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Investigation and analysis of operation and maintenance efficiency of prefabricated buildings in Yunnan earthquake stricken area——Take Zhaotong, Yunnan Province as an example

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ABSTRACT
Due to the special geological and climatic conditions in Yunnan Province, natural disasters occur frequently. This study takes the prefabricated buildings in post-disaster reconstruction in Zhaotong, Yunnan Province as the research object, and uses the research methods of literature review, questionnaire survey, on-the-spot investigation and expert interview to explore the present situation and challenges of the operation and maintenance management of prefabricated buildings. It is found that prefabricated buildings are widely used in post-disaster reconstruction because of their rapid construction and cost-effectiveness, but at the same time, there are problems such as structural safety hazards, equipment maintenance difficulties and insufficient technical level of operation and maintenance personnel, which affect the long-term use safety of buildings and the quality of life of residents. In order to improve the safety and living comfort of prefabricated buildings, this paper puts forward some improvement measures, such as establishing regular inspection and maintenance system, introducing intelligent monitoring technology and perfecting technical training system, hoping to optimize operation and maintenance management, prolong the service life of buildings, improve the quality of life of residents and provide more effective technical support for post-disaster reconstruction areas.

KEYWORDS: Prefabricated buildings, post-disaster reconstruction, operation and maintenance management

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I. INTRODUCTION

Yunnan Province, located in the southwestern part of China, lies within the Mediterranean-Himalayan volcanic earthquake zone. Due to its geographical location and climatic conditions, it is not only subjected to the forces exerted by the Indian Plate subduction along the Burma arc from west to east but also experiences lateral compression from the Qinghai-Tibet Plateau and other dynamic forces. Additionally, Yunnan's complex fault structure makes it one of the regions with the highest frequency of earthquakes in China and even globally. The seismic belts in Yunnan Province mainly include the Xiaojiang Seismic Belt, Zhongdian-Nanjian Seismic Belt, Daguan-Mabian Seismic Belt, Lancang-Gengma Seismic Belt, Lushui-Tengchong Seismic Belt, Simao-Puer Seismic Belt, and Tonghai-Shiping Seismic Belt (refer to Figure 1.1). Apart from earthquakes, other natural disasters are also frequent in Yunnan, causing severe damage and impact on local residents and infrastructure (Li Tianshun, 2023). For example, earthquakes can result in collapsed houses, road damage, bridge collapses, casualties, and interruptions in transportation. Floods may inundate farmland, houses, and infrastructure, affecting crop growth and residents' lives. Mudslides and landslides may destroy houses, farmland, infrastructure, and transportation arteries, posing serious threats to the lives and property of mountain residents. According to the latest climate change research reports, the high mountain areas of Yunnan Province are experiencing more frequent rare heavy snowfall events due to warming temperatures, leading to transportation disruptions and shortages of essential supplies, exacerbating the local residents' living difficulties (China Climate Change Research Center, 2024).

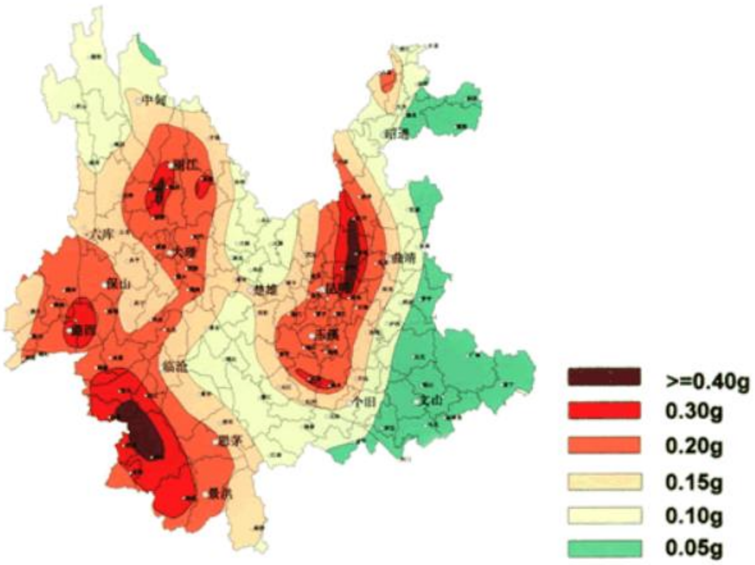

Figure 1.1 Distribution of seismic zones in Yunnan Province

Source: Yunnan Seismological Bureau

1.1Background

Due to frequent natural disasters such as earthquakes, landslides, and floods in the Yunnan region, the disaster-stricken areas of Yunnan have suffered significant casualties and property losses. Between 2004 and 2024, there have been nearly 35 earthquakes ranging from magnitude 5.0 to 5.9 and 5 earthquakes ranging from magnitude 6.0 to 6.9, totaling 44 earthquakes. These earthquakes have caused disasters in 14 prefectures, cities, and counties, affecting most cities in Yunnan. Nearly a thousand people have died, 7,433 have been injured, and over 100,000 houses have collapsed (China Earthquake Administration). For example, on August 3, 2014, an earthquake disaster occurred in Zhaotong City, Yunnan Province, China. The epicenter was near Ludian County, Zhaotong City, with a magnitude of 6.5. The earthquake caused severe casualties and property losses. The depth of the earthquake epicenter was 12 kilometers. As of August 8, 2014, the earthquake had caused 617 deaths, 112 missing persons, 3,143 injuries, and affected 1.0884 million people. Among them, the Ludian County earthquake caused 526 deaths, 109 missing persons, and 80,900 collapsed houses. Many buildings collapsed or were severely damaged, severely affecting the lives of residents in the disaster-stricken area (data source: Ludian Earthquake Memorial Hall). The earthquake disaster plunged the local residents into difficulties, urgently requiring large-scale post-disaster reconstruction work to be carried out promptly (see Figure 1.2).

Figure 1.2 Disaster situation after earthquake in Ludian county

Source: People's Daily Online

In addition, landslides are also common occurrences in the Yunnan region. On January 22, 2024, a severe landslide event occurred in Zhaotong City, Yunnan Province. This event resulted in a large amount of soil and rocks collapsing, burying 18 households, causing 34 fatalities, and leaving 10 people missing, resulting in severe casualties and property losses (People's Daily - People's Daily Online, Xinhua News Agency). Numerous houses were buried or destroyed, roads were blocked, and communication was disrupted, posing significant challenges to rescue efforts.

Faced with frequent natural disasters, post-disaster reconstruction has become routine work for local government departments and various sectors of society. Despite the complex geographical and climatic conditions in disaster-stricken areas, efforts to repair damaged buildings and infrastructure, improve the living conditions of residents in disaster areas, and promote the sustained development and progress of disaster areas have become the common goals of all sectors of society.

1.2 Significance

In order to quickly and effectively restore the life and production order in disaster-stricken areas, prefabricated buildings are widely used as a method of rapid post-disaster construction. Prefabricated Rapid Construction includes aspects such as construction speed, cost, and quality. For example, prefabricated construction is typically faster than traditional construction methods, often saving up to 30% to 50% or more of on-site construction time (Zhou Changlin, 2021), and its cost is usually lower than that of traditional construction, with cost savings of up to 20% (Zuo Wenjian, 2019). Moreover, prefabricated construction is conducted in a factory environment, using standardized design and production, which allows for better control of construction materials and quality, thus usually meeting higher quality standards.

Prefabricated construction, because materials can be precisely prefabricated in factories, can also reduce construction waste and energy consumption, minimizing waste. By using renewable materials and designing more energy-efficient building systems, prefabricated construction helps reduce the environmental impact of buildings and is suitable for various types of construction, including residential, commercial, schools, hospitals, etc.

However, the phenomenon of "heavy construction, light management" is prevalent in most projects after construction investment. Researchers from Tsinghua University's Architectural Design and Research Institute pointed out that in some reconstruction projects in China, although attention is paid to the implementation of technology and engineering during the construction phase, management after the project is put into use is relatively weak. For example, in the reconstruction of earthquake-stricken areas after the Wenchuan earthquake, although some residential communities and public buildings adopted modern design and technology during the construction phase, there were problems with poor management and inadequate maintenance during the usage phase, leading to a gradual decline in building quality and functionality (Wang Binbin, 2012).

Some international studies have also discussed this phenomenon. For example, researchers from the University of Houston in the United States pointed out after tracking and investigating post-disaster reconstruction projects that there are challenges in the management and maintenance of reconstruction projects after construction is completed, mainly manifested in the inefficient operation of management institutions, insufficient investment, and lack of effective maintenance mechanisms.

Therefore, after the reconstruction of disaster areas, the operation and maintenance (O&M) management of prefabricated buildings remains crucial. Effective O&M work not only prolongs the service life of buildings but also ensures the safety and quality of life of residents.

(1) Theoretical significance: By thoroughly studying the problems and challenges of prefabricated building operation and maintenance in the earthquake-stricken area of Zhaotong, Yunnan, new theoretical perspectives and research ideas can be provided for the field of post-disaster reconstruction. Exploring the impact of the disaster area environment on the operation and maintenance of prefabricated buildings enriches the relevant theoretical knowledge system and provides new theoretical support for research in the field of post-disaster reconstruction.

(2) Practical significance: By addressing practical problems in the operation and maintenance of prefabricated buildings, the service life and safety of buildings in disaster areas can be improved, providing residents in disaster areas with a safer and more comfortable living environment. Proposing solutions and suggestions for problems in the operation and maintenance phase of prefabricated buildings will provide scientific basis and technical support for the reconstruction work in the earthquake-stricken area of Zhaotong, Yunnan, promoting the development of post-disaster reconstruction towards a more sustainable direction.

(3) Social significance: Effectively solving the operation and maintenance problems of prefabricated buildings in disaster areas can not only improve the quality of life of residents in disaster areas but also promote local economic development and social stability. Providing a path for sustainable development in disaster area reconstruction helps reduce losses from similar disasters, enhances overall disaster resistance, and makes positive contributions to the sustainable development of society.

Potential problems that prefabricated buildings may face in the operation and maintenance phase in the Zhaotong earthquake-stricken area of Yunnan include but are not limited to structural safety hazards, unclear responsibility for upgrading and renovation, failure to achieve set green star ratings, failure to meet expected performance requirements, lack of experienced property management companies, and inadequate maintenance of prefabricated buildings (Wang Mengnan, 2017). These issues not only affect the long-term effectiveness of buildings but also directly relate to the safety and quality of life of residents in disaster areas. Therefore, in-depth research on the problems and challenges of prefabricated building operation and maintenance in the earthquake-stricken area of Zhaotong, Yunnan, is of great significance for further improving post-disaster reconstruction work and enhancing the long-term sustainability of reconstruction projects.

II. LITERATURE REVIEW

2.1 Definition and development of prefabricated buildings

Prefabricated Construction is a construction method that involves the production, assembly, and prefabrication of building components within a factory, followed by transportation to the site for installation and assembly. This construction approach, compared to traditional on-site construction, significantly reduces construction time, lowers construction costs, enhances building quality, and reduces resource consumption and environmental impact on the construction site (Zhang Hongling, 2018). Prefabricated Construction may include prefabricated wall panels, roof components, floor systems, and modular units, among others. These components are manufactured in the factory through standardized production processes, ensuring consistency in quality and dimensions. Once completed, these components can be conveniently transported to the construction site via land or sea transportation, and then assembled and installed with ease to complete the construction (Zheng Minli and Yu Deguo, 2018).

According to the "Technical Regulations for Prefabricated Concrete Structures in China", Prefabricated Construction can be categorized into various types such as prefabricated concrete buildings, prefabricated steel structure buildings, and prefabricated wood structure buildings. These types adhere to a series of strict standards and specifications throughout the design, manufacturing, and installation processes to ensure the safety, reliability, and durability of the buildings. Prefabricated Construction has been widely applied globally, especially in the context of rapid urbanization and population growth, where its advantages have gained more recognition and attention. Through continuous technological innovation and experience accumulation, Prefabricated Construction will play an increasingly important role in future development, contributing positively to the construction of more sustainable and intelligent urban environments. Prefabricated Construction is not only applicable to residential buildings but also extensively utilized in commercial, educational, and medical sectors, providing rapid, efficient, and sustainable solutions for various types of building projects.

Prefabricated construction has emerged as a significant trend in the construction industry in recent years. With the acceleration of urbanization and the continuous growth of construction demand, traditional on-site construction methods face numerous challenges, such as long construction periods, difficulties in ensuring quality, and significant waste issues. Therefore, prefabricated construction, as an industrialized and intensive construction model, has gradually gained attention and favor. Since the mid-20th century, European and American countries have led the research and practice of prefabricated construction, followed by Asian countries such as Japan, Singapore, and China, all of which have achieved significant achievements (Cheng Xiaoke, 2021).

China, as one of the world's largest construction markets, has played a crucial role in driving the development of prefabricated construction. According to the "Development Report of Prefabricated Construction in China's Construction Industry," since 2015, the Chinese prefabricated construction market has maintained an annual growth rate of over 20%. It is projected that by 2025, prefabricated construction should account for 30% of the newly built construction area, and the market size of prefabricated construction will reach 2.5 trillion RMB (Liu Kai et al., 2021). This growth momentum is attributed to government policy support and encouragement for prefabricated construction, as well as the market's increasing demand for quality, efficiency, and environmental protection. The "14th Five-Year Plan for the Development of the Construction Industry" issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China proposes that by 2025, prefabricated construction should account for more than 30% of new construction (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2022-01-19 [2023-05-09]).

Internationally, prefabricated construction has also attracted considerable attention. According to the "Global Prefabricated Building Market Report," the global prefabricated construction market size increased from approximately 119.5 billion USD in 2015 to about 298.7 billion USD in 2020, with a compound annual growth rate of 8.2% (Liu Kai et al., 2021). The global prefabricated construction market size from 2011 to 2020 is shown in Figure 2.1.

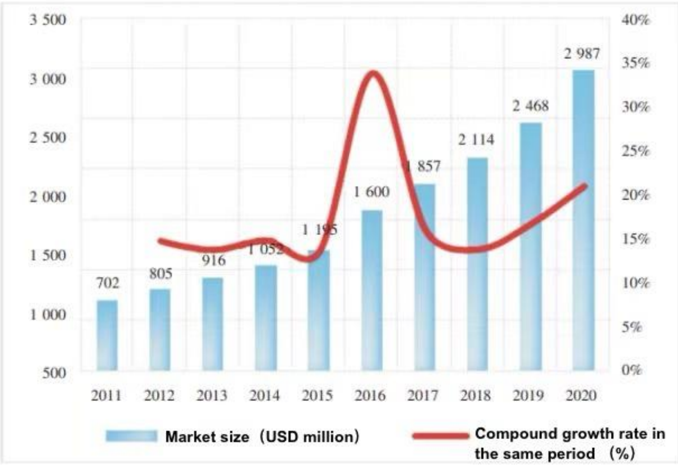

Figure 2.1 Global market scale of prefabricated buildings from 2011 to 2020

Photo source: China Industry Information Network Intelligent Research report

This growth benefits from the many advantages of prefabricated buildings, including shortening time periods, reducing costs, improving quality, and reducing waste. With increasing industrialization, the advantages of prefabricated buildings become more obvious, and it is expected that the global prefabricated building market will reach $493.2 billion by 2025 (as shown in Figure 2.2) (Liu Kai et al., 2021).

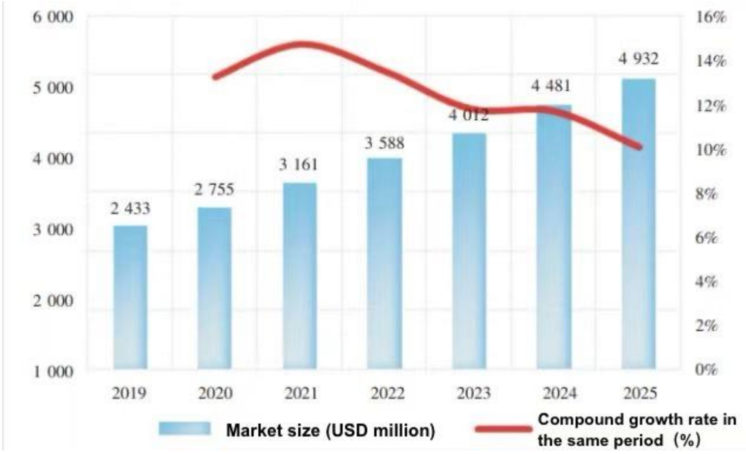

Figure 2.2 Prediction of global prefabricated building market scale from 2019 to 2025

Photo source: China Industry Information Network Intelligent Research report

The development of prefabricated construction is driven by several key factors. Technological advancements in materials science, structural design, and production processes continuously expand its possibilities. Market demand also pushes the construction industry towards prefabricated methods due to a growing need for higher quality and faster construction. Policy support from many countries, introducing relevant policies and standards, further promotes its application. As prefabricated construction technology matures and gains market traction, its use is expanding beyond residential buildings to commercial, public, and industrial projects (Zhang Meiqiang, 2023). The integration of digital technologies like Building Information Modeling (BIM) enhances design and management capabilities, supporting greater intelligence and customization (Li Chen, 2024). In conclusion, prefabricated construction is emerging as a vital, modern, and efficient construction model, poised to drive future industry development and contribute to sustainable urban growth

2.2 Relevant theories of post-disaster reconstruction area

Post-disaster reconstruction areas are territories where comprehensive planning and restoration occur following significant damage from natural or man-made disasters (National Disaster Reduction Center, 2018). These areas suffer severe losses, including collapsed houses and damaged infrastructure, necessitating extensive reconstruction to restore normalcy and economic growth (Qiu Jian and Zeng Fan, 2015). Reconstruction involves urban planning, architectural design, infrastructure rebuilding, and social security, aiming to revitalize and enhance disaster resilience. Successful reconstruction requires collaboration among governments, social organizations, international institutions, and affected populations to create safer, healthier, and more livable communities, offering improved living conditions and development opportunities for residents.

Post-disaster reconstruction areas face significant damage, including collapsed houses and infrastructure, requiring extensive, long-term efforts involving governments, social organizations, and international institutions (Lan Dingxiang, 2011). Reconstruction must consider disaster recurrence and implement mitigation measures to enhance resilience. Challenges include population mobility, social psychological health, and rebuilding social order. However, reconstruction also presents opportunities for development, improving living conditions, and promoting regional economic and social progress. Prioritizing basic needs, infrastructure restoration, economic development, and social stability is crucial. Emphasis should be on sustainability, social fairness, protecting vulnerable groups' rights, and effective risk management to mitigate future disaster impacts.

2.3 Application of prefabricated buildings in the post-disaster reconstruction areas

Prefabricated construction technology has been instrumental in post-disaster reconstruction, as seen in the Wenchuan earthquake recovery. The 2008 earthquake caused extensive damage, leading to large-scale reconstruction efforts using prefabricated components like precast concrete panels and steel structures. This method allowed for the rapid assembly of temporary shelters, providing immediate housing for the affected population. Prefabricated construction was also used to rebuild public facilities, such as schools, hospitals, and community centers, supporting the socioeconomic recovery of the area. The Wenchuan reconstruction highlights the benefits of prefabricated technology, offering swift, efficient, and reliable solutions to restore housing and infrastructure in disaster-stricken regions, thus accelerating recovery processes and restoring order (Liang Xin et al., 2020; Chen Shidong, 2014).

Practical cases of prefabricated construction in post-disaster reconstruction abroad illustrate the benefits of advanced technologies. The O3office project in Japan used IoT and intelligent equipment for remote monitoring and intelligent operation and maintenance management. Sensors tracked air quality, temperature, humidity, and energy consumption in real-time, with data analyzed through a cloud platform using AI algorithms for predictive maintenance. This approach improved operational efficiency and energy performance, with digitized records and shared information aiding long-term management (KIMURA et al., 2018).

Similarly, the One Central Park project in Seattle adopted an intelligent building management system combined with IoT and big data analysis for real-time monitoring and control of air conditioning, lighting, and utilities. Data were analyzed on a cloud platform, enabling management personnel to monitor facilities via mobile apps or computer terminals, quickly addressing issues. The system also optimized energy usage, reducing costs and enhancing efficiency (Gavin et al., 2018).

Both cases demonstrate the advantages of IoT and intelligent systems in improving the operational efficiency, quality, and sustainability of prefabricated buildings.

2.4 The advantages, disadvantages, and operation and maintenance management modes of prefabricated buildings in post-disaster reconstruction areas.

The application of prefabricated buildings in post-disaster reconstruction offers several advantages. They enable rapid construction, providing swift emergency housing, and ensuring quality control for consistent building stability and safety. Prefabricated buildings reduce material waste, conserve resources, and lower costs, while their flexible design can meet diverse reconstruction needs. Additionally, their eco-friendly nature supports sustainable development in disaster areas (Zhang, 2018). However, they also have drawbacks: limited design flexibility due to industrialized production, high transportation costs, significant initial investment, and maintenance challenges requiring specialized skills and equipment (Guo, 2020). Despite these challenges, prefabricated buildings' advantages, including the use of renewable materials and reusable modules, highlight their importance in accelerating and enhancing the efficiency and quality of post-disaster reconstruction (Wu & Wei, 2021).

Table 2.1 Comparison of advantages and disadvantages of prefabricated buildings in post-disaster reconstruction areas

Advantage	Disadvantage
Rapid construction: mass production in factory conditions, and quickly assembled on site, so it can quickly meet the emergency housing needs in the affected areas, and is conducive to the rapid recovery of living conditions in the affected areas.	**Design limitations:** Prefabricated buildings are limited by factory production, and the design may not be flexible enough to meet specific personalized needs.
Quality control: the production process of prefabricated buildings is subject to strict quality control, and the size, materials and processes of components can ensure consistency and stability, so as to improve the quality level of the building, and is conducive to ensuring the safety of the affected people.	**Transportation costs:** The components of the prefabricated buildings need to be transported from the factory to the construction site, which may involve high transportation costs, especially in the post-disaster reconstruction areas, where the transportation conditions may not be convenient.
Saving resources: material waste can be reduced in the production process of prefabricated buildings, because the quantity of required materials can be accurately calculated according to the design, avoiding the waste phenomenon in the traditional site construction, which is conducive to saving resources and reducing costs.	**High initial investment:** Although prefabricated buildings can save construction time, their initial investment is high, including the cost of factory equipment and technical personnel training.
Flexible adaptation: the prefabricated building design is flexible, which can be customized according to different post-disaster reconstruction needs, to meet the building needs of different regions and different uses, with strong adaptability.	**Difficulty of maintenance:** prefabricated buildings usually adopt modern materials and technologies. Once faulty or need maintenance, they may require special technology and equipment, which is difficult to maintain.

In the field of prefabricated buildings, the operation and maintenance management mode is crucial to ensuring the normal operation and maintenance of building facilities. Three common operation and maintenance management modes of prefabricated buildings, as shown in Table 2.2:

Table 2.2 Comparison of three operation and maintenance management modes

Operation and maintenance mode	Advantage	Disadvantage
Traditional operation and maintenance mode	With strong practical experience and skills, be able to quickly respond to the field problems.	There may be problems such as information asymmetry and low maintenance efficiency, which cannot make full use of advanced technology.
Intelligent operation and maintenance mode	It improves the equipment operation efficiency, reduces the maintenance cost, and reduces the human intervention.	High intelligence of equipment, which requires a large cost for system integration and technical update.
Modular maintenance mode	Facilitate standardized management and rapid maintenance, reducing maintenance costs and cycles.	Need to establish a sound module inventory and replacement mechanism, which may affect the integration of the overall building.

In traditional maintenance models, specialized teams conduct regular inspections, cleaning, and repairs based on fixed schedules, leading to lower efficiency and susceptibility to human error. In contrast, the intelligent operation and maintenance model leverages IoT, AI, and big data analytics for remote monitoring, predictive maintenance, and automated operations, improving efficiency and precision through real-time monitoring and early issue detection (Zhao, 2024). Additionally, this model allows for the digitization and sharing of operational information, enabling comprehensive management and evaluation. The modular operation and maintenance model involves standardized modules with specific functions, facilitating rapid replacement and upgrades (Xie et al., 2024). Overall, intelligent and modular models are better suited to modern building needs, enhancing efficiency and reliability, and should be chosen based on a thorough assessment of building characteristics, technological capabilities, and costs.

III. RESEARCH METHODS

In this study,the questionnaire survey method was used to understand the recovery and reconstruction of prefabricated buildings in disaster areas. Two clear and concise questionnaires were designed and distributed to civil engineering professionals and residents in the disaster areas. A total of 153 valid responses about resident satisfaction and 58 about the current status of post-disaster reconstruction were collected. The data were organized, statistically analyzed, and interpreted to obtain reliable results. The questionnaire survey method was crucial, providing efficiency, quantitative analysis, and large sample coverage for a comprehensive understanding of the situation.Questionnaire design link: https://www.wjx.cn/vm/hIIVjgr.aspx#

This study uses field research to deeply understand the recovery and reconstruction of prefabricated buildings in disaster areas. By visiting disaster areas and directly observing and recording the situation, authentic and objective data were obtained. Detailed research plans were made, and research sites were carefully selected. Observations and recordings of the site environment, crowd behavior, and building structures provided rich data. These data will form the foundation for in-depth analysis and policy formulation. Field research is crucial as it offers direct and comprehensive materials for understanding and analyzing the research objects.

This study also adopts the expert interview method to investigate the recovery and reconstruction of prefabricated buildings in disaster areas. Through face-to-face communication and interviews with experts who have rich experience and authoritative status, we obtained professional insights, expertise, and viewpoints. Detailed interview plans were formulated, and experts' opinions and recommendations were promptly recorded during the interview process. Through the organization and analysis of interview content, we gained significant information and insights, facilitating an in-depth understanding and support for the research. The expert interview method plays a crucial role in this study, providing professional perspectives and recommendations, and promoting a comprehensive understanding and analysis of the recovery and reconstruction of prefabricated buildings in disaster areas.

IV. DATA ANALYSIS

The survey questionnaire for this study is divided into two parts. The first questionnaire is aimed at assessing the satisfaction of residents in disaster areas with prefabricated housing, while the second questionnaire is focused on investigating the current status of prefabricated building operation and maintenance management in post-disaster reconstruction projects involving civil engineering professionals.

4.1 Survey of residential satisfaction of residents of prefabricated buildings

The survey received 153 valid responses, primarily from residents of Ludian County. Of the respondents, 59.48% had lived in prefabricated houses for over 5 years, 22.22% for 3-5 years, 14.38% for 1-3 years, and 3.92% for less than a year. Additionally, 83.01% used these buildings as long-term residences, 13.73% for commercial purposes, and 3.27% as temporary residences. These findings provide a detailed understanding of the living conditions and usage patterns of prefabricated buildings in Ludian County, offering valuable data for decision-makers. Figure 4.1 illustrates the specific distribution.

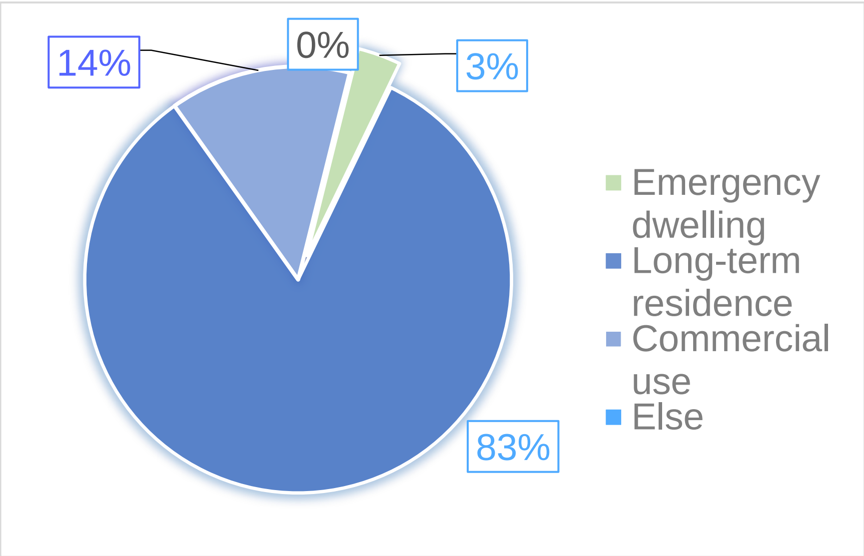

Figure 4.1 Proportion of main uses of prefabricated buildings

4.1.1 Comparative analysis of the performance of prefabricated buildings and traditional buildings

The survey results indicate (see Figure 4.2) that in terms of sound insulation,The average score of prefabricated buildings in sound insulation is 3.14, which is slightly lower than that of traditional buildings (3.16), indicating that their sound insulation performance is slightly poor. The thermal insulation performance is similar, the prefabricated building is 3.16 and the traditional building is 3.12. In terms of indoor air quality, the score of traditional buildings is slightly higher, which is 3.2, and that of assembled buildings is 3.1, indicating that traditional buildings have more advantages in ventilation and environmental conditions. However, prefabricated buildings scored higher in lighting and ventilation, with 3.18 and 3.22 respectively. The scores of structural stability and durability are similar, both being 3.16. Generally speaking, participants' evaluation of prefabricated buildings is similar to that of traditional buildings, but prefabricated buildings have a slight advantage in lighting and ventilation. These findings provide an important reference for evaluating and improving the performance of prefabricated buildings.

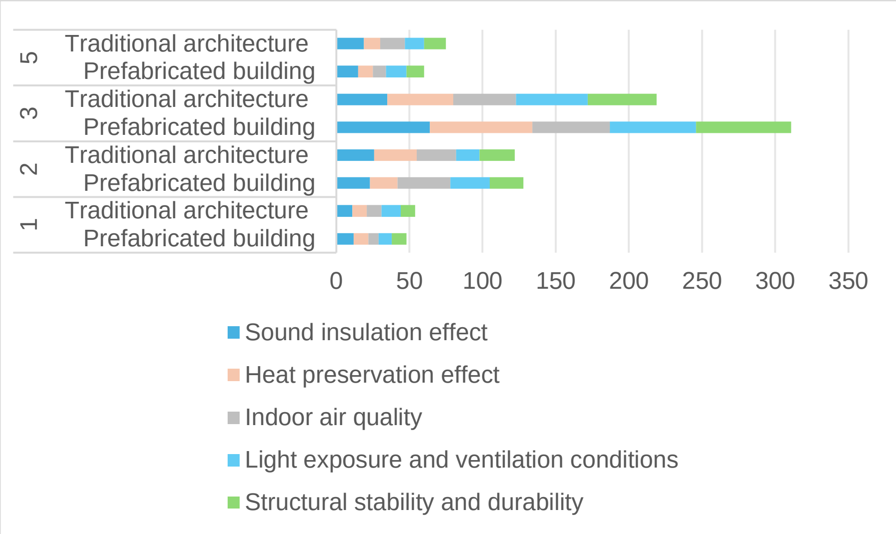

Figure 4.2 Comparative analysis of performance between prefabricated buildings and traditional buildings

4.1.2 Survey Results on Relevant Issues

Table 4.1 Results of questionnaire survey on related questions

Questionnaire title	Option	Copies	Percentage
6. How do you think your quality of life has changed since the post-disaster reconstruction?	Significant improvement	53	34.64%
	A slight improvement	50	32.68%
	Unchanged	29	18.95%
	Slightly worse	15	9.80%
	Significant deterioration	6	3.92%
7. The preference of prefabricated buildings compared to traditional buildings?	Strong preference	15	9.80%
	A little preference	32	20.92%
	Indifferent	76	49.67%
	I like tradition a little bit	21	13.73%
	Strong preference for tradition	9	5.88%
9. What is your overall satisfaction with living in a prefabricated building?(1 point is very dissatisfied, 5 points are very satisfied)	1 Points	12	7.84%
	2 points	25	16.34%
	3 points	59	38.56%
	4 Points	46	30.07%
	5 Points	11	7.19%
10. What are the services or facilities you need to improve or add in the prefabricated buildings you live in?	Safety performance improvement (such as fire prevention, shock prevention, etc.)	73	47.71%
	Improvement of living comfort (such as sound insulation, thermal insulation, etc.)	86	56.21%

	Perfect public facilities (such as elevators, parking lot, etc.)	92	60.13%
	Green and leisure space	62	40.52%
	Other	0	0%
13. How are you satisfied with the operation and maintenance management of the current prefabricated buildings in the post-disaster reconstruction projects?	Very satisfied	13	8.50%
	Satisfied	49	32.03%
	Commonly	55	35.95%
	Discontent	22	14.38%
	Very dissatisfied	14	9.15%
14. Is your willingness to live in prefabricated buildings in the future?	Would love to	12	7.84%
	Be willing	43	28.10%
	Commonly	62	40.52%
	Unwillingness	28	18.30%
	Very reluctant	8	5.23%

The analysis of the survey results (see Figure 4.1) shows that most interviewees think that the quality of life has been significantly improved or slightly improved since the reconstruction, which indicates that the prefabricated buildings have achieved some success in improving the quality of life of residents. Although some interviewees prefer traditional buildings, perhaps because of their familiarity and cultural identity, on the whole, there is still room for improvement in safety performance and living comfort of prefabricated buildings. However, the respondents were generally satisfied with the prefabricated buildings and recognized their operation and management, which may be because the prefabricated buildings are easier to manage and more efficient. Looking forward to the future, respondents are willing to continue to live in prefabricated buildings, showing their confidence in their potential advantages and future development. According to these insights, decision makers and stakeholders can better understand residents' needs, guide future architectural design and reconstruction, and improve residents' quality of life.

4.1.3 Analysis of Satisfaction with Performance of Prefabricated Buildings

Table 4.2. Performance satisfaction of prefabricated buildings

Title/Options	Very dissatisfied	Unsatisfied	Commonly	Satisfy	Very satisfied	Average
Safety	10	27	60	40	16	3.16
Amenity	8	28	58	51	8	3.15
Complexity of facilities	6	28	71	42	6	3.09
Environmental friendliness	13	26	56	49	9	3.1
Problem processing and solution speed	14	23	61	45	10	3.09

Title/Options	Very dissatisfied	Unsatisfied	Commonly	Satisfy	Very satisfied	Average
Maintenance and maintenance services	8	30	54	52	9	3.16
Estate management	8	25	62	42	16	3.22
Subtotal	67	187	422	321	74	3.14

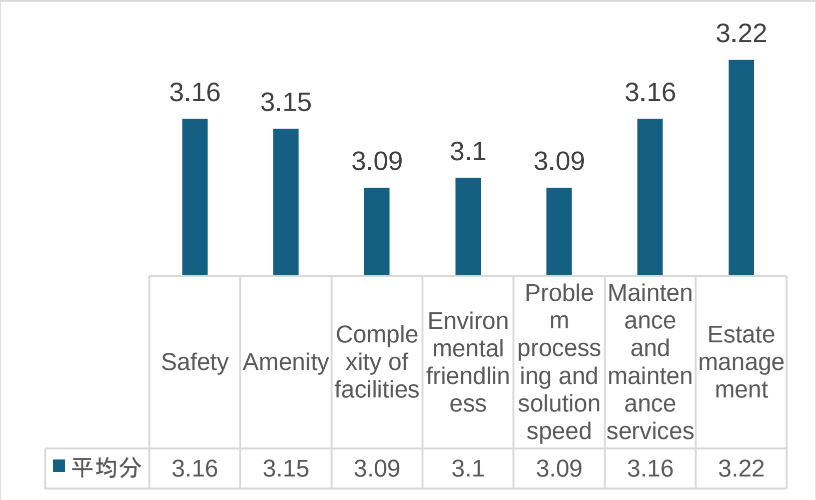

Figure 4.3 Performance satisfaction of prefabricated buildings

According to the survey results (see Table 4.2 and Figure 4.3), Participants have different satisfaction with the performance of prefabricated buildings. The safety is highly satisfactory, with an average score of 3.16, which reflects the safety considerations in design and construction. Similarly, the comfort satisfaction is high, with an average score of 3.15, which stems from the emphasis on residents' comfort. However, the evaluation of facilities integrity, environmental friendliness, speed of problem solving, maintenance service and property management is significantly different, with an average score of 3.09 to 3.22, reflecting the different influences of personal experience and needs. Generally speaking, most participants are satisfied with the prefabricated buildings or moderately satisfied, with an overall average score of 3.14, which shows that they have considered various factors such as safety, comfort and the integrity of facilities and services in their evaluation.

4.1.4 Summary of Survey on Resident Satisfaction with Prefabricated Buildings

According to the survey results, the overall residential satisfaction of prefabricated building residents is relatively high. In terms of safety, comfort and convenience, most residents expressed satisfaction or high satisfaction. However, some residents still put forward suggestions to improve the completeness of the facilities and environmental friendliness. This suggests that prefabricated buildings perform well in providing basic residential needs, but there is still room for improvement in detail. In general, the survey results show the residents' overall recognition of the living environment of the prefabricated buildings, which provides a useful reference for further improvement and optimization.

4.2 Survey on the Operation and Maintenance (O&M) Management Status of Prefabricated Buildings in Post-Disaster Reconstruction Projects

This survey focuses on the current situation of the operation and maintenance management of prefabricated buildings in the post-disaster reconstruction projects. By issuing 58 questionnaires and recovering all 58 questionnaires, 58 valid questionnaires were obtained, and the effective recovery rate was 100%. The survey respondents are mainly from the construction units and the operation and maintenance management departments, accounting for 75.886%, while the remaining 24.14% of the survey respondents are from the property management units. In terms of the type of organization, government agencies accounted for 13.79%, private enterprises for 39.65% and foreign enterprises for 46.55%. The survey design aims to fully understand the understanding and practice of the staff in the field of civil engineering for the prefabricated building operation and maintenance management, and to provide reliable data support and guidance suggestions for the operation and maintenance work in the post-disaster reconstruction projects.

4.2.1 Distribution of Work Experience

The working life of the respondents is mainly 1-10 years, of which 4 to 6 years accounted for 44.83% and effective 1 to 3 years accounted for 27.59%. The effective life of 7 to 10 years accounts for 15.52%, and the effective life of more than 10 years accounts for 12.07%. The working life of the respondents is generally long, which is conducive to the effective identification of the operation and maintenance management status of prefabricated buildings in post-disaster reconstruction. The specific distribution is shown in Table 4.3:

Table 4.3 Distribution of working years

Working life	Quantity (person)	Percentage (%)	Effective percentage of (%)	Cumulative percentage of (%)
1-3 Years	16	27.59%	27.59%	27.59%
4-6Years	26	44.83%	44.83%	44.83%
7-10Years	9	15.52%	15.52%	15.52%
More than 10 years	7	12.07%	12.07%	12.07%
Total	58	100%	100.00%	100.00%

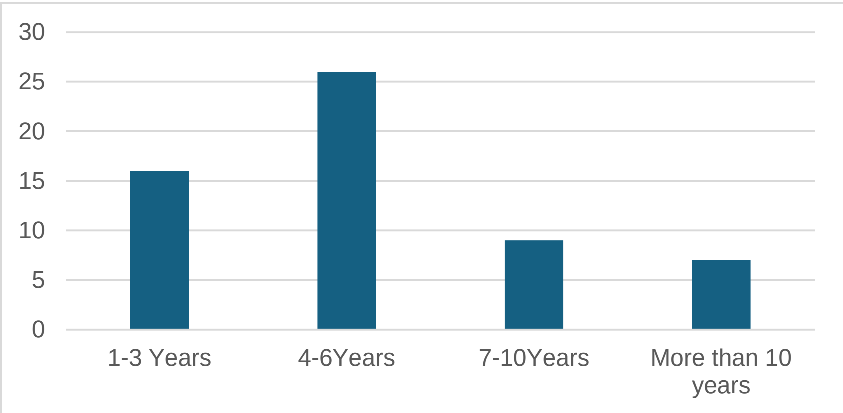

Figure 4.4 Histogram of the distribution of years of service

Additionally, the survey also involved the primary purposes of prefabricated building projects in which relevant personnel participated. The survey results indicate that prefabricated building projects engaged by civil engineering professionals cover multiple sectors (see Figure 4.5). Among them, 51.72% of projects are primarily for residential purposes, while 56.9% are for commercial purposes. Furthermore, 50% of the projects are designated for educational purposes, and 29.31% for medical services. It is noteworthy that the survey did not include prefabricated building projects for other purposes. These data reflect the wide-ranging applications of prefabricated building projects engaged by civil engineering professionals across various sectors, providing diversified solutions for different industries.

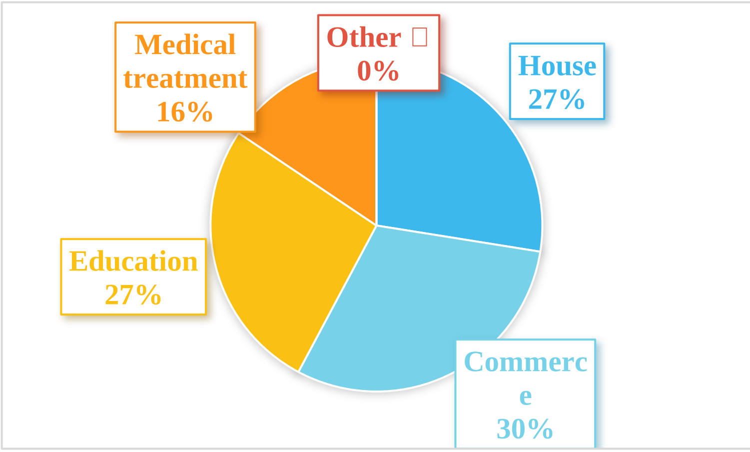

Figure 4.5 Main uses of prefabricated building projects

4.2.2 Survey Results on Relevant Issues

Table 4.4 Results of questionnaire survey on related questions

Questionnaire title	Option	Copies	Percentage
What is your opinion on the applicability of the existing O & M management software in prefabricated buildings?	Suit	17	29.31%
	Not applicable enough	35	60.34%
	Dimness	6	10.34%
Do you think the adoption of digital technology (such as IoT, BIM, etc.) in post-disaster reconstruction projects helps to improve the operation and maintenance management of prefabricated buildings?	Yes	46	79.31%
	No	2	3.45%
	Indeterminacy	10	17.24%
What role do you think the government should play in promoting the operation and maintenance management of prefabricated buildings in post-disaster reconstruction projects?	Provides training and support	40	68.97%
	Formulate relevant policies	41	70.69%
	Provide financial support	37	63.79%
	Other (please indicate)	0	0%
How do you view the residents' needs and feedback on prefabricated buildings?	Very important	9	15.52%
	Important	18	31.03%
	Commonly	16	27.59%
	Not too important	9	15.52%
What do you view of the application prospect of prefabricated buildings in future post-disaster reconstruction projects?	Very optimistic	3	5.17%
	Optimistic	19	32.76%
	Neutrality	18	31.03%
	Pessimistic	15	25.86%
	Very pessimistic	3	5.17%

According to the survey results, 60.34% of the respondents think that the existing maintenance management software is not suitable for prefabricated buildings, mainly because the software lacks the consideration of the uniqueness of prefabricated buildings and the customization function, as well as the technical complexity requirements. 79.31% of the respondents believe that digital technologies (such as Internet of Things and BIM) can enhance maintenance and management, improve efficiency and accuracy, reduce costs and enhance security through real-time monitoring, predictive maintenance and remote management.

Respondents believe that the government should provide training, policy and financial support to promote the maintenance and management of prefabricated buildings in post-disaster reconstruction projects. Most people emphasize the importance of residents' needs and feedback, which reflects the close relationship between prefabricated buildings and daily life. Although they have different views on the future prospects, 32.76% of the respondents are generally optimistic, recognizing the potential and advantages of prefabricated buildings in post-disaster reconstruction, and believe that they will be more widely used with technological progress and policy support.

4.2.3 Analysis of Key Factors to Improve O&M Efficiency of Prefabricated Buildings

According to the survey results (see Table 4.5 and Figure 4.6), Participants believe that regular maintenance and inspection is the most important factor, accounting for 63.79%, because it can find and solve problems in time and ensure the normal operation of building facilities. During the on-site inspection, problems such as damp walls, mold, paint peeling and railing corrosion are common. Staff training and education (60.34%) and technological innovation and upgrading (67.24%) are also regarded as key points. Maintenance quality can be improved by improving the skills of maintenance personnel and introducing new technologies. In addition, a reasonable maintenance budget (67.24%) and an optimized management system (58.62%) are equally important to ensure the smooth implementation of maintenance activities and improve work efficiency. These factors can effectively improve the maintenance efficiency of prefabricated buildings and ensure their long-term stable operation.

Table 4.5 Key factors to improve the operation and maintenance efficiency of prefabricated buildings

Element	Number of people	Scale
Periodic maintenance and inspection	37	63.79%
Staff training and education	35	60.34%
Technological innovation and upgrading	39	67.24%
Reasonable operation and maintenance budget	39	67.24%
Optimization of management system	34	58.62%
Other	0	0%
Summation	58	100.00%

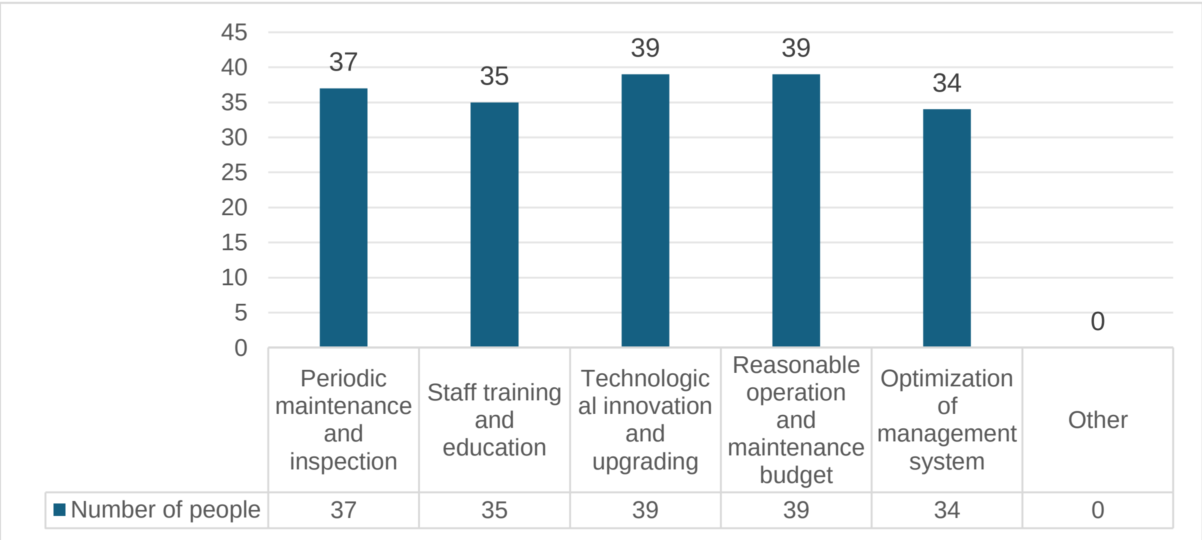

Figure 4.6 Key factors to improve the operation and maintenance efficiency of prefabricated buildings

4.2.4 Summary of Survey on the Operation and Maintenance (O&M) Management Status of Prefabricated Buildings in Post-Disaster Reconstruction Projectsaditional buildings

According to the survey, most respondents think that the existing maintenance management software is not suitable for prefabricated buildings because it does not consider the uniqueness of prefabricated buildings or lacks customization functions. They generally believe that using digital technology, such as real-time monitoring and predictive maintenance, can improve maintenance efficiency, reduce costs and enhance security. Respondents believe that the government should provide training, policy and financial support to promote the maintenance and management of prefabricated buildings in post-disaster reconstruction projects. Despite their different attitudes, respondents are generally optimistic about the future prospects of prefabricated buildings. The key factors to improve maintenance efficiency include regular maintenance inspection, staff training, technological innovation, reasonable budget and optimized management system, which will ensure the long-term stable operation of prefabricated buildings.

V. DISCUSSION

The establishment of regular inspection and maintenance system is helpful to solve the maintenance difficulties of equipment and facilities of prefabricated buildings in Yunnan earthquake-stricken areas and improve the overall level and efficiency of operation and maintenance management(Ma et al., 2024). The inspection and maintenance plan should be made according to the characteristics of prefabricated buildings and the use of equipment, and the inspection period and maintenance plan should be defined, and a sound maintenance record and information management system should be established to accumulate long-term maintenance data. Clear responsibilities and operating procedures to ensure timely and effective completion of maintenance tasks, and regularly evaluate and improve equipment performance. Personnel training and skills upgrading are also very important. Maintenance personnel should receive relevant training and constantly improve the maintenance system through technical exchange and experience sharing. This not only improves the reliability and stability of equipment, reduces the maintenance cost, but also improves the professionalism and skills of maintenance personnel, thus comprehensively improving the operational efficiency and management level of prefabricated buildings.

Introducing intelligent monitoring technology is an effective measure to solve the maintenance difficulties of assembled building equipment and facilities. Through the Internet of Things (IoT), the real-time monitoring of equipment operation status can be realized, so that anomalies and faults can be found in time, the maintenance response time can be shortened, and the operation efficiency and equipment reliability can be improved (Wu, 2023). In addition, using artificial intelligence (AI) and big data analysis, intelligent monitoring system can monitor and collect data in real time, provide fault diagnosis and maintenance suggestions, optimize maintenance strategy and resource allocation, and reduce maintenance costs (Liu et al., 2023). Intelligent monitoring technology can find potential problems in advance through data analysis and predictive maintenance, enhance the stability and availability of equipment, and significantly improve the operational efficiency and management level of prefabricated buildings.

Establishing maintenance records of equipment and facilities is a key measure to solve the maintenance difficulties of prefabricated buildings. The maintenance process, including date, content, personnel, etc., is recorded by the system, which provides reference for future work and contributes to the normal operation of the equipment and prolongs its service life (Yuan, 2023). In addition, evaluate and improve the maintenance status regularly, find and solve problems in time, and improve the efficiency and quality of maintenance management. The electronic maintenance record system is established by using information technology to realize centralized management, rapid retrieval and digital storage of maintenance information, and improve the accuracy and reliability of information (Jiang, 2023). The system can also provide scientific basis and reference for maintenance management decision-making through data analysis and statistical functions.

Establishing a comprehensive technical training system is an important way to solve the technical shortage of assembled building maintenance personnel. By designing systematic training courses, compiling targeted training materials and building experienced teachers, maintenance personnel can obtain comprehensive technical training and improve their technical proficiency and comprehensive ability. Training courses should cover building structure, equipment maintenance, safety management, etc. Teaching materials should pay equal attention to theory and practice, and teachers should have practical experience and teaching ability. (Wu, 20204) Increase the investment in training, expand the scale, increase the frequency and depth, meet different needs through centralized training, on-site training, distance education and other forms, constantly improve the professional level and skills of maintenance personnel, and adapt to the changes in operation and maintenance management and technological progress.

By introducing more maintenance personnel and establishing a talent pool, the human resource requirements for the operation and maintenance management of prefabricated buildings can be ensured.

Establish a talent pool, and manage the information of maintenance personnel, including qualifications, skills and training records, by creating a database to achieve flexible deployment and utilization. Regular talent reserve and training plan can improve the professional ability of maintenance personnel and make them better cope with emergencies and project changes (Wu, 2021). Cooperate with relevant units and institutions, share talent resources and information, adopt collaborative sharing mode, significantly improve the efficiency and quality of maintenance management, and provide reliable talent support for the operation and maintenance management of prefabricated buildings.

Collaboration and sharing is an important strategy to solve the shortage of maintenance personnel in prefabricated buildings. Cooperation and sharing of resources with other regions or units can effectively alleviate the shortage of personnel and improve the efficiency and quality of maintenance management. By integrating human resources and optimizing allocation, a larger talent pool will be formed and abundant human support will be provided (Zhuang, 2024). In addition, in cooperation with universities, research institutions and industry associations, technical seminars and academic lectures are organized to provide technical learning and exchange platforms for maintenance personnel, so as to enhance their professional skills and capabilities, thereby improving the level and quality of maintenance management of prefabricated buildings.

VI. CONCLUSION AND RECOMMENDATION

This study summarizes the disaster situation and emergency response in Yunnan earthquake-prone areas in the past 20 years, and deeply investigates the application and challenges of prefabricated buildings. Questionnaire analysis shows that although prefabricated buildings have accelerated post-disaster reconstruction, there are problems in maintenance, technical ability and human resources. The study puts forward some strategies, such as establishing regular inspection system, introducing intelligent monitoring technology, perfecting technical training system and talent reserve mechanism, in order to improve the maintenance management level and ensure the quality of life of residents. Prefabricated buildings are very important for post-disaster reconstruction, and their management quality directly affects the sustainability of reconstruction results and residents' lives. The research provides reference for Yunnan and other disaster-prone areas, and points out that technological progress and experience accumulation will solve the current challenges, promote social stability and economic recovery, and have important enlightenment significance for future reconstruction strategies.

This study puts forward strategies to deal with natural disasters and optimize the application of prefabricated buildings, including strengthening the awareness of disaster prevention and reduction, making a comprehensive emergency plan and adopting advanced technologies to enhance disaster resistance. In the design and construction, we should consider the influence of earthquakes, floods and other disasters, adopt reinforced structures and seismic materials, and plan evacuation routes. In addition, improve the professional skills and disaster response ability of maintenance managers, and improve their disaster awareness and operational skills through systematic training. The government and enterprises need to jointly promote the development of prefabricated construction industry, establish inter-departmental cooperation mechanism, strengthen information sharing and resource integration, and improve the efficiency and quality of post-disaster reconstruction. Encourage technological innovation and industrial upgrading to improve building quality and performance, ensure reliable and efficient solutions for post-disaster reconstruction, and thus build a safer and more sustainable social environment.

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