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Research on the Collaborative Mechanism of Construction Automation and Civil Engineering Technology under the Background of Digital Transformation

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Abstract. In recent years, the civil engineering industry has witnessed a transformative evolution. The advent of digital technologies, most notably Building Information Modeling (BIM), has revolutionized project management throughout the entire lifecycle. This paper centers on the research on the integration of construction automation and civil engineering technology. The paper analyzes the development process from early simple attempts to deep integration driven by key technologies, and analyzes the current problems of poor technical compatibility, high cost, and difficult integration at the technical, application, and industry levels. It is predicted that emerging technologies will drive the deepening of integration in the future, giving rise to innovative application scenarios such as smart cities and disaster emergency buildings. At the same time, it points out the shortcomings of the research in the application of complex geology, dynamic analysis of economic feasibility and research on regional differences, which provides direction for the subsequent research and aims to provide theoretical and practical support for the construction industry's digital transformation and the construction of integration paradigm.

Keywords: construction automation, civil engineering, technical compatibility, digital transformation

1. Introduction

The civil engineering industry has undergone profound changes in recent decades. Starting from the introduction of industrialized construction technology in the 20th century, followed by the gradual popularization of prefabricated components and modular construction, and then in the 21st century, digital tools like BIM have revolutionized the entire life-cycle management of engineering. As a result, the industry has been moving towards being technology-intensive. At the same time, the field of construction automation is also booming, and automation equipment is gradually moving towards systematization and intelligence [1]. However, traditional civil engineering technology and construction automation have long been in a relatively separate state. The separation between the two has given rise to a number of problems, which make it difficult to meet the increasingly complex functional needs and high-quality development requirements of modern buildings.

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With the breakthrough of artificial intelligence, digital twin and other cutting-edge technologies, construction automation and civil engineering technology have accelerated the integration [2]. At present, the construction industry faces multiple challenges such as lagging behind other industries in productivity and intelligent transformation [3], and the deep integration of construction automation and civil engineering technology has become a key path for the industry to break through. Therefore, it is of great significance to study the evolution path, synergistic mechanism and innovation paradigm of the integration of the two. However, there are many shortcomings in the current research. Synergistic mechanism research mostly stays in the case description, and has not yet built a theoretical framework covering technology, organization and other dimensions; innovation paradigm exploration is constrained by data barriers and the lack of industry standards, and it is difficult to form a generalizable practice model.

In view of this, this paper will combine the literature, focusing on the integration of construction automation and civil engineering technology to carry out in-depth research, sorting out its development history, analyzing the current situation, exploring the relationship between the two, and predicting the future direction,to break through the bottlenecks of the digital transformation of the industry, and constructing a new paradigm of integration and development to provide theoretical basis and practical guidance.

2. The evolution of the integration of construction automation and civil engineering technology

The integration of construction automation with civil engineering technology is a process that has evolved over time. In the early days, civil engineering technology relied mainly on manual labor to meet basic housing and use needs. At this time, the concept of construction automation had not yet been formed, but the application of some simple mechanical devices can be regarded as the embryonic form of integration.

With the advent of the Industrial Revolution, the field of civil engineering witnessed great changes. The wide application of new materials such as steel and cement, as well as the emergence of new construction techniques, made the scale and complexity of the building increasing. At the same time, mechanical automation technology began to emerge. In civil engineering construction, steam-powered machinery gradually replaced part of the human labor, such as the application of steam excavators and other equipment, greatly improving the construction efficiency. During this period, construction automation and civil engineering technology began to have preliminary attempts at combination, and the application of mechanical automation in civil engineering is gradually expanding [4].

Into the 20th century, the development of science and technology is changing rapidly, and the rise of electronic information technology has injected new vitality into the integration of construction automation and civil engineering technology. In civil engineering, high - rise buildings, large bridges and other complex projects keep emerging, which pose higher requirements for construction accuracy and safety. In the field of construction automation, electronic control technology is starting to be applied to construction equipment and construction machinery. For example, automated concrete mixing equipment can accurately control the proportion and improve the quality of concrete; the emergence of automated elevators provides convenience for vertical transportation in high-rise buildings.

On this basis, the emergence of BIM technology is a key milestone. BIM technology takes the 3D digital model as the carrier, integrates all kinds of information throughout the building's entire life cycle, and provides an important platform for the in-depth integration of construction automation and civil engineering technology. Through the BIM model, the automation control of construction

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machinery can be more accurate, and the construction automation system can be better adapted to the building structure and function, realizing the collaborative work between the two in the design, construction and operation and maintenance stages [5].

Nowadays, with the continuous development of emerging technologies such as the Internet of Things and artificial intelligence, the integration of construction automation and civil engineering technology presents a broader prospect. The application of these new technologies will further enhance the intelligent level of the building and promote the development of the construction industry in the direction of higher quality and higher efficiency.

3. Analysis of the current status of the integration of construction automation and civil engineering technology

3.1. Current status of technology integration

At present, construction automation and civil engineering technology are deeply integrated in many aspects. In the field of construction machinery, automation control technology is widely used. In construction management, BIM technology builds a three-dimensional digital model, integrates the whole life cycle information of construction, and provides information support for the collaborative operation of automation systems and civil engineering.

However, technology integration still faces challenges. Poor compatibility between different technology systems and non-uniform communication protocols and data formats leads to difficulties in information interaction [6], making it difficult to realize efficient collaboration. At the same time, the high application cost of advanced technology, including the cost of equipment purchase, system maintenance and personnel training, has limited the technology investment of some enterprises. In addition, the lack of composite talents who know both civil engineering and automation technology hinders the popularization and application of new technologies.

3.2. Current status of application fields

In the field of residential construction, the smart home system is combined with the building structure to realize the automatic adjustment of the indoor environment and security automation, thus improving the comfort and safety of living. However, residents' acceptance of the new technology varies, and the system has high maintenance costs. In commercial construction automation is used for energy management and equipment operation and maintenance to improve operational efficiency, but the system integration is difficult and needs to meet a variety of regulatory requirements. In industrial buildings, automation production lines are integrated with construction automation to improve production efficiency, but the requirements for technical reliability and safety are extremely high, and once the failure is prone to cause serious accidents [7].

3.3. Current status of industry development

The industry's acceptance of the integration of construction automation and civil engineering technology has gradually increased, with large-scale enterprises and advanced design units actively exploring and playing a demonstration role. However, there are regional differences in application. It is more extensively applied in developed regions and large cities in the east, while it is relatively lagging behind in the central and western parts of the country and in small projects. Meanwhile, the development of the industry is also facing numerous problems. Specifically, in terms of policies and regulations, the relevant standards and norms are imperfect, and supervision and guidance are

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insufficient; at the market level, the maturity of technology integration products and services is low, and price fluctuations are large; finally, in terms of personnel training, the professional personnel training system is not sound, and it can't satisfy the industry's needs. All of these constrain the full promotion of technology fusion in the industry [8].

4. Relationship between construction automation and civil engineering

4.1. Interdependence

Civil engineering is the cornerstone of construction automation. It erects the physical architecture of the building, whether it is the beams and columns of a house or the piers of a bridge, providing space for the placement of construction automation equipment. At the same time, the functional attributes given to the building by civil engineering determine the configuration of the construction automation system. For example, hospital construction, because of its special requirements for environmental control, logistics transmission, etc., it prompts the construction of a targeted construction automation system.

Construction automation also counteracts the influence of civil engineering. During construction, automated machinery improves efficiency and precision, like intelligent tower cranes that can accurately lift materials. During operation and maintenance, automated monitoring can detect hidden structural problems in a timely manner, providing support for the maintenance of civil engineering projects and guaranteeing building safety and longevity.

4.2. Technology complementarity

Civil engineering specializes in structure and construction, focusing on the application of material properties and mechanical principles in the building entity to ensure the stability and safety of the building. Construction automation is good at control and information processing, with the help of sensing, communication, intelligent algorithms and other technologies to realize the intelligent control of equipment [9].

The advantages of the integration of the two are obvious. In intelligent buildings, the optimized enclosure structure of civil engineering reduces energy consumption, and the intelligent control system of construction automation adjusts the equipment as needed to achieve energy conservation together. In construction, the positioning technology of civil engineering combined with automated sensing technology makes mechanical construction more accurate.

4.3. Development synergy

The development of civil engineering continues to generate the need for innovation in construction automation. The emergence of large and complex construction projects, such as skyscrapers and sea bridges, requires more advanced automated monitoring and management systems to safeguard operations. Advances in construction automation, in turn, bring new opportunities for civil engineering. Automated construction technologies are revolutionizing construction methods, and 3D printing and robotic construction are improving efficiency and quality.

The two synergistically promote the change of the construction industry [10]. They lead the industry towards the direction of intelligence, efficiency, and greenness, prompt the updating and improvement of industry standards, and make the cultivation of cross-disciplinary talents more urgent, helping the construction industry to realize sustainable development and transformation, and better responding to the challenges and needs of the future.

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5. Future predictions for the integration of construction automation and civil engineering technology

5.1. Technology development trends

In the future, the integration of construction automation and civil engineering technology will show the trend of multi-technology collaborative innovation. Artificial intelligence technology will be deeply embedded in the architectural design and construction process, through machine learning algorithms to optimize the architectural design program, so that the design is more in line with the actual needs and site conditions at the same time, the building can learn from the service industry and the manufacturing industry has been successfully implemented [11]. At the same time, to give the construction machinery the ability of autonomous decision-making, so that it can be based on the complexity of the situation on-site automatic adjustment of the operating parameters to enhance the accuracy and efficiency of the construction [12].

The wide application of IoT will realize the interconnection of equipment and systems in the whole life cycle of construction. Various types of sensors collect data in real time, covering structural health, environmental parameters, equipment operation status, etc., just like the mode of data-driven engineering decision-making in intelligent construction, which provides rich information support for intelligent management of buildings. Big data analysis technology conducts in-depth mining and analysis of these massive data to help managers accurately grasp the trend of building performance changes, warn of potential problems in advance, and realize the refined operation and maintenance of the building.

5.2. Expanding application areas

In terms of application in new fields, the integration of construction automation and civil engineering technology will have broad space. In the development of urban underground space, drawing on the concept of automated construction and cooperative operation in intelligent construction technology, automated excavation, support and monitoring will be realized to improve construction safety and efficiency. In the field of ecological architecture, the integration of the two will further optimize the efficiency of the building's use of natural energy, such as through intelligent control systems and special civil engineering structural design, to achieve efficient collection and conversion of solar energy, wind energy and other clean energy, to create a low-carbon and environmentally friendly buildings. In addition, in the field of disaster emergency construction, temporary buildings with automation monitoring and emergency safeguard functions can be quickly constructed to provide safe and comfortable shelter for the affected people, just like the application of intelligent construction in ensuring construction safety and efficiency, which can quickly respond to the needs in emergency situations [11].

5.3. Industry development trends

Driven by technology integration, the construction industry will accelerate its transformation towards a green, intelligent and integrated direction. In terms of green, through technology integration, building energy consumption and pollution emissions will be reduced, and the efficient use of resources will be achieved, which is in line with the goal of intelligent construction to promote the green development of civil engineering. At the intelligent level, the whole process from design to operation and maintenance is intelligent, which greatly improves the building quality and

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service level, just like the seamless connection and intelligent management in each stage of intelligent construction. Integration emphasizes the collaboration between upstream and downstream of the industrial chain, breaks the traditional barriers, and realizes the efficient integrated management of construction projects.

However, the development of the industry also faces challenges. For example, the technical standards are not unified, which restricts the promotion of new technologies, and talent training lags behind to meet the needs of the industry. To solve these problems, all parties in the industry need to work together to improve the standard system and strengthen personnel training, thus promoting the construction industry to move forward steadily on the road of integrating construction automation and civil engineering technology, so as to achieve high-quality development.

6. Conclusion

This paper conducts a comprehensive analysis of the integration of construction automation and civil engineering technology. In the development process, from the initial simple attempt to the deep integration promoted by key technologies such as BIM. At present, although progress has been made in technology, application and industry development, the technology compatibility is poor, the cost is high, the integration of application fields is difficult, the regional differences in the industry are large, and the policy, market and talent shortage are obvious. In the future, emerging technologies will drive the continuous deepening of the integration of the two.

There are still limitations in the research, the application of fusion technology in complex geological conditions is not enough, and there is a lack of dynamic analysis on the economic feasibility of fusion technology. At the same time, the research on the differentiation of different regional integration models around the world is not in-depth enough.

Looking forward to the future, the integration of construction automation and civil engineering technologies will give rise to many innovative application scenarios. In the construction of Smart City, construction automation systems and civil engineering structures can work together to automatically regulate building energy consumption based on environmental and urban operational data, realizing the efficient deployment of urban resources and helping the construction industry to develop innovatively.

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