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Research on Applications of Intelligent Construction in the Renovation of Aged Residential Communities under the Background of Urban Stock Renewal

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Abstract. At present, Chinese aged residential communities suffer from problems such as aging facilities and functional deficiencies. To enhance people's well-being and the quality of cities, these problems can be effectively renovated based on intelligent construction. This study explores the multiple applications of intelligent construction in the renovation of aged residential communities, including the application scenarios of Artificial Intelligence, the Internet of Things, Building Information Modeling, and other technologies in the three phases of project planning and design, construction operation, and operation and maintenance. It is found that the systematic integration of intelligent construction technologies has achieved the digital control of the whole process of aged residential communities' renovation and significantly improved the efficiency and quality of the renovation. Intelligent construction realizes visual diagnosis of hidden engineering problems and multi-professional collaborative optimization in the early planning stage, which significantly improves the scientificity and feasibility of renovation plans. In the mid-construction stage, it effectively overcomes construction problems such as site constraints in the aged residential communities and significantly improves the quality of the project and the safety of the construction at the same time. And in the latter stage, it improves the efficiency of the service response and realizes sustainable operation of the community facilities through the optimization of the data-driven decision-making, which makes the sustainable operation of community facilities come true. The analysis in this paper can provide theoretical support and practical reference for promoting sustainable and high-quality urban development.

Keywords: Intelligent Construction, Urban Renewal, Aged Residential Communities, Existing Stock Renovation, Sustainable Development.

1. Introduction

Currently, China's urbanization rate has exceeded 65%, and the urbanization process has gradually shifted from large-scale rapid construction to a new stage based on stock renewal [1]. In many cities, land resources are tight and new construction land is restricted. The previous mode of "large-scale demolition and construction" is no longer sustainable. The commercial and residential communities

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and infrastructure built in the early days are gradually aging. Some communities built at the end of the last century generally face problems such as outdated equipment and missing functions, which pose a risk of a decline in the quality of daily life for community residents. In addition, keywords such as “transformation of old neighborhoods” and “revitalization of stock” have repeatedly appeared in policy documents related to urban governance. As an important means to improve people's livelihood and enhance the quality of cities, the renovation of aged residential communities has become an essential part of urban stock renewal [2]. Therefore, it is necessary to carry out high-quality renovation of aged residential communities.

In the existing research, some scholars have analyzed the predicaments faced by the renovation of aged residential communities with the application scenarios and advantages of related technologies. Cai et al. expounded on the predicaments faced by old residential areas in their research and proposed that a management approach of continuous assessment should be maintained throughout the entire life cycle of old residential area renovation projects [3]. Han et al., through studying the mechanism of action of the City Information Modeling platform, proposed its application value in scenarios such as the construction of basic databases and intelligent management platforms in the renovation of old residential areas [4]. Wu et al. proposed the achievements and benefits of intelligent technologies such as prefabricated assembly construction technology in the renovation of aged residential communities by comparing them with the traditional mode [5]. The above-mentioned studies have all provided many ideas for the high-quality renovation of aged residential communities in China.

However, there are over 200,000 aged residential communities in China built before 2000, involving more than 42 million households. They generally face problems such as aging infrastructure, lack of public services and deterioration of living environment, and there is an urgent need for systematic renewal. The traditional renovation mode has pain points such as low efficiency, high cost and difficult coordination, which makes it hard to meet the needs of high-quality development. In recent years, with the rapid development of technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI), the application of intelligent construction has gradually emerged, providing a new technical path for the renovation of aged residential communities.

This article aims to explore the current application status, key technologies and future trends of intelligent construction in the renovation of aged residential communities under the background of urban stock renewal, providing theoretical support and practical reference for promoting high-quality urban development. First of all, it illustrates the current situation of the renovation of aged residential communities in China and the challenges it faces. Secondly, the application of intelligent construction technology in each stage of the renovation of aged residential communities is analyzed in combination with relevant cases. Finally, it summarizes the advantages of intelligent construction in the application of aged residential communities' renovation and looks forward to its future development trend.

2. Overview of the renovation of aged residential communities

2.1. The current situation of the renovation of aged residential communities

With the deepening of the urban stock renewal strategy, the renovation of aged residential communities in China has entered a comprehensive promotion stage since 2020, presenting the characteristics of continuous expansion in scale and deepening in connotation. In terms of renovation scale, the number of renovation projects in various regions has grown rapidly in recent

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years. In 2024, over 58,000 urban-aged residential communities were started to be renovated across the country, benefiting nearly 10 million households. In many provinces, the actual number of old residential areas that started to be renovated exceeds the planned amount [6].

Nowadays, the renovation content of aged residential communities has gradually expanded from the initial infrastructure maintenance to multiple dimensions such as building energy conservation, elderly-friendly renovation and smart community construction, forming a more comprehensive renovation system. In addition, the gradual improvement of the policy support system has also provided a strong guarantee for the renovation work. The central and local governments at all levels have successively issued a series of policy opinions on renovation strategies, financial subsidies and other contents, and the relevant technical standard system is also continuously being improved and optimized [7].

2.2. The challenges of renovating aged residential communities

At present, although the renovation of aged residential communities is being advanced in depth across the country, it still faces multi-dimensional practical challenges in the specific implementation process, such as the initial design, construction and water management, which directly affect the quality and effectiveness of the renovation project work.

In the planning and design stage, the primary challenge is the insufficiency of technical information. Due to their long construction years, the original architectural drawings, engineering pipelines and other key materials of most aged residential communities have become impossible to find, which has set up a huge obstacle for the formulation of renovation plans. Furthermore, the diversified characteristics of residents' demands are increasingly prominent. Opinions of residents of different age groups on issues such as the renovation of public spaces often vary greatly. The differences in interests and demands make it necessary for design plans to go through repeated arguments and revisions before they can be finally implemented [8].

When entering the construction stage, spatial limitations and residents' interference become the main restrictive factors. Aged residential communities generally have characteristics such as high building density and small public Spaces, which restrict the entry and use of some large construction machinery. On the other hand, the construction process that lasts for several months will generate problems such as noise and dust, which are likely to cause complaints from nearby residents. This not only affects the progress of the project but also tests the ability of community grassroots service personnel to mediate conflicts.

And in the management stage after its completion, the lag problem in the management concepts and methods of traditional community renovation is particularly prominent. The risk response mechanisms in some communities are still not sound enough. Daily inspection work is still mainly carried out manually, which has drawbacks such as narrow coverage and low efficiency, making it difficult to detect problems such as equipment failures and damage to public facilities in a timely manner.

3. The applications of intelligent construction in the renovation

Intelligent construction is a new type of construction and management model that takes the new generation of information technology as its core and realizes the digitalization, intelligence and greenness of the entire engineering life cycle through modern technological means such as BIM, IoT, AI and robot technology [9]. In the field of aged residential communities' renovation, intelligent construction, through the technical path of "data-driven + intelligent decision-making + precise

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execution", can effectively solve the problems of low efficiency, poor quality and serious disturbance to residents existing in traditional renovation methods.

The core characteristics of intelligent construction are mainly reflected in the three stages of the renovation engineering life cycle [10]. The first is digitalization in the design stage to achieve precise modeling of the transformation object and optimization of the scheme; The second is to systematize the construction stage and enhance operational efficiency through automated equipment. The third is the intelligent operation and maintenance stage to achieve long-term management during the building's usage process [11]. Intelligent construction, through highly integrated digital information technology, conducts refined processing of each stage to achieve high-quality construction and management effects throughout the entire life cycle of the renovation project.

3.1. Application in the planning and design stage

In the early planning and design stage, intelligent construction technology can achieve precise assessment for the renovation of aged residential communities. By obtaining building point cloud data through a 3D laser scanner and combining it with infrared thermal imaging technology, a 3D digital model with millimeter-level accuracy can be established, which is convenient for identifying hidden defects in community buildings [12]. By using unmanned aerial vehicle aerial photography and AI image recognition algorithms, problem points such as damaged facades and exposed pipelines can be quickly marked [13]. Overall, the BIM technology platform is utilized to integrate multi-dimensional professional data, construct a complete building information model, and provide the accurate scientific basis for the formulation of renovation plans.

3.2. Application in the construction and operation stage

During the construction operation stage, intelligent construction technology can maximize the working efficiency of the renovation project. By using modern modular prefabricated construction technology, building components are prefabricated in factories in advance. At the construction site, only assembly is needed to complete the vast majority of construction work, significantly reducing construction waste and construction noise [14]. All kinds of construction robots can replace human labor to complete some high-risk or repetitive tasks, which not only ensures construction safety but also improves work efficiency. The intelligent monitoring system conducts real-time tracking and management of the entire construction process, ensuring the controllability of project quality and progress, and significantly enhancing the efficiency of project management.

3.3. Application in the management and maintenance stage

In the later management and maintenance stage, intelligent construction technology can establish a long-term management mechanism for the renovation project. The IoT monitoring network enables all-weather monitoring of the facilities and equipment in the community, and can promptly detect and warn of various potential hazards. The intelligent management platform integrates multiple functions such as property management, security protection and emergency handling, providing convenient services for residents. The predictive maintenance system based on data analysis can detect potential problems in advance and transform passive maintenance into active care [15]. These intelligent measures not only enhance management efficiency but also ensure the long-term maintenance of the renovation results, creating a safer and more comfortable living environment for residents.

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3.4. Summary of comprehensive benefits throughout the entire life cycle

As shown in Table 1, intelligent construction technology has formed a systematic solution throughout the entire cycle in the renovation of aged residential communities. During the planning and design stage, the application of technologies such as 3D laser scanning has enabled the precise identification and assessment of renovation requirements. During the construction stage, through the application of technologies such as prefabricated construction, engineering efficiency and operational safety have been significantly enhanced. During the operation stage, relying on technological platforms such as the IoT, a long-term facility operation and maintenance mechanism has been established. This full-process technological integration not only realizes the standardization and digital management of the renovation process but also, through data sharing and collaboration at each stage, comprehensively enhances the quality, efficiency and sustainability of the renovation of aged residential communities, providing an innovative technological path for the renewal of urban stock.

Table 1: Full-cycle application and benefits of intelligent construction technology in the renovation of old residential areas

Stages	Core technologies	Key applications	Achievements and advantages
Planning and design	Three-dimensional laser scanning	Construction of three-dimensional models with millimeter-level accuracy	Accurately assess the renovation requirements, provide a basis for scientific decision-making, and reduce design rework
	Infrared thermal imaging	Identification of concealed defects	
	AI image recognition	Facade damage marking	
Construction and operation	Prefabricated construction	Factory prefabrication and on-site assembly	Reduce construction waste and noise, improve construction safety and efficiency, and achieve dual control of quality and progress
	Construction robot	High-risk operation substitution	
	Intelligent monitoring	Real-time tracking of the entire construction process	
	Internet of Things cloud platform	All-weather monitoring of facilities and equipment	
Management and maintenance	Intelligent management platform	Multi-functional integration of property management, security and emergency response	Extend the service life of facilities, reduce operation and maintenance costs, and enhance satisfaction and sustainability
	Predictive maintenance system	proactive maintenance by data analysis	

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4. The analysis of a typical case

4.1. Background of the project

The Building 8 of Huapichang Hutong is located in the core area of Xicheng District, Beijing. It was first built in 1978 with a building age of over 40 years. The original residence has problems such as an aging structure, outdated facilities and prominent safety hazards. The area where the project is located is characterized by high building density and narrow roads. Moreover, due to the low willingness of residents to relocate and the significant pressure of construction disturbing the residents, the traditional renovation mode faces numerous difficulties in advancement [16]. To break through the existing limitations, the project introduced the concrete modular integrated building technology (C-MiC) in 2023, combined with the full-process intelligent construction methods, to explore the feasible path of the "in-situ redevelopment" mode in the renovation of aged residential communities [17].

4.2. The application practice of intelligent construction

The project takes the industrialization and digitalization of the entire process from "design - production - transportation - construction" as its core and systematically applies intelligent construction technology, specifically including four different stages. Firstly, as shown in Figure 1 and Figure 2, in the design stage, BIM technology is used to achieve forward modeling of multiple specialties such as schemes, structures, and mechanical and electrical facilities. Combined with module splitting and detailed design, the integration of mechanical and electrical and decoration is completed in advance, laying a foundation for subsequent efficient construction. Secondly, during the production stage, all modules are prefabricated in the factory, and systems such as MES and QMS are applied to achieve full-process digital management, ensuring that the precision of components is controlled at the millimeter level, thereby enhancing production efficiency and product quality. Secondly, in the transportation process, a dual-code identification system is adopted. Combined with the order management platform, the transportation route is optimized and the on-site assembly is precisely matched to ensure that the modules are "installed immediately upon arrival", reducing product stacking and mutual interference. Finally, the C-SMART intelligent construction site platform is deployed during the construction stage to achieve multi-dimensional visual management of personnel, progress and materials, improve construction accuracy and collaborative efficiency, and realize full-process traceability and dynamic control [18]. The project will also continue to apply intelligent construction-related technologies to achieve intelligent operation and maintenance after delivery, in order to provide full coverage services throughout the entire life cycle of the engineering building.

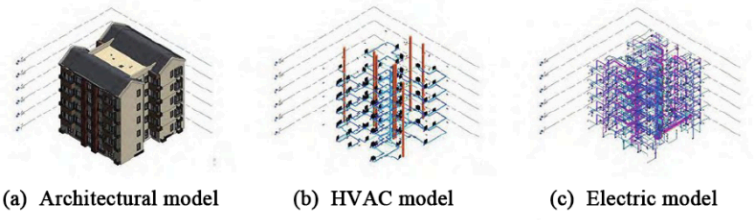

Figure 1: The full professional forward design model of the renovation project of Building 8, Huapichang Hutong, Beijing [18]

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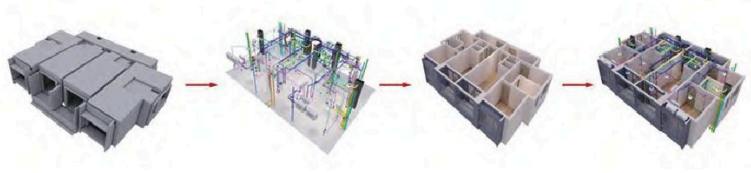

Figure 2: The detailed pre-model of the entire process of the renovation project of Building 8, Huapichang Hutong, Beijing [18]

4.3. Achievements and advantages

The application of intelligent construction technology has significantly enhanced the implementation benefits of the project. First, the construction period was significantly shortened. The project was completed from demolition to delivery in just three months, effectively reducing the cost of residents' relocation. Second, the engineering quality is excellent. The newly built buildings meet the standards of permanent structures, with a design service life of up to 50 years. The seismic fortification intensity reaches 8 degrees, outdoor noise is reduced by 6 to 7 decibels, and the water, electricity, gas and heat facilities are comprehensively upgraded to be intelligent. The functional configuration and living comfort are significantly improved [19]. Third, it has a high level of digitalization, achieving digital integration throughout the entire process from design, and manufacturing to delivery, and establishing a "digital archive" for the building, providing strong support for later operation and maintenance. Fourth, the green benefits are outstanding. Construction waste has been reduced by over 75%, carbon emission intensity has dropped by approximately 25%, and energy consumption is more than 30% lower than the national standard, achieving the goals of resource conservation and low-carbon environmental protection [20]. The project of Building 8 in Huapichang Hutong has deeply integrated intelligent construction with C-MiC technology, establishing a new model for the renovation of aged residential communities that is efficient, green and replicable, providing a dual demonstration of technology and practice for urban renewal.

5. Conclusion

This article conducts an in-depth discussion on the application of intelligent construction in the renovation of old residential areas under the background of urban stock renewal. By analyzing the current situation and challenges of the renovation of aged residential communities, the applications at different stages during the entire renovation cycle, and the practices of related typical cases, this study has drawn a series of conclusions.

(1) In the application of the renovation of aged residential communities, the integrated advantages of intelligent construction technology are significant. Through the systematic integration of technologies such as BIM, modular prefabrication, and IoT monitoring, the entire process of aged residential communities' renovation, from planning and design to operation and maintenance, has been digitally controlled, significantly enhancing the efficiency and quality of the renovation.

(2) In terms of the application of intelligent construction during the planning and design stage, the full-process digital design has fundamentally changed the planning mode of traditional renovation projects. By establishing a high-precision building information model, the visual diagnosis of concealed engineering problems and multi-disciplinary collaborative optimization has been achieved, significantly enhancing the scientificity and feasibility of the renovation plan. This

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digital design method not only overcomes the limitations of traditional manual surveying but also provides a precise and reliable data basis for subsequent construction.

(3) In terms of the application of intelligent construction during the construction operation stage, modular prefabrication and industrialized construction technologies have demonstrated revolutionary advantages. The construction mode combining factory prefabrication and on-site assembly effectively overcomes construction difficulties such as limited space in old residential areas, while significantly improving project quality and construction safety. The application of the intelligent construction management system has achieved precise control over the entire process from component production to on-site installation, pioneering a new model of high-efficiency and low-interference renovation construction.

(4) In the application of intelligent construction during the management and maintenance stage, the IoT and big data technologies have driven its transformation. The combination of the real-time monitoring system and the intelligent management platform has established an active preventive facility maintenance system, completely transforming the traditional passive maintenance operation and maintenance mode. This intelligent management not only enhances the efficiency of service response but also achieves the sustainable operation of community facilities through data-driven decision optimization, providing an innovative solution for the long-term management of aged residential communities.

In the future application practice of intelligent construction in the renovation of aged residential communities, it is still necessary to focus on breaking through the construction of two major aspects: the standard technical system and the multi-party collaboration mechanism. On one hand, it is necessary to establish and improve technical standards and evaluation systems covering the entire process from design, and construction to operation and maintenance, providing standardized guidance for renovation projects. On the other hand, it is necessary to establish a multi-party collaborative mechanism of "government - enterprises - residents", achieve information sharing and collaborative decision-making through digital platforms, and form an open and transparent intelligent transformation ecosystem. This not only ensures the implementation of technical standards but also truly meets the needs of residents, thereby promoting the high-quality development of the transformation work.

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