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RESEARCH ARTICLE

A Qualitative Study of Safety Issues in Industrialised Buildings in China

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ABSTRACT - Industrialised buildings, while emphasizing efficiency and innovation, brings about safety risks that surpass those of traditional construction methods. This study aims to identify and understand the inherent safety risk factors in industrialised buildings, with the ultimate goal of improving safety standards. Qualitative research was conducted, involving in-depth interviews with 20 individuals including scholars, prefabricated manufacturer, contractors, and policymakers. The interviews revealed common safety issues: shortage of skilled workers, challenges in hoisting operations, lack of management responsibility, and problems with machinery and equipment. Addressing these multifaceted challenges is crucial for enhancing safety in industrialised buildings projects. The findings provide valuable insights for safety management in the industry, protecting workers, ensuring construction quality, and supporting its ongoing development.

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1.0 INTRODUCTION

Industrialised buildings, also known as prefabricated or modular construction, is a modern construction method. Its main characteristics are the prefabrication of some or all building components in factories, followed by on-site assembly, thereby enhancing the efficiency and standardisation of the construction process [1]. Statistically, Industrialised buildings can improve production efficiency by about 20-30%, reduce construction costs by 10-15%, and shorten construction periods by nearly 40%. It also contributes to improving the working environment, increasing worker safety by about 50%, and reducing environmental pollution by nearly 50% [2]. Therefore, Industrialised buildings has significant value in promoting the modernisation process of the construction industry, achieving high-quality economic development, and advancing green building and environmental protection.

The Chinese government recognises the importance of Industrialised buildings and encourages its development through a series of policies. For instance, in 2016, the State Council of China issued the "Guidelines on Vigorously Developing Prefabricated Construction", explicitly proposing a goal to achieve a proportion of over 30% of Industrialised buildings in new buildings nationwide by 2020 [3]. In 2020, the Ministry of Housing and Urban-Rural Development (MOHURD) of China further clarified in the "Fourteenth Five-Year Plan for China's Construction" the target and direction for the development of Industrialised buildings. As a crucial research and development task, Industrialised buildings is included in the specialised planning and key tasks in fields such as rural revitalisation and urban-rural human settlement construction. The emphasis is on the technical research and development of the whole chain design deployment in areas such as the basic theory, design, standard specifications, testing and evaluation, component production, construction and building, and industrialisation of Industrialised buildings, with the expectation of promoting its rapid development in China. Meanwhile, China has also released a series of supportive policies, including preferential loans, tax reductions, and technical research and development support, to encourage enterprises and individuals to adopt the Industrialised buildings method. The goal is to drive the transformation and upgrading of the construction industry, improve production efficiency, reduce energy consumption and environmental pollution, and enhance the quality of life for residents [4].

While Industrialised buildings is rapidly developing in China, it confronts a significant challenge. This construction mode is distinctly different from traditional construction models in aspects such as the production, transportation, and hoisting of prefabricated components, which leads to some safety issues not encountered in traditional building methods [5]. For instance, the production and transportation of prefabricated components may involve larger weights and volumes, potentially increasing the risk of work-related accidents [6]. Simultaneously, the hoisting and installation of prefabricated components require more precise operations, otherwise serious safety issues may arise [7].

Due to its unique working environment and operational conditions, the construction industry has always been a high-incidence area for work-related accidents [8]. Although research over the past few decades has delved into safety issues in the construction industry, most have primarily focused on safety issues at construction sites [9]. There is relatively less research on the safety of emerging Industrialised buildings [10]. Therefore, it is necessary to conduct in-depth research on the unique safety issues of Industrialised buildings to enhance its safety and efficiency.

Through the results of our study, we aim to provide practical insights and recommendations concerning safety issues to the relevant stakeholders in Industrialised buildings, in order to promote the safety and sustainable development within

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this field. This will contribute towards the improvement of design, construction, and management in Industrialised buildings, ensuring the safety and health of personnel and reducing the risk of accident occurrences [11].

2.0 LITERATURE REVIEW

As the development of Industrialised buildings continues, its safety issues become increasingly prominent, attracting the attention of numerous scholars. Industrial buildings place more emphasis on integrated manufacturing than traditional cast-in-place buildings, increasing the potential for safety hazard accidents [12][13].

Regarding the study of causes leading to safety incidents in Industrialised buildings, the US Occupational Safety and Health Administration (OSHA), based on data from an analysis of 125 types of accidents related to modular/prefabricated construction, concluded that the most common type of injury in modular/prefabricated construction was 'fracture' and the most common cause of the accident was 'fall'. The most common cause was 'unstable structure'[14]. In China, some scholars have identified and analysed the sources of hazards affecting the safety of Industrialised buildings through the State General Administration's Case Study on Safety Management in Construction Projects and the Ministry of Construction's Safety Inspection Standards for Building Construction, with reference to the provisions of the Identification of Major Hazardous Sources (GB18218-2000). The results of the study show that deviations in the specifications of prefabricated components, defects in component systems and low technical level of assembled components are among the most common causes of safety accidents [15].

A number of scholars generally consider prefabricated components to be the greatest troublemaker for on-site safety. The Analytic Hierarchy Process was used to calculate the safety risk factor and the results showed that the requirements for materials in Industrialised buildings differ from those of traditional cast-in-place methods [16]. The produced prefabricated components are usually large in volume, and if improperly stacked at the construction site, they may become unstable, leading to potential collapse or slippage. This can cause injury or damage to construction workers or other facilities at the construction site. Moreover, if the storage environment for the prefabricated components is poor, such as being too damp, hot, or cold, it could affect the structural performance of the components, or even cause structural failure, thereby increasing safety risks [17]. Some scholars using a combination of cause-effect analysis, fault tree analysis, and data envelopment analysis, suggested that the installation of prefabricated components is a link in construction projects that is prone to safety incidents and is easily overlooked [18]. Therefore, it is essential to provide technical briefings to the relevant operators before installation, ensuring the quality of component connections, and reducing safety risks [19].

In summary, although existing research has made certain contributions to the safety issues of Industrialised buildings, there still exists an oversight of off-site factors and inadequate consideration of deep-seated factors. Firstly, existing studies primarily research from the perspective of accident types and hazard sources, focusing on analysing the direct causes of safety incidents. However, the root causes of safety problems in Industrialised buildings are often more complex, with deep-seated indirect causes and potential factors often overlooked. These factors might involve organisational management, personnel quality, cultural atmosphere, and policies and regulations, all of which have a significant impact on the safety of Industrialised buildings. Secondly, while most scholars use quantitative methods which can provide measurable and comparable data, suitable for statistical analysis, these methods might not fully understand the complex factors and background leading to safety incidents, such as working environment, organisational culture, and management strategies. Therefore, the safety issues of Industrialised buildings still require further research and resolution. This research needs to consider more comprehensively the characteristics of Industrialised buildings, as well as the relationship with the intrinsic causes of safety issues, in order to prevent and control the occurrence of safety incidents more effectively.

3.0 METHODOLOGY

In this research, we choose to adopt a combined research method of the "4M1E" theory and interviews, aiming for a thorough investigation of the safety issues in Industrialised buildings.

The "4M1E" theory we adopted is a structured framework for understanding and analysing safety issues. This theory covers five aspects: Man, Machine, Material, Method, and Environment, thoroughly examining the key factors that may influence the safety of Industrialised buildings. Moreover, the 4M1E theory emphasises the interactive influence among these factors, providing a systemic perspective to understand and reveal hidden safety risks.

We opted for qualitative research interviews as our primary data collection method to gain more in-depth and comprehensive insights. Interviewing offers rich detail, can handle complex and intertwined variables, and reveals internal relationships and interactions, which is vital for studying the complex, dynamic, and intricate issue of construction safety. Through interviews, we can obtain participants' viewpoints, experiences, and feelings directly, which will aid in our deep understanding and interpretation of safety issues in Industrialised buildings. Semi-structured interviews were used.

On the sample of respondents, we will interview 20 experts, including managers of prefabrication manufacturers, managers of Industrialised buildings contractors, scholars, and relevant policy-makers. This set-up aims to acquire diversified viewpoints for a comprehensive understanding of safety issues in Industrialised buildings. Respondents are

asked to identify possible solutions based on their past experiences and opinions. Due to geographical constraints, the interviews were conducted online via video. Each interviewee's interview time was approximately 20-30 minutes. The related information of the respondents is shown in Table 1.

Table 1. Respondents' profile

Serial No.	Position	Background	Number	Proportion
1	Managers	manufacturers	3	15%
2	Managers	Contractors	8	40%
3	Professor	Scholars	6	30%
4	Policy-makers	Government	3	15%

All respondents were required to have more than five years of work experience in the field of construction and to have participated in at least two Industrialised buildings projects. Additionally, they were required to hold at least an undergraduate degree. These two criteria aimed to ensure that the respondents had a sufficiently in-depth and comprehensive understanding of the research subject. The requirement for work experience meant that the respondents could provide specific, detail-rich information from a practical perspective, which is of great value in revealing the complexity and diversity of the research topic. At the same time, holding at least an undergraduate degree ensured that the respondents had sufficient theoretical knowledge and analytical capabilities to conduct in-depth reflection and theoretical analysis of the research subject. Such requirements helped to enhance the quality of interview data and the credibility of the research. The specifics are depicted in Figure 1.

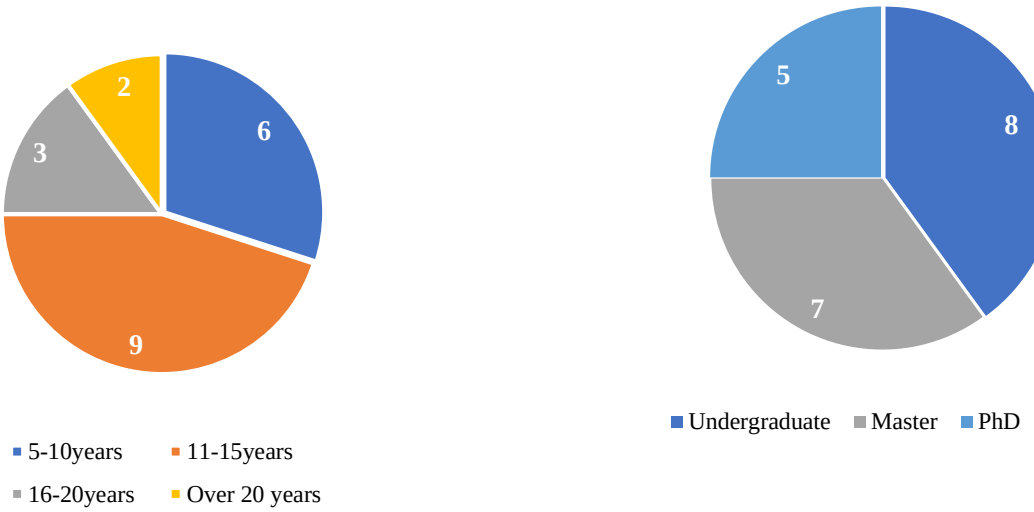

Figure 2. Respondent's experience and educational background in Industrialised buildings

4.0 RESULTS AND DISCUSSION

Based on the data from 20 respondents, we have identified the relative frequencies of four major factors for safety risks in Industrialised buildings (Figure 2). Details will be discussed in the following sections.

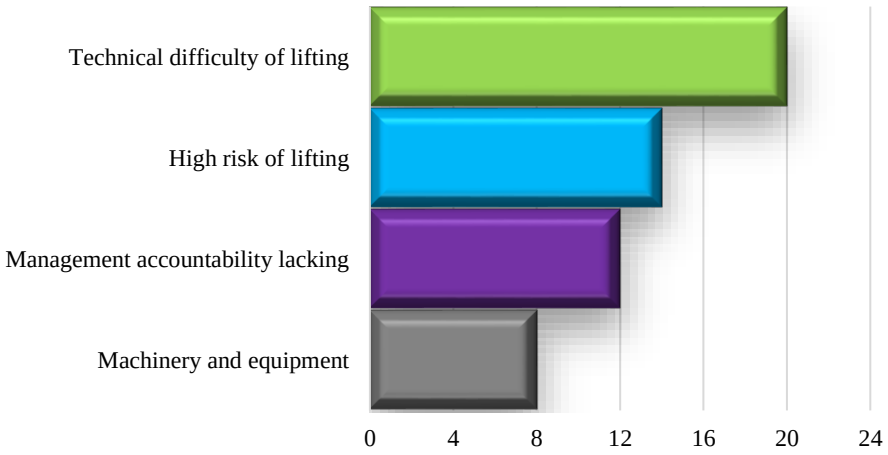

Figure 1. Frequency of safety issues in industrialised buildings

4.1 Lack of skilled workers

All respondents unanimously believe that the lack of technical personnel with rich theoretical and practical experience in Industrialised buildings in China is a significant factor threatening safety. Industrialised buildings demand high precision and standardisation, as all components are prefabricated in a factory environment before being transported to the construction site for assembly. This means that each prefabricated component must meet very precise specification requirements, as any errors can potentially impact the quality and safety of the entire building. In this context, technically proficient workers, with their wealth of experience and technical depth, can manufacture and install prefabricated components more accurately according to design requirements, thereby improving the precision and safety of construction [20]. Industrialised buildings also require an efficient and smooth construction process, as all prefabricated components need to be installed within a predetermined time and sequence; any delay can affect the progress and quality of the entire project. This calls for workers to possess professional knowledge and practical experience, to better understand and execute the construction plan, and improve construction efficiency [21]. Technically proficient workers can identify and solve problems during the construction process in a timely manner, avoiding delays and conflicts that could potentially lead to accidents. Inevitably, accidents and emergencies occur during the construction process [22]. Technically proficient workers, with their rich experience and professional training, are usually able to make quick, accurate judgements, and take appropriate emergency measures, avoiding or mitigating the occurrence of safety accidents [23].

However, the current reality is that safety education and training for construction project participants is lagging, and new technologies cannot be effectively popularised and deployed. Daily construction operations are not being conducted entirely according to construction specifications. Indeed, the majority of participants in China's Industrialised buildings projects are still traditional construction workers, many of whom are migrant workers. These workers generally have a lower level of education and are older, leading to resistance to new technologies due to factors such as age and educational level. There are also issues in the industry with low requirements for technical proficiency. Some companies may prefer to hire workers with lower salaries but inadequate skills, resulting in workers with insufficient technical levels performing jobs that require high technical proficiency on construction sites. Secondly, in many cases, there is a lack of adequate training and education for workers. This could be due to companies not providing sufficient on-the-job training, or the training provided being of poor quality, resulting in workers not receiving adequate technical training and knowledge.

Therefore, the lack of skilled technical workers is a critical factor in the occurrence of safety incidents in Industrialised buildings. Workers with proficient skills play a decisive role in enhancing the safety of Industrialised buildings. As such, we must continually improve workers' technical skills, strengthen their safety awareness, and continually optimise existing technologies and processes to reduce safety risks and ensure the smooth progress of construction.

4.2 High risk of lifting

More than half of the respondents believe that in Industrialised buildings, the condition of components is one of the crucial factors determining the safety of hoisting operations. The weight, shape, texture, and size of components affect the choice of hoisting equipment and operating methods, as well as the calculation of loads and the design of hoisting paths. Firstly, the weight of the component forms the basis for load calculation and is a key factor in selecting hoisting equipment. If the weight of the component exceeds the maximum load of the equipment, it increases the risk of equipment overload, leading to equipment damage or dropped loads [24]. The shape and size of the component influence the operating methods of the hoisting equipment and the design of the hoisting path. For example, components with irregular shapes or large sizes may require special hoisting methods and equipment. Simultaneously, more detailed path design is needed to avoid collisions with surrounding facilities or personnel [25]. Furthermore, the texture of the component is also a factor to consider. Some fragile or sensitive components require special handling and hoisting methods to prevent damage or deformation during the hoisting process. For these components, special hoisting plans need to be developed, and special hoisting equipment and auxiliary devices may be needed. Therefore, a comprehensive understanding and assessment of the components, along with the development of appropriate hoisting plans based on the component's condition, are vital steps to ensure the safety of hoisting operations.

On the other hand, hoisting technical decision-making is a crucial element in hoisting operations, encompassing the choice of hoisting equipment, load calculation, hoisting path design, and equipment operation, among others. These decisions directly relate to the safety of hoisting operations. For instance, selecting appropriate hoisting equipment is the first step in hoisting technical decision-making. This involves not just the type and scale of the equipment, but also its performance and condition. A wrong choice of equipment can lead to equipment overload or instability, thus increasing the risks involved in hoisting operations. Load calculation is another critical decision-making stage. If calculations are inaccurate, they could lead to equipment overload or instability, or cause the hoisted object to shift or fall during the hoisting process. The design of the hoisting path must take into account the conditions of the working site, the size and shape of the hoisted object, and surrounding facilities and personnel, among other factors. An irrational path design can increase the risk of collisions and displacements during the hoisting process. Lastly, equipment operation is the execution phase of hoisting operations and is the stage that directly impacts safety. Incorrect operational methods could lead to dropped loads or equipment failure. Therefore, operators need to possess sufficient technical proficiency and experience.

In these decision-making processes, the professional skills and experience of technical personnel are paramount. They need to be able to accurately assess component conditions, select appropriate equipment, calculate precise loads, design rational hoisting paths, and operate the equipment correctly.

4.3 Management accountability lacking

During the interview process, some respondents believe that the role of management personnel is critical in construction projects, and their sense of responsibility directly affects the safety of industrialized buildings in workplaces such as component production, transportation, and installation. Managers not only need to ensure the smooth progress of work technically but also need to ensure that all safety standards and procedures are implemented at the management level.

In the component production stage, managers need to ensure that the production process complies with safety regulations, that workers operate machinery according to the prescribed methods, use qualified raw materials, and need to timely detect and resolve potential safety hazards during the production process. If managers lack a sense of responsibility and are not strong in the supervision and management of these aspects, it may lead to safety accidents during the production process.

In the component transportation phase, managers need to ensure the safety of transportation equipment and routes, ensure reasonable loading and fixing, and prevent component damage or safety accidents caused by bumps and emergencies during transportation. For managers, they need to make detailed transportation plans and supervise and handle emergencies during transportation.

In the component installation stage, the responsibility of management personnel is manifested in strictly following design drawings and construction standards, timely detecting and repairing equipment problems, and ensuring the safety of workers. If management is not strong in managing and supervising these stages, it can lead to serious safety accidents.

Therefore, the sense of responsibility of managers has a profound impact on the safety of industrialized buildings. Managers who lack a sense of responsibility often lead to omissions in safety management, thereby increasing the risk of safety accidents. For the above problems, possible solutions mainly include strengthening management training, increasing supervision, and establishing a company culture that encourages safety. For managers, more rigorous management training should be conducted to improve their professional skills and management capabilities, especially their understanding and handling of project safety [26]. At the same time, supervision of managers should be increased to ensure that they strictly follow safety procedures in their daily work and handle potential safety hazards in a timely manner. In addition, establishing a company culture that encourages safety is also very important. This not only requires the company to pay attention to it in terms of policy but also needs to spread the concept of safety among employees in various ways, such as regular safety training, safety drills, and safety rewards. This can make all employees, including managers, fully realize the importance of safety, voluntarily comply with safety procedures, and improve the safety of work.

4.4 Machinery and equipment

Mechanical equipment used in industrialized construction is also one of the topics of concern to respondents. In addition to the use of concrete prefabricated component production equipment in industrialized construction, it usually also includes various types of lifting equipment, transportation equipment, cutting equipment, etc. This equipment are powerful, efficient, but also carry a higher degree of danger. Although most mechanical equipment will fully consider safety factors in the design, such as installing guards or other protective facilities, to prevent possible harm to personnel or the equipment itself during operation. To operate these mechanical equipment, specific technology and experience are still needed, and must be operated through special training. And during the operation process, certain safety procedures must be followed, such as wearing necessary protective equipment, prohibiting loitering around the equipment, etc. Lifting equipment such as tower cranes, truck cranes, etc., their main function is to lift and move heavy building components to a designated location. Improper operation or equipment defects may cause accidents such as equipment overturning, component dropping, etc., posing a serious threat to the safety of personnel. Transportation equipment such as forklifts, transport vehicles, etc., are mainly used to transport building components or materials. The over speed of the equipment, brake failure, unclear line of sight, etc., may cause accidents such as collisions and rollovers, causing personnel injuries or component damage. Cutting equipment such as electric saws, cutting machines, etc., the high-temperature sparks and sharp cutting blades generated during use have a high degree of danger. Improper operation of equipment or failure of protective devices may cause fires or personnel injuries.

For the above problems, possible solutions mainly include strengthening equipment maintenance, improving the technical proficiency of operators, and establishing a sound safety inspection system. Regular maintenance and maintenance of equipment is an important means to prevent equipment defects, which can timely discover and repair equipment problems and ensure the normal operation of the equipment. The technical proficiency of operators is crucial to the safe use of equipment. They need to be familiar with the operation method of the equipment, understand the performance characteristics of the equipment, and be able to make correct judgments and deal with problems when the equipment has problems. The establishment of a safety inspection system can allow management personnel to regularly check the equipment and work environment, find and deal with potential safety hazards in time, and prevent accidents.

5.0 CONCLUSION

Through in-depth interviews, this study reveals the four major issues facing safety in Industrialised buildings: the lack of skilled technical workers, challenges in hoisting operations, the lack of responsibility among management personnel, and issues related to machinery and equipment. Strategies to address these issues include enhancing technical training, developing safer and more efficient hoisting equipment and methods, strengthening training and assessment for management personnel, and improving maintenance and upkeep of equipment. Looking forward, we anticipate more research and practices focusing on optimising the technical training system, developing new hoisting equipment and techniques, enhancing the sense of responsibility and capabilities of management personnel, and more effective ways of maintaining and using equipment, in the hope of achieving higher safety standards in the development of Industrialised buildings.

6.0 AUTHOR CONTRIBUTIONS

Xue Chen: Original draft preparation, Conceptualization, Methodology.

Mohamed Nor Azhari Azman: Supervision and Editing.

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Not applicable

8.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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10. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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