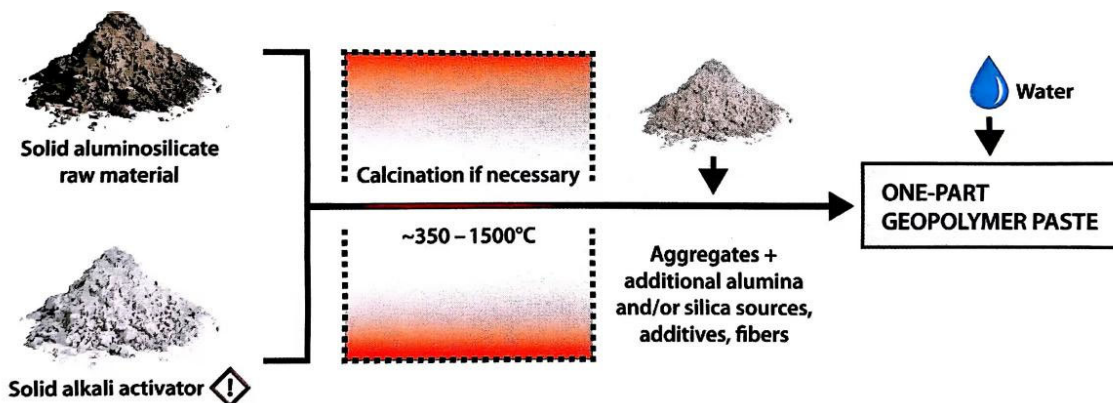


Figure 4. The general procedure of one-part geopolymer preparation.

With the rapid development of the construction industry, the treatment of mass-produced solid waste is an important problem to overcome. Landfills have long been used as an important means of solving solid waste problems effectively. However, as the land resources are decreasing and environmental pollution is becoming more and more serious. The landfill method may cause great pollution to the surrounding land and groundwater. However, the 3D printing concrete technology can regenerate part of the waste into raw materials for processing concrete, for example, the use of slag, fly ash, and recycled aggregates to replace some of the fresh raw material, which reduces the need for fresh raw materials and reduces the damage to the environment.

4. 3D Printing Concrete Mechanical Properties

Many mechanical properties of 3D printed concrete, such

as compressive strength, tensile strength, and impact resistance, are of great concern to civil engineers and crucial for engineering applications, which are also an important basis for building structural design. 3D printed concrete primarily uses concrete and does not require formwork. Its design and construction methods are significantly different from conventional concrete and cannot simply apply traditional concrete structures directly. There is a need to seek construction methods suitable for the process. To ensure the stability of the printed layers and to prevent deformation, concrete with low slump or zero slump is generally used for printing. In addition to printability, consideration must also be given to mechanical properties and durability. It is necessary to effectively control the adhesion, flowability, formability, curing time, and printing strength of the printed layers. Figure 5 shows the mechanical properties required for 3D printed concrete.

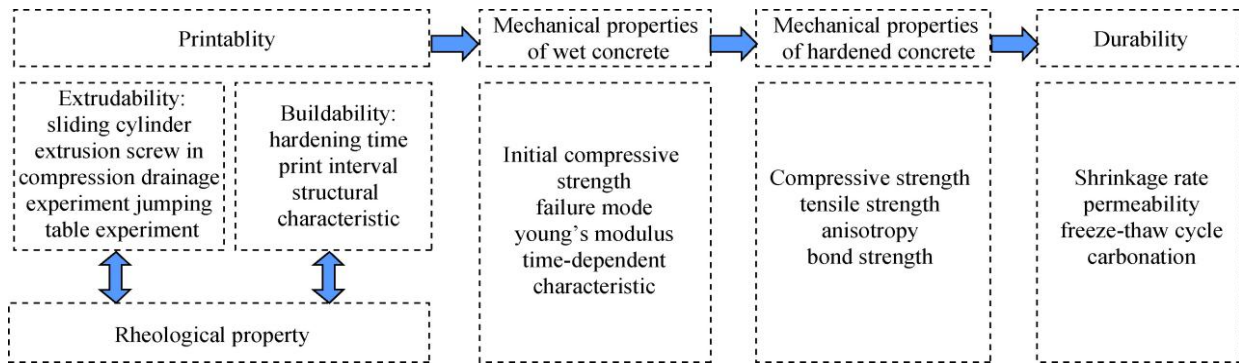


Figure 5. Mechanical properties required for 3D printed concrete

Various social studies at present found that the connection strength between 3D printing layers is of great significance for the entire structure. Some studies have shown that changes in temperature and settling time during printing on different layers can affect the bonding strength between the layers of 3D printing concrete. Changing the temperature, time and other conditions of the printing process to find the most effective printing method is one of the key points. Adding some chemical components such as fibres can also affect the experimental results. Taking into account various factors comprehensively and improving the mechanical properties of concrete is a future research direction.

5. Applications

As 3D printing technology matures, the construction engineering field is increasingly using this technology. In recent years, many 3D printing technologies have played a huge role in the construction field in China, such as the

Shenzhen Bao'an 3D Printing Park, the east gate of Nanjing Happy Valley theme Park. 3D printing reduces the time required for construction and the cost of construction, and makes a great contribution to the sustainable development of the environment.

The Shenzhen Bao'an 3D Printing Park is a model of innovative application in digital design and 3D printing technology, created jointly by Professor Xu Weiguo's team from Tsinghua University and China Metallurgical Group Corporation Twenty. This project is not only a key part of the intelligent urban construction of Bao'an District but also a breakthrough in the field of 3D printing technology in architecture. The core of the plaza lies in the introduction of robotic 3D printing concrete technology, an innovative construction method that integrates digital design and automated control systems. Through precise digital models and advanced printing equipment, special concrete materials are printed layer by layer, forming structures that are both practical and aesthetically pleasing.



Figure 6. The Shenzhen Bao'an 3D Printing Park.

The east gate of Nanjing Happy Valley theme Park adopts a steel structure design(see Fig.9). Except for the relatively flat parts of the roof that are not visible and use some GRP materials, the other coloured outer skins are constructed using a 3D modified plastic outer skin printing system. The geometry of the structure and the multiple colours put forward extremely high requirements for the success rate and accuracy

of 3D printing, and the accuracy level of 3D printing is guaranteed through the application of spatial topological printing methods and optimization algorithms in global optimization and unit calculation. The practical application of 3D printing concrete technology provides a good model for the future development of this technology.



Figure 7. The east gate of Nanjing Happy Valley theme Park.

The team from the University of Hong Kong has demonstrated the prototype of its 3D-printed "future traditional houses". This innovation combines traditional and modern architectural techniques and aims to address the urbanization challenges in rural areas of China. The project is located in Nanlong Village, Guizhou Province. By integrating 3D printing and wooden frame techniques, it aims to

revitalize rural houses. The core of the project lies in the coordination between 3D-printed buildings and traditional craftsmanship. The on-site robotic printing technology enables precise customization and efficient construction. Combined with the expertise of carpenters, it integrates modernity with traditional craftsmanship.



Figure 8. The integration of wooden architecture and 3D-printed concrete in Nanlong Village

6. Conclusion

Concrete is widely used in today's construction industry. By using 3D printing concrete technology, waste concrete can be recycled, effectively reducing concrete waste, and higher performance concrete can also save concrete usage. 3D printed concrete technology undoubtedly has great development potential for resource conservation and environmental protection. Moreover, 3D printing concrete technology is an important exploration in the field of civil engineering, which integrates the wisdom of multiple disciplines and creates the possibility for civil engineers to build a smart and resilient future. The development of 3D printing concrete technology has the potential to become an important part of innovation in the field of civil engineering, providing valuable solutions to meet the new demands of the new era.

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