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# A Review of the Application of 3D Printing Technology in Civil Engineering Technology

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## Abstract

**With the rapid development of science and technology, 3D printing technology, an epoch-making manufacturing technology, is quietly changing the face of various industrial fields. In recent years, it has emerged in many fields, showing its incomparable advantages and huge application prospects. The core idea is to accurately transform the digital model into a physical object by accumulating materials layer by layer. This layer-by-layer process opens up unprecedented possibilities for the fabrication of complex structures. As the cornerstone of infrastructure construction, civil engineering technology has also begun to explore 3D printing technology in depth. The purpose of this paper is to comprehensively review the application status of 3D printing technology in civil engineering, analyze its challenges, and look forward to its future development trend, in order to provide valuable reference for related research and practice.**

## Keywords

**3D Printing Technology; Material Innovation; Application Status.**

## 1. Introduction

In terms of architectural design, 3D printing technology has shown its unique advantages. It enables the manufacture of components with complex curved surfaces and internal structures, which greatly increases the degree of freedom and individuality of architectural design. This not only significantly enhances the aesthetic value of the building, but also provides more possibilities for the functionality of the building, allowing the designer's creativity to be more fully displayed.

In terms of construction, 3D printing technology has significant advantages over traditional pouring and molding processes. It eliminates the use of molds, has a high degree of automation, and greatly saves labor and construction period. In the context of an aging global population and increasing labor costs, the application of this technology is particularly important. It can not only reduce the dependence on labor, but also reduce the uncertainty in the construction process and improve the quality and efficiency of construction.

In addition, 3D printing technology has also brought about revolutionary changes in the use of materials. The formwork cost required by the traditional construction form accounts for a considerable part of the total cost of the concrete structure, and the use of 3D printing technology can not only reduce this part of the cost, but also reduce the generation of construction waste and reduce the impact on the environment. Studies have shown that the use of 3D printing technology can reduce construction waste by 30-60%, labor costs by 50-80%, and production time by 50-70%.[1-2]

Overall, 3D printing technology has revolutionized the civil engineering industry, with advantages such as precision and efficiency, personalized design, reduced costs, and reduced environmental impact. With the continuous progress of technology and the continuous expansion of the scope of application, it is believed that 3D printing technology will play an increasingly important role in the development of building industrialization and intelligence.

# 2. Application Status of 3D Printing Technology in Civil Engineering

## 2.1 Architectural Printing

As a cutting-edge application of 3D printing technology in civil engineering, architectural printing is gradually showing its great potential. With the help of large-scale 3D printers, building components and even entire buildings can be printed directly, an innovation that not only significantly increases the speed of construction, but also significantly reduces material waste and labor costs. At present, architectural printing technology has achieved a number of successful cases around the world, including the realization of 3D printing of residential buildings, bridges and other building structures. In particular, modular prefabricated buildings have become the main application area of this technology. In this mode, the different building modules are manufactured using 3D printing technology and then transported to the site for assembly, enabling efficient and precise building construction. WinSun has made remarkable achievements in this field, and its "Future Office" in Dubai, built using 3D printing concrete technology, is a milestone in the construction industry.[3] The building is modular and the walls, floors and ceilings are all manufactured using 3D printing technology. This modular production method greatly simplifies the complexity of on-site construction, reduces labor costs, and opens up a new path for the sustainable development of the construction industry. In addition, 3D printing of small monolithic buildings is also possible. By using a 3D printer directly in the factory to construct a small house and other buildings, and then transporting them to the site for lifting, the cumbersome on-site assembly process is eliminated, and the construction efficiency is further improved.

It is worth mentioning that the attempt to directly 3D print concrete buildings on site is also gradually unfolding. By installing the 3D printer directly on the construction site, it is possible to directly construct the building, which greatly shortens the construction period. The Belgian company Kamp C has successfully built a two-storey building directly with 3D printed concrete, an innovative practice that opens up more possibilities for the future development of the construction industry.[4]

In addition to housing construction, 3D printing concrete technology has also shown broad application prospects in the field of transportation. For example, Tsinghua University used 3D printing technology to build a pedestrian bridge[5] in Shanghai's Baoshan District, which took only 450 hours to complete, demonstrating its efficiency and convenience.

To sum up, the application of 3D printing concrete technology in civil engineering is constantly expanding and deepening, and its advantages such as improving construction efficiency and reducing material costs have injected new vitality into the innovation and development of the construction industry. In the future, with the continuous progress of technology and the continuous expansion of applications, it is believed that 3D printing technology will play a more important role in the field of construction, bringing more convenience and surprises to our lives.

## 2.2 Structural Optimization and Design Innovation

3D printing technology can create complex structures that are difficult to achieve with traditional processes, providing civil engineers with more design possibilities. Through 3D printing technology, structures with optimized mechanical properties can be manufactured, improving the safety and durability of buildings.

3D printed concrete technology can be combined with structural design to optimize the design of traditional buildings to achieve structural weight reduction. Verttico in the Netherlands cooperated with the University of Ghent in Belgium to conduct topology optimization design experiments on the structure of a pedestrian bridge.[6] Compared with the traditional construction method, the use of 3D printing concrete technology reduces the materials used in bridge construction by 60%, reduces the weight of the structure at the same time, reduces the energy consumption in the construction process,

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and is a green and economical construction method. 3D printing technology makes it possible to customize the design of building structures. Architects can design building structures with unique shapes and functions according to actual needs to improve the overall performance of the building. 3D printing technology can expand the design space, improve design efficiency, and interdisciplinary cooperation for design innovation.

### 2.3 Material Innovation

3D printing technology has revolutionized the field of civil engineering with its wide range of application materials, including concrete, polymers, and metals. This technology not only facilitates the development and application of new building materials, but also meets the diverse needs of civil engineering by precisely manufacturing materials with specific properties and functions.

In terms of material optimization, 3D printing technology has shown its unique advantages. It enables precise control of the distribution and density of building materials to maximize the use of material resources. In addition, by choosing high-strength and lightweight materials, the weight of the building structure is not only reduced, but also its seismic performance is significantly improved.

Architectural 3D printing materials are usually composed of cementitious materials, aggregates, admixtures, fiber materials and admixtures. Compared with traditional concrete, the composition of 3D printed cementitious materials has undergone significant changes,[7] which are mainly to meet their special process needs, such as extrudability, fluidity, interlayer bond strength, setting time, etc.

In the selection of cementitious materials, cement is the most common cementitious material in architectural 3D printing. However, researchers are also exploring other types of cement, such as sulfoaluminate cement or aluminate-modified Portland cement, which have faster setting times and higher early strength.[8] In addition, geopolymer, as an environmentally friendly and high-performance material, is also expected to partially replace traditional cement.

The choice of aggregate is equally important. In 3D printing, the particle size of the aggregate needs to be carefully controlled to avoid clogging the nozzle or affecting the performance of the concrete. Researchers are experimenting with using solid waste as aggregates, such as desert sand, bauxite tailings, copper slag and discarded glass, to reduce costs and improve the strength of concrete. Nowadays, it is more associated with solid waste utilization. For example, desert sand is 3D printed as fine aggregate, the compressive strength of the printed sample reaches 62.05MPa, the thermal conductivity reaches 1.069 W/m·K, and the flexural strength, Vickers hardness, fracture toughness and thermal expansion coefficient of the sample reach the level of conventional process samples. Some researchers are using bauxite tailings, copper slag and waste glass to process into fine aggregates, such as magnesium slag, when the replacement rate of magnesium slag is appropriate, magnesium slag can improve the strength of concrete; the digestion of magnesium slag at an appropriate time is very necessary, but the digestion time should not be too long; the effect of magnesium slag substitution rate on the compressive strength of concrete is significant, and the optimal combination of various factors is the digestion time of magnesium slag is 3 d, the replacement rate of magnesium slag is 30%, and the amount of fly ash is 20%. The addition of coarse aggregate to 3D printed concrete has significant advantages such as low cementitious material consumption, low carbon footprint, cost savings, reduced shrinkage, and the increased proportion of coarse aggregate results in higher compressive strength of up to 65MPa compared to no coarse aggregate.[9-10]

Fiber materials also play an important role in architectural 3D printing. Traditional steel fibers, carbon fibers, glass fibers, etc., as well as modern polymer fibers such as polyethylene, polypropylene, etc., all provide excellent performance enhancements for 3D printing mortars. These fibrous materials not only improve tensile and bending capabilities, but also have properties such as impact resistance and fatigue resistance.

The use of mineral admixtures also enriches the performance of 3D printed concrete. Commonly used admixtures such as fly ash, granulated blast furnace slag powder, silica fume and steel slag powder

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can improve the flow properties and setting time of 3D printing mixtures. Some special admixtures, such as iron tailings, will significantly improve the flexural strength of concrete, although they will reduce the compressive strength and splitting tensile strength of concrete. As the dosage increases, the flow properties and setting time of the 3D printing mix are improved, and the hardening performance is improved when up to 10% brick waste powder is added.[11]

Finally, admixtures play an integral role in 3D printing. They can adjust the rheological properties, extensibility, mechanical properties and setting time of the printing material to meet the special needs of 3D printing. From superplasticizers to retarders, from early strength agents to anti-dispersants, a variety of admixtures work together to ensure the smooth progress of the 3D printing process and the stability of the construction quality.[12-13]

In summary, 3D printing technology has shown great potential in the research and development and application of building materials. By precisely controlling the composition and properties of materials, we can create more efficient, environmentally friendly and high-performance building materials that will lead to a better future for the civil engineering sector.

## 3. Challenges of 3D Printing Technology in Civil Engineering Applications

Although 3D printing technology has shown great potential in civil engineering, its application still faces some challenges. First of all, the high R&D and manufacturing costs of large-scale 3D printers limit their popularity in civil engineering. Due to transportation, installation and technical reasons, the size of the printing equipment is limited, which in turn affects the printed building. Secondly, the quality control and performance evaluation of 3D printing buildings have not yet formed a perfect standard system, which needs to be further improved, and the construction environment of 3D printing technology has high requirements, and how to achieve stable and efficient printing in a complex and changeable environment is also a technical problem. In addition, in terms of printing materials, the components printed with cement-based or geopolymer materials commonly used in construction are often brittle. Although many researchers have tried to improve its ductility characteristics by incorporating fibers or configuring steel bars, there are still needs to be evaluated in terms of material ratio, type, and solid waste utilization.

Fourth, the future development trend of 3D printing technology in civil engineering.

With the continuous advancement of technology and the reduction of costs, the application of 3D printing technology in civil engineering will be more extensive. In the future, 3D printing technology will pay more attention to the combination of digital and intelligent technologies to realize the automation and intelligence of civil engineering design. At the same time, the research and development and application of new printing materials will also provide more possibilities for civil engineering. In addition, with the improvement of relevant standards and specifications, the application of 3D printing technology in civil engineering will be more standardized and safe. It is an important aspect of research to design intelligent printing systems with multiple devices working together or large-scale printing equipment with integrated functions to meet the construction needs of large-scale buildings. For the construction of high-rise buildings, the climb of printing equipment is also an important research direction.

## 4. Conclusion

The application of 3D printing technology in civil engineering has brought revolutionary changes to the construction industry. By reviewing its application status, challenges and future development trends, we can see that 3D printing technology has great potential and broad application prospects in the field of civil engineering. However, in order to achieve its wide application in civil engineering, some technical difficulties and cost issues need to be overcome. In the future, with the continuous progress of technology and the reduction of costs, it is believed that 3D printing technology will play a greater role in civil engineering and promote the sustainable development and innovation of the industry.

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