SAFETY ISSUES ASSESEMENT FOR INDUSTRIALISAED BUILDINGS IN SHANNXI PROVINCE, CHINA BY USING ANALYTIC HIERACHY PROCESS

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ABSTRACT

This research aims to develop a comprehensive safety assessment framework for Industrialised Buildings using the Analytic Hierarchy Process (AHP). The research identifies key safety risks and assesses the critical factors influencing the safety of Industrialised Buildings. A quantitative research approach was employed, with data collected from 324 participants involved in Industrialised Building projects completed between 2018 and 2023 in Xi'an, Yan'an, and Ankang in Shaanxi Province. Respondents included academics, policymakers, contractors, and prefabricated component manufacturers. The results were validated through interviews and focus group discussions. Descriptive statistical data analysis was applied to rank the safety risk factors, and AHP was used to establish a structured safety assessment framework. Reliability and validity tests were conducted to ensure the robustness of the findings. The results indicate that management, technical, and human factors are the primary factors in safety assessment. Strong consensus was found among respondents on the secondary criteria of safety training and accident education, establishing safety reward and penalty systems, and conducting practical drills. However, discrepancies were observed in stakeholders' priorities: regulatory bodies emphasised policy enforcement and emergency preparedness, while contractors and manufacturers focused on operational feasibility and resource management. This study proposes a safety assessment framework for Industrialised Buildings that integrates diverse perspectives to strengthen risk management in Industrialised Building projects. The findings provide valuable insights for policymakers and industry professionals, assisting them in enhancing safety performance, reducing risks, and promoting the sustainable development of Industrialised Buildings. Future research should explore the adaptability of this framework in different regions and its potential integration with digital safety monitoring systems.

PENILAIAN ISU KESELAMATAN UNTUK BANGUNAN INDUSTRI DI WILAYAH SHANNXI, CHINA DENGAN MENGGUNAKAN ANALISIS PROSES HIERARKI

ABSTRAK

Penyelidikan ini bertujuan untuk membangunkan rangka kerja penilaian keselamatan yang komprehensif untuk Bangunan Berindustri menggunakan Analisis Proses Hierarki (AHP). Penyelidikan mengenal pasti risiko keselamatan utama dan menilai faktor kritikal yang mempengaruhi keselamatan Bangunan Berindustri. Pendekatan penyelidikan kuantitatif telah digunakan, dengan data dikumpul daripada 324 peserta yang terlibat dalam projek Bangunan Berindustri yang disiapkan antara 2018 dan 2023 di Xi'an, Yan'an dan Ankang di Wilayah Shaanxi. Responden termasuk ahli akademik, penggubal dasar, kontraktor dan pengeluar komponen pasang siap. Keputusan telah disahkan melalui temu bual dan perbincangan kumpulan fokus. Analisis data statistik deskriptif digunakan untuk menilai faktor risiko keselamatan, dan AHP digunakan untuk mewujudkan rangka kerja penilaian keselamatan berstruktur. Ujian kebolehpercayaan dan kesahan telah dijalankan untuk memastikan keteguhan dapatan. Keputusan menunjukkan bahawa faktor pengurusan, teknikal dan manusia adalah faktor utama dalam penilaian keselamatan. Konsensus yang kukuh didapati dalam kalangan responden mengenai kriteria menengah latihan keselamatan dan pendidikan kemalangan, mewujudkan sistem ganjaran dan penalti keselamatan, dan menjalankan latihan praktikal. Walau bagaimanapun, percanggahan diperhatikan dalam keutamaan pihak berkepentingan: badan kawal selia menekankan penguatkuasaan dasar dan kesediaan kecemasan, manakala kontraktor dan pengilang memberi tumpuan kepada kebolehlaksanaan operasi dan pengurusan sumber. Kajian ini mencadangkan rangka kerja penilaian keselamatan untuk Bangunan Berindustri yang mengintegrasikan pelbagai perspektif untuk mengukuhkan pengurusan risiko dalam projek Bangunan Berindustri. Penemuan ini memberikan pandangan yang berharga untuk penggubal dasar dan profesional industri, membantu mereka dalam meningkatkan prestasi keselamatan, mengurangkan risiko, dan mempromosikan pembangunan mampan Bangunan Berindustri. Penyelidikan masa depan harus meneroka kebolehsuaian rangka kerja ini di kawasan yang berbeza dan potensi integrasinya dengan sistem pemantauan keselamatan digital.

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14th CIDP	14th Five-Year Construction Industry Development Plan
AQSIQ	State General Administration of the People's Republic of China for Quality Supervision and Inspection and Quarantine
BIM	Building Information Modelling
CFA	Confirmatory Factor Analysis
CIBD	Construction Industry Development Department
CSC	The Chinese State Council
CSHM	Construction Safety and Health Monitoring
EFA	Exploratory Factor Analysis
ETA	Event Tree Analysis
FMEA	Failure Mode and Effect Analysis
FTA	Failure Tree Analysis
HAOE	Hazard Assessment of Operating Environment
HAZOP	Hazard Operability
HDB	Housing Development Board
HURDB	Housing and Urban-Rural Development Bureau
IBS	Industrialised Buildings System (IBS)
MMR	Mixed Methods Research
MOHURD	Ministry of Housing and Urban-Rural Development
PHA	Prior Hazard Analysis

CHAPTER 1

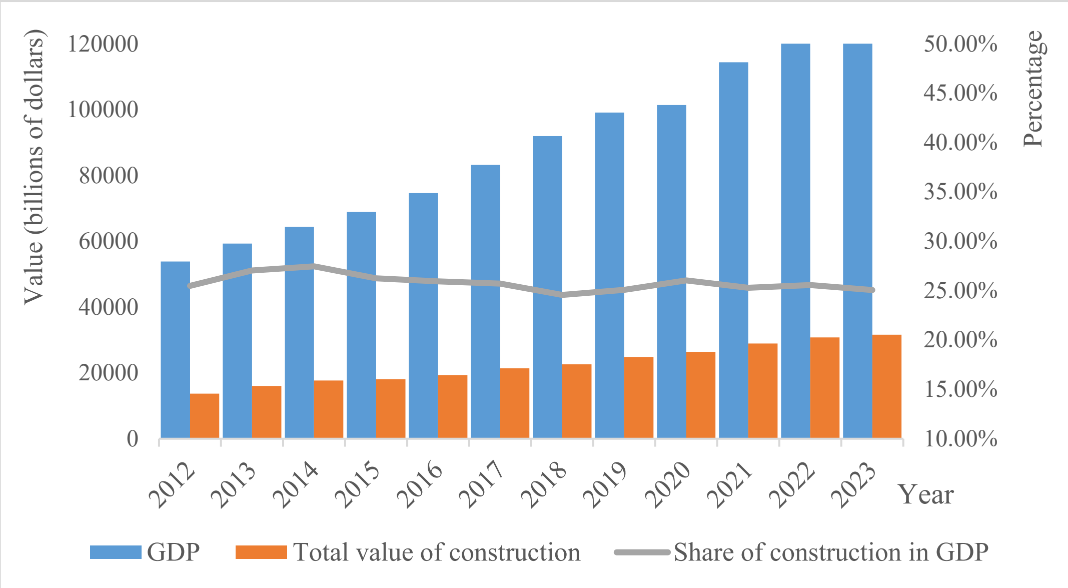
INTRODUCTION

1.1. Introduction

The construction industry is one of the key pillars of the Chinese economy and plays a very important role in driving the current fast growing Chinese economy. According to the China National Economic Data Statement for 2023 published by the National Bureau of Statistics (NBS), the total production value of China's construction industry reached RMB 31591.2 billion by 2022, accounting for 25.06% of GDP for the whole year of 2022, accounting for more than a quarter of the total, which is basically the same as the same period in 2020. The percentages are shown in Figure 1.1.

Figure 1.1

China's GDP and Gross Construction Output From 2012 to 2023.



Source: NBS http://www.stats.gov.cn/

As demonstrated by the data presented above, the construction industry has historically played a pivotal role in China's economic advancement, particularly with regard to its magnitude, efficiency, and the number of individuals it employs. This industry is a crucial component of the nation's overall living standards. The construction industry also plays a huge driving role in the development of the national economy if take into account its close interrelationship between other sectors such as materials, services and finance. Despite the impact of COVID-19, China's construction industry grows by RMB 5,196.46 billion from 2020 to 2023, at an average annual growth rate of 4.52%.

In recent years, China's building area has also been growing steadily since 2014, and Table 1.1 shows that building area will reach 15,563.60 million square metres in 2022, a decrease of 1.2% from 2022. However, the construction amount is still huge.

Table 1.1

Building Area and Growth Rate in China's Construction Industry (2014-2022)

Year	Building Area (Million Square Meters)	Growth Rate
2014	12498.3	-
2015	12397.2	-0.8%
2016	12642.2	2.0%
2017	13184.7	4.3%
2018	13719.9	4.1%
2019	14415.1	5.1%
2020	14947.5	3.7%
2021	15754.6	5.4%
2022	15563.6	-1.2%

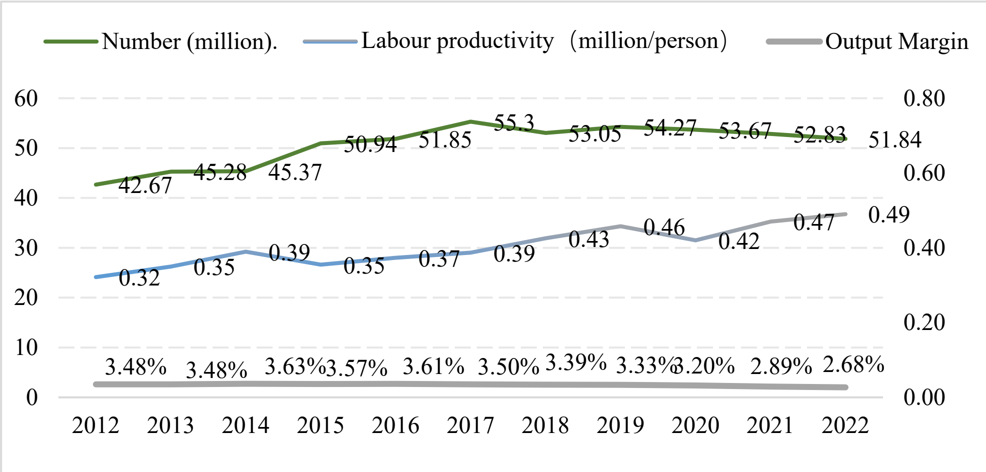
Source: NBS http://www.stats.gov.cn/

On 20 April 2020, China's National Development and Reform Commission (NDRC) proposed the development of a "new infrastructure" in China, including information infrastructure, convergence infrastructure and innovation infrastructure. It can be expected that the development of China's construction industry will continue to grow in the future.

In this process, however, the Chinese construction industry faces two problems. Firstly, China is gradually entering an ageing society and the construction labour force is in short supply, with a large gap in the construction industry's age-appropriate workforce. According to the China Construction Association, the number of enterprises in the construction industry in 2022 was 143,446, and the number of front-line construction workers reached 52.83 million, accounting for only 6.69% of the country's labour force, and the age structure shows that only 15% of the workers were under 30, while those over 50 accounted for nearly 43%. From 2007 to 2021, the average age of frontline workers in the construction industry increased by 10.4 years in ten years. 62.5% of China's working age (16-59 years old) population in 2021, a decrease of 6.7% compared to 2012, with a continuing downward trend. The average age of migrant workers in China has risen from 38.3 years in 2014 to 41.7 years in 2021. The average age of migrant workers also shows that the ageing of China's working population is increasing year by year. In addition to this, Figure 1.2 shows that the number of labourers in China's construction industry has declined for four consecutive years from 2019. The profitability of the output value of the construction industry is also decreasing year by year. At the same time, although labour productivity has continued to increase, it is still at a very low level, and there is a large gap between it and Western developed countries.

Figure 1.2

Construction Workforce and Labor Productivity in China From 2012 to 2020.



Source: NBS http://www.stats.gov.cn/

According to Ministry of Housing and Urban-Rural Development (MOHURD), it is expected that from 2020 onwards. In the next five to ten years, the construction industry will still maintain a low to medium growth rate of around 6%, along with the urbanization process in China. The construction industry is labor-intensive and with relatively constant per capita labour efficiency, an increase in construction output will inevitably lead to an increase in the number of human resources required. In such a situation, the question of how to improve labour efficiency while the number of people employed in the construction industry is decreasing in the future is an important issue. Therefore, industrialised buildings as such meets this requirement precisely, because the production of components in prefabricated plants increases the utilization rate of construction materials and can reduce the manual workload at the building construction site, further reducing the number of labourers required. According to Usman and Hamim (2018) more and more construction companies were recognizing the drawbacks of traditional construction methods and are adopting prefabricated construction methods. The prefabricated components could be produced in large quantities and were not affected by uncertainties such as weather, and the assembly of the components at the construction site greatly accelerates the progress of the project and improves the efficiency of the work. In addition, Karthik et al. (2020) found that the main advantages were improved quality and reduced time, cost and complexity of site construction, with fewer personnel involved making site activities easier. Industrialised buildings was becoming a trend in the global construction industry because it could increase the construction rate, shortened the project schedule, and reduced the consumption of materials compared to the traditional "wet work" method on construction sites (Wasim and Oliveira, 2022).

Secondly, China's industries have developed rapidly in recent years, and the living environment and natural resources have suffered great damage, and the past rough construction mode has caused great waste in resources and capital. The 2020 China Building Energy Consumption Research Report showed that the energy consumption and carbon emissions of the whole process of the construction industry alone account for about half of the country's total energy consumption, accounting for 46.5% of the country, and the total carbon emissions of the whole process of 4.93 billion tons of CO_2, accounting for 51.3% of the country. This statistic reflected the fact that the construction industry was a high energy consumption and high emission industry.

In terms of construction material production, steel, cement, and glass are all high energy-consuming industries with huge carbon emissions. In consideration of the subsequent utilisation of edifices, it is imperative to acknowledge the significance of emissions arising from the daily operation of heating systems, equipment, and electricity consumption. These emissions should not be underestimated when assessing the environmental impact of buildings. What is more alarming is that with the rapid urbanization and deep adjustment of industrial structure, carbon emissions from urban and rural construction and its proportion to the total carbon emissions of the whole society are likely to further increase(Xu & Wang, 2020).

After the 17th National People's Congress of China put forward the requirement of ecological civilization and green ecological development, the country introduced a series of supporting policies, such as the Green Building Action Plan in 2013 and the Opinions on Further Strengthening Urban Planning and Construction Management in 2015, to further strengthen the development of industrialised buildings, promote the standardization of industrialised buildings, improve the replaceability and universality of prefabricated parts, promote construction and decoration in one, and form industrialised construction. These policies have clarified the development goals of China's industrialised buildings, and promote the deep coordination and integration of industrialization and information technology development.

Meanwhile on September 3, 2016, China acceded to the Paris Climate Change Agreement, becoming one of the 23 parties to complete ratification of the agreement. In order to meet the commitments made to global climate impact, on June 30, 2022, MOHURD and NDRC issued the Implementation Plan for Carbon Peaking in Urban and Rural Construction, which sets out important goals for carbon reduction in buildings. By 2030, carbon emissions in urban and rural construction will reach a peak. China strive to achieve a comprehensive green and low-carbon transformation of urban and rural construction methods by 2060 (Dong et al., 2018). Higher standards for environmental protection will further promote the development of industrialised buildings technology. The development of industrialised buildings technology was further facilitated by the higher standards of environmental protection imposed by countries around the world. The advantages of industrialised buildings in terms of high efficiency, energy efficiency, and sustainability are gradually gaining popularity in the market (Gallo et al., 2021).

Combining these two reasons, in 2016 the Chinese State Council (CSC) issued "Several Opinions of China on Further Strengthening Urban Planning and Construction Management", a document indicating that China should strive to achieve a 30% share of industrialised buildings in new construction by around 2025. This new construction mode could not only ensure construction quality and efficiency, but also greatly reduced the number of on-site construction personnel, reduced noise disturbance and protected the environment. The construction mode of industrialised buildings had made great progress in technological innovation and change, enhancing, and improving the quality of the environment in which people lived and realizing the role of residential industrialisation for the progress and development of society.

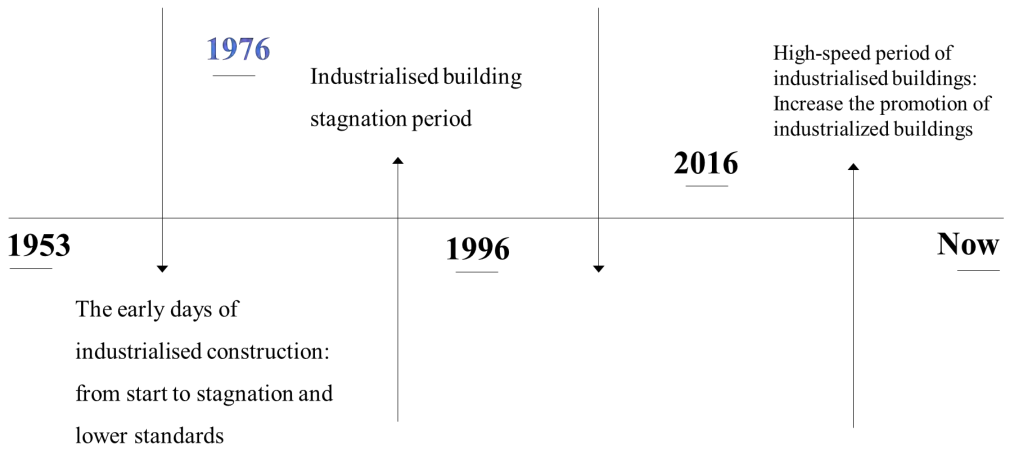
Industrialised buildings in China could be traced back to the first high point of industrialised buildings development in the late 1950s, which was attributed to the introduction of Soviet assembled concrete slab construction in China. Since the mid-1980s, the market for assembled slab housing system was gradually shrinking due to the economic level and technical conditions at that time, and by the early 1990s, most of the original domestic prefabricated slab factories stopped production or switched to production, and the fully assembled slab buildings basically disappeared in the construction market(Junjun et al., 2021).

In 1995, the Ministry of Construction issued the "Outline of the Development of Construction Industrialization" (1995 No. 188) clearly put forward "construction industrialization is the direction of development of China's construction industry. The construction industry should gradually transition from the traditional manual-based production method to the mechanized production method". It proposes to promote new technologies that can provide industrialization level, promote close cooperation between design and construction, reform and develop new building materials, gradually realize technical equipment combining construction mechanization and hand-held machines, and develop integrated building components and pre-products production and so on.

In 1996, MOHURD released the "Outline of Pilot Work for Modernization of Residential Industry" and began to pilot the modernization of residential buildings. In 1998, the Ministry of Construction established the Housing Industrialisation Promotion Center to coordinate the research, development, and promotion of building industrialisation technology from the national level(Wang et al., 2021). According to Wen(2016), the study showed that starting from 1999, China began to vigorously promote the development of industrialised buildings. Figure 1.3 shows the history of the development of assembled buildings in China.

Figure 1.3

Development of Industrialised Buildings in China



In 2006, the former Ministry of Construction issued the "Trial Measures for National Residential Industrialisation Base" to encourage construction enterprises to participated in the construction of national residential industrialisation base to promote the development and implementation of construction industrialisation, and China's residential construction industrialisation began to enter a period of comprehensive promotion. During 2012-2016, real estate companies represented by Vanke began to fully explore the panel structure, and industrialised buildings gradually entered an accelerated development stage. At the end of 2016, the total area of industrialised buildings in China reached about 80 million square meters, accounting for about 5% of new construction.

Although industrialised buildings started late in China, the Chinese government was gradually increasing the investment in industrialised buildings. With the gradual emphasis on industrialised buildings, in 2016 CSC issued the 13th Five-Year Plan for National Economic and Social Development of the People's Republic of China, set the development goals for industrialised buildings in China, a document that not only showed the importance China attaches to industrialised buildings, but also promotes the development of the technical level of industrialised buildings.

In the "China Construction 14th Five-Year Plan" released by China MOHURD in 2020, the goal and the development direction of industrialised buildings were further clarified as special planning and key tasks in the fields of rural revitalization and urban and rural habitat construction, and industrialised buildings were taken as key tasks for scientific research and development. The focus was on the whole chain of design and deployment of technology research and development on the basic theory, design, standard specification, testing and assessment, component production, construction, and industrialisation of industrialised buildings (Li et al., 2020). Table 1.2 shows that after 2016, many policies related to industrialised buildings have been developed in China to promote their development.

Table 1.2

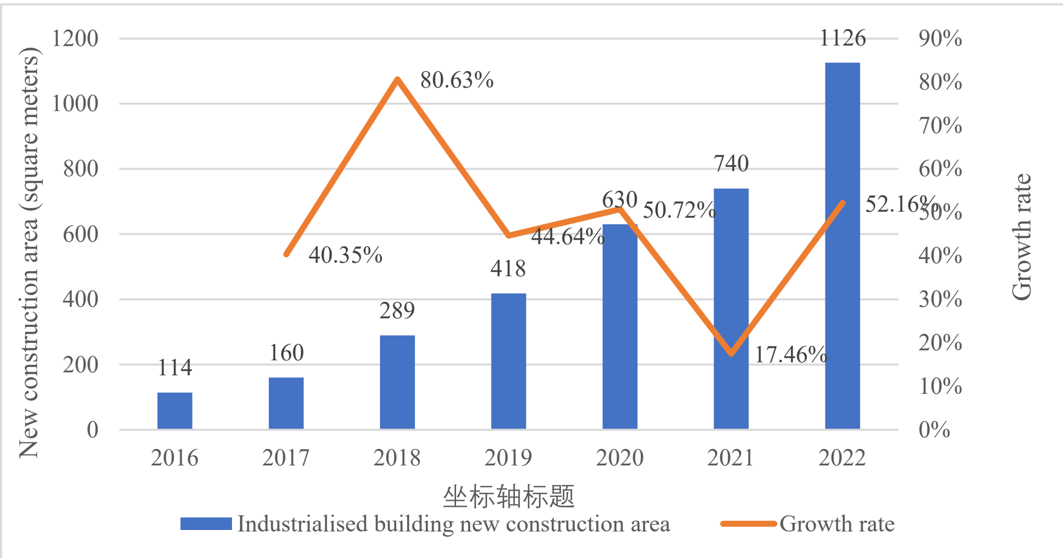
Major Policies and Their Contents For Industrialised Buildings In China After 2016

Time	Department	Policy Title	Main Content
2016.02	CSC	Opinions on further strengthening urban planning and construction management	Strive to use about 10 years to make industrialised buildings construction account for about 30% of new buildings
2016.09	CSC	Guidance on the vigorous development of industrialised buildings	Clearly put forward to vigorously promote industrialised buildings to ensure measures: increase policy support, give tax incentives to enterprises, land security and so on.
2017.03	MOHURD	Thirteenth Five-Year Plan Industrialised Building Action Plan	Require the proportion of industrialised buildings to reach 15% of new buildings in 2020; cultivate more than 50 national industrialised building demonstration cities and more than 200 industrialised building innovation technology bases
2017.03	MOHURD	Thirteenth Five-Year Plan Industrialised Buildings Action Plan	Clearly put forward the implementation of policy support, strengthen land security, tax incentives and other policies
2017-2018	MOHURD	Technical standards for industrialised building concrete construction; Technical Standards for Industrialised Building Steel Structure Construction; Technical standards for industrialised buildings with wood structures; Industrialised building assessment standards	Clarify the assessment criteria for industrialised buildings
2019.03	MOHURD	Housing and Urban-Rural Construction Market Supervision Division Work Highlights	Carry out pilot work of industrialised buildings such as steel structures

It is concluded that the development of industrialised construction in China was mainly driven by policies. After the formulation of relevant development policies from 2016 to 2020, the development of industrialised buildings in China had been rapid. According to MOHURD's statistics on the new building area of industrialised buildings in China from 2016 to 2022, as shown in Figure 1.4. Compared with 2016, China's industrialised buildings in 2022 raised almost 10 times, reached 1,126 million square metres.

Figure 1.4

Trend of New Construction Area of Industrialised Buildings in China (2016-2022)



According to the national industrialised building policy requirements, at present, 31 provinces, autonomous regions and municipalities directly under the Central Government of China have issued specific implementation opinions, plans and action plans for industrialised buildings, of which Beijing, Shanghai, Tianjin, Zhejiang, Jiangsu and other economically developed regions require the industrialisation rate of construction to reach more than 30% in 2020, much higher than the national target, most regions require to reach 15% or more than 20%, some of the central and western provinces such as Ningxia, Qinghai and other regions to put forward the target of 10% according to local conditions. At the same time, local governments were actively giving full incentives to industrial development through various methods such as tax concessions, land support, financial subsidies, and floor area ratio incentives. Provinces' support projects for industrialised buildings are shown in Table 1.3.

Table 1.3

China's Industrialised Building Support Policies by Province

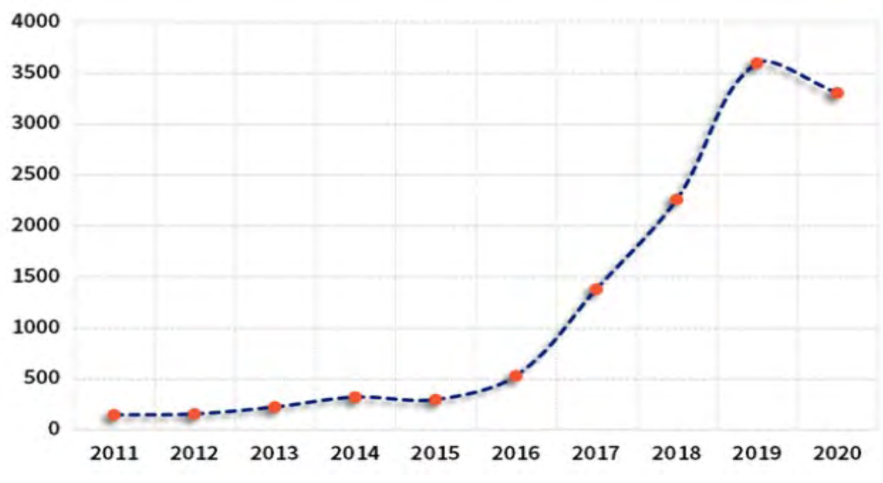
Province/City	Land Support	Financial subsidies	Dedicated funds	Tax Benefits	Credit Loan Support	Industry Support
Beijing		√		√	√	
Shanghai		√		√	√	
Tianjing		√		√		√
Chongqin		√		√		√
Hei longjiang	√	√		√	√	√
Jilin	√		√	√		√
Liaoning	√		√	√		√
Hebei	√		√	√		√
Shanxi	√			√		√
Henan	√	√	√	√		√
Hubei			√			√
Shandong	√			√	√	√
Hunan		√		√		√
Nei menggu	√		√	√		√
Jiangsu	√	√		√		
Anhui	√		√	√		√
Zhejiang	√		√			√
Jiangxi	√		√	√		
Fujian	√			√		
Guangdong	√	√		√	√	√
Guangxi	√			√		√
Hainan	√		√	√		
Shaanxi	√	√	√	√		√
Gansu		√		√		
Ningxia		√		√	√	√
Qinghai	√			√		√
Xinjiang	√	√	√	√	√	√
Guizhou	√		√	√	√	√
Sichuan	√			√	√	
Yunnan	√			√	√	
Xizang	√	√		√	√	√

Source: Provincial, Municipal Governments and Housing and Construction Departments (Self-Organized)

With the call of policy and government efforts at all levels to promote the industrialised construction industry was experiencing a rapid promotion, development, growth and perfection of the process, some regions have achieved considerable performance and results, with a considerable number of PC prefabricated components factory enterprises, not the least of which were some enterprises with a considerable scale of production. There were currently 13,500 industrialised construction-related companies in China. As shown in Figure 1.5, annual registrations of related companies had risen significantly since 2016, with 3,301 new companies registered throughout 2020 and 3,627 new registrations in 2021, an increase of 5% year-on-year.

Figure 1.5

Number of New Registrations of Industrialised Construction Enterprises in China(2011-2020)

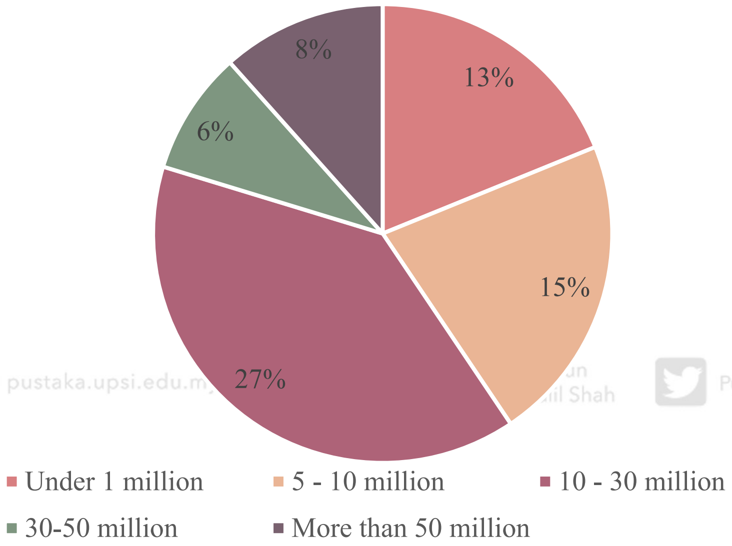


Source: *MOHURD*

The number of private enterprises among industrialised construction enterprises is relatively small, accounting for only 2%. As Figure 1.6 shows, the registered capital of industrialised construction enterprises is generally high in terms of registered capital. The largest number of industrialised construction enterprises with registered capital of 10 to 30 million yuan, accounting for 27%. The registered capital of 1 million - 5 million yuan accounted for 21%, and 50 million yuan or more accounted for 18%.

Figure 1.6

Distribution of Registered Capital of Industrialised Construction Enterprises



Source: MOHURD

The distribution of industrialised construction enterprises across China reveals significant regional disparities. Hunan Province leads the country with 2032 enterprises, followed by Shandong, Jiangsu, Guangdong, and Anhui in the top five, with 1658, 1252, 1148, and 996 enterprises, respectively. In terms of city distribution, Changsha City leads in the number of industrialised construction enterprises, with 1,418. In addition, the top five are Shenzhen, Hefei, Xi'an and Jining, with 468, 361, 340 and 313 enterprises respectively.

It could be concluded that the scale of industrialised buildings and the number of enterprises were developing rapidly under the promotion of relevant national and regional policies. It showed that China's industrialised buildings market is large in scale and in great demand. At present, the country has developed a large number of industrialised buildings enterprises integrating design, production and construction. There are very successful cases in various places, and in China, industrialised buildings have been vigorously promoted and used(Cao et al., 2022).

According to China's Industrialised Building Assessment Standard released in 2015, Industrialised buildings was defined as a building in which a large amount of on-site work in the traditional construction method is transferred to a factory, where building components and accessories (such as floor slabs, wall panels, stairs, balconies and so on.) were processed and made, transported to the building construction site, and assembled and installed on site by means of reliable connections. Industrialised buildings include the following four main features compared to traditional buildings.

i. Standardised design and production.

ii. Industrialised production methods.

iii. Industrial integration.

iv. Modern information management technology.

Therefore, industrialised buildings was based on industrialised construction system, used production technology to change the traditional cast-in-place construction method in the construction industry with systematic thinking, standardizing and generalizing prefabrication of components, coordinating and coordinating design, production, construction and assembly and project management activities, aiming at reducing costs, improving production efficiency and quality, and finally realizing sustainable development of construction(He & Liu, 2022). Compared with the cast-in-place construction method, industrialised construction has changed the construction process, and the information flow, capital flow and logistics between construction organizations have changed, which is a reform of the traditional construction method. Moradibistouni et al. (2019) compared the different phases of the two construction methods and concluded that assembly construction requires a complete technical system, including standardized, integrated and information-based design methods in the design phase, prefabrication processes that are compatible with the main structure technology in the production phase, mature and live construction methods in the construction phase, and strengthened inspection and acceptance safeguards, and maximized the overall benefits of the whole process through general contracting.

Industrialised buildings are usually divided into prefabricated industrialised concrete structures, industrialised steel structures, modern wood buildings and industrialised container buildings (Tam et al., 2007). The whole construction process of modern industrialised buildings is that firstly, designers standardize the design of building projects, then the production of components is carried out in prefabricated factories, and the assembly of components is carried out by workers through transportation to construction sites, and this series of processes also requires the integration of modern technologies, such as information management and intelligent applications(Ghaswala, 1967).

Industrialised production of building components greatly improves the construction efficiency of industrialised buildings and the utilization rate of building materials, while saving a large amount of resources and providing a new direction for the future development of the construction industry.

1.2. Background

Despite the large scale and rapid development of China's construction industry, the past sloppy development approach has led to frequent safety accidents. According to statistics, the last 20 years of China's housing and municipal construction accidents showed that an average of 782 construction accidents and 916 deaths occurred each year for 20 years.

Table 1.4 reflects the number of construction accidents and deaths per year for the 20 years between 2000 and 2020.

Table 1.4

China's Housing and Municipal Construction Safety Accident Statistics （2000-2020）

Year	Number of Accidents	Number of deaths
2000	846	987
2001	1004	1045
2002	1208	1298
2003	1238	1524
2004	1144	1324
2005	1015	1193
2006	882	1041
2007	859	1012
2008	814	989
2009	684	802
2010	627	772
2011	589	738
2012	487	624
2013	512	636
2014	552	648
2015	442	554
2016	634	735
2017	692	807
2018	734	850
2019	773	904
2020	689	749

Source: MOHURD http://www.mohurd.gov.cn/

Safety problems not only caused huge losses to all parties involved in the project and bring irreparable pain to countless families, but also hinder the healthy development of the construction industry and destabilise the society(Niskanen and Saarsalmi, 1983).

In construction projects, there were the so-called "three controls", namely quality control, schedule control, cost control, and at the same time safety management should always be throughout the whole project life cycle. In some current prefabrication projects, business personnel tend to focus more on the quality, schedule, and cost of component connection construction at the production site of prefabricated components, while safety issues during production, transportation, and on-site assembly are often neglected (Ayhan and Tokdemir, 2020). Industrialised buildings have incomparable characteristics such as large volume of prefabricated components, technically difficult, large investment, and pay more attention to manufacturing integration. However, it is necessary to pay attention to the fact that during the construction process, there are more suppliers and subcontractors interrelated with the assembled buildings and the processes are more complicated, which consequently causes a greater possibility of safety risk accidents and construction safety cannot be well guaranteed. The most obvious feature of assembled buildings is the increased lifting of components, but because of the complexity and risk of the process, the slightest slackness on the part of the construction workers may lead to safety accidents, and it is due to a combination of reasons that the development of assembled buildings is limited(Yuan, 2018).

Therefore, in the face of the huge market size, it is very important to promote assembly and ensure its construction safety, reduce the safety hazards during construction, eliminate the occurrence of safety accidents and possible casualties and economic losses, and create a safe construction environment to promote the steady development of assembly construction (Yelgin et al., 2014).

At the present stage of the safety risk assessment of industrialised buildings, the actual situation is that either the safety risk is overestimated, and in order to ensure safety, a large amount of financial investment is wasted, and a conservative strategy is adopted in various links, which to a certain extent limits the development of China's industrialised buildings; or the safety risk is underestimated, and no effective means of prevention is adopted, resulting in the destruction of a certain link and causing safety accidents. Therefore, the safety of industrialised buildings is a problem that China have to face, and it is also an important topic worth studying.

1.3. Problem Statement

The current safety assessment method used in construction projects is based on traditional construction procedures, focusing on the early warning and diagnosis of risks at the construction site stage to prevent or mitigate the corresponding risk factors in advance. This has been highly valued by construction industry managers as it has improved the safety management capability of the construction industry and to some extent reduced the unbudgeted capital investment in dealing with emergencies and improved economic returns(Beim, 2013). After decades of research and development, theoretical studies on the assessment of safety risks in traditional building construction have matured and good results have been achieved in concrete practice. However, these methods are not applicable on industrialised buildings.

Industrialised buildings present the significant characteristics of integrated manufacturing in the construction process. Compared with traditional cast-in-place buildings, the construction process of industrialised buildings is more complex, involving design, component production, transportation, lifting and on-site assembly, which brings many new sources of danger (Ahn et al. 2020). These factors give rise to a multitude of new sources of hazards. During the project, the more suppliers and subcontractors were associated with industrialised buildings, the more complicated the processes became, and the greater the possibility of safety risks arising from them, and the construction safety could not be well guaranteed (Ekanayake et al.,2021). On 17 September 2021, a worker lost his right leg to amputation when it was crushed by PC component production equipment at Wanning City Haijian Industrialised Buildings Engineering Company Limited. The accident was caused by the fact that the injured worker belonged to a steel subcontractor company, which had not provided safety training to the worker and had given him free access to the production area of the equipment. This case demonstrates that ineffective identification and control of hazards in the management chain (workers not trained, unclear safety responsibilities) can lead directly to serious consequences. Industrialised buildings take 'standardised design, factory production and mechanised assembly' as their core features, and their whole life cycle involves multi-stage synergy in design, manufacturing, transportation and assembly, which results in the types, distribution and evolution paths of risk sources that are fundamentally different from those of traditional buildings. If traditional methods are simply used, risk control may be ineffective due to deviations in the identification of hazards, thus threatening construction safety.

Industrialised buildings have specific sources of hazards at different stages, which are often directly or indirectly related to accidents. In the design stage, the standardised design of prefabricated components requires strict control of the tolerance range, and if the deviation of the lifting hole position exceeds ±5mm (Li et al., 2023), it may lead to uneven stresses in the components during installation, which may result in structural instability. Such hazards at the design stage do not exist in conventional construction, but may be transferred to subsequent stages through the supply chain.

Further, the hoisted installation phases of industrialised buildings introduce new sources of hazard. The large dimensions and extra weight of prefabricated components lead to a significant increase in transport risks. These unique sources of danger, if not adequately identified and controlled during the construction of industrialised buildings, may directly lead to accidents or even trigger more serious consequences. Jin et al.(2019)

feel that the increased lifting of components is the most obvious feature of industrialised buildings, but due to the complexity and risk of the process, the slightest negligence of the construction personnel during the construction process may lead to safety accidents, and it is due to the combination of these reasons that the development of industrialised buildings is limited. Zhejiang Lishui city's safety announcement shows, on 30 September 2019, a lifting injury accident occurred at Zhejiang Baisheng Industrialised Buildings Company Limited, in which a worker was hit by a falling steel spreader in the course of working with an overhead crane and died on the spot. The direct cause of the accident was the quality of the wire rope, while the deep-rooted cause was inadequate safety inspection and maintenance at the lifting operation site.

The above accidents show that the sources of hazards in industrialised construction are not limited to the construction site, but are present throughout all stages of the project, including design, production, transport and on-site installation. Compared with traditional construction, these sources of hazards in industrialised buildings are unique and systematic, such as dimensional deviation of prefabricated components, irrational design of connecting nodes, overloading or insecure fixing during transportation, and failure of lifting operators to operate in accordance with specifications. If these unique sources of danger are not adequately identified and controlled during the construction of industrialised buildings, they may directly lead to accidents or even trigger more serious consequences. It is of great significance to promote the healthy development of industrialised buildings by guaranteeing their construction safety, reducing potential safety hazards and eliminating the occurrence of safety accidents (Einstein et al., 1995). Therefore, the safety assessment of industrialised buildings should first focus on the identification of risk factors, especially the in-depth analysis of unique sources of danger.

However, there are two main problems with current risk identification in industrialised buildings: the incompleteness of risk identification and the limitations of risk identification methods. Traditional risk identification usually focuses on the immediate causes of accidents, this is corroborated by a mechanical injury accident in Taizhou City, Jiangsu Province, on 2 April 2020, where the apparent cause of the accident was equipment operating errors, but the root cause was that the equipment had not passed safety acceptance and the workers had not received effective training.

Traditional risk identification methods are mostly based on the experience of cast-in-place construction, and such methods are often insufficient to identify new sources of risk in industrialised buildings. The use of prefabricated components in industrialised buildings may create new safety risks during production, transport and installation, such as increased risk of accidents due to the weight and volume of components during transport (Xu et al., 2019), or falling components due to improper handling during lifting (Wang et al., 2022). Much of the literature on safety risks in industrialised buildings still focuses on the construction phase. Therefore, the proposed risk control measures primarily target the safety risks of contractors on site. However, in industrialised building, a significant part of the construction work is outsourced to factories, which means that need to consider risk control measures not only from the perspective of contractors, but also from the perspective of manufacturers of prefabricated components(Kaol, 2017). For example, risk control measures should consider aspects such as factory production processes, equipment safety and employee safety training. Governments, as policy makers, also have a significant impact on risk control in industrialised building. Government policies and regulations can have a significant impact on the safety of industrialised building. For example, the government can improve the safety of industrialised building by setting strict safety standards and regulations. However, there is currently a lack of research on risk control measures from the perspective of manufacturers and government policy makers(Yuan et al., 2021)

In conclusion, industrialised buildings were a new construction method that was quite different from traditional cast-in-place building construction. During the construction process, not only the safety risks of traditional cast-in-place construction may occur, but also the safety risks of new links such as on-site lifting and assembly would be added, leading to an increase in the types of safety hazards, changes in management requirements and increased management difficulties, and the simple following of traditional safety management methods was no longer applicable, for example, using traditional safety assessment methods to evaluate industrialised building projects, the process was easy to fall into established thinking, followed by the mistake of bringing in the causes of accidents in traditional cast-in-place building, leading to risk identification errors. The traditional passive safety assessment method was difficult to cope with the complex safety problems in industrialised construction projects, so the original safety assessment content should be updated, and the safety management system should be comprehensively evaluated according to the needs of industrialised construction safety assessment, and the differences in safety management needs between the two construction methods should be compared. Therefore, there was an urgent need to evaluate the safety management of the construction phase of prefabricated buildings, and promote the transformation of the existing safety management model and the adoption of new safety assessment methods.

1.4. Research Objectives

In this paper, by studying the whole process production method of China's construction industrialisation, its research objectives are mainly three points.

1) To identify and rank safety issues and influencing factors for industrialised buildings projects.

2) To identify criteria for the development of new safety assessment method for industrialised buildings.

3) To incorporate criteria with decision makers preferences in the deriving

safety management framework for industrialised buildings.

1.5. Research Questions

According to the above four research objectives, the research questions are as follows.

1) What are the safety issues for industrialised buildings projects and factors influencing it according to ranking?

2) What are the criteria in the development of safety assessment method for industrialised buildings project?

3) How the criteria in the development of new safety assessment method will derive into safety management framework for industrialised buildings project?

1.6. Theoretical Framework

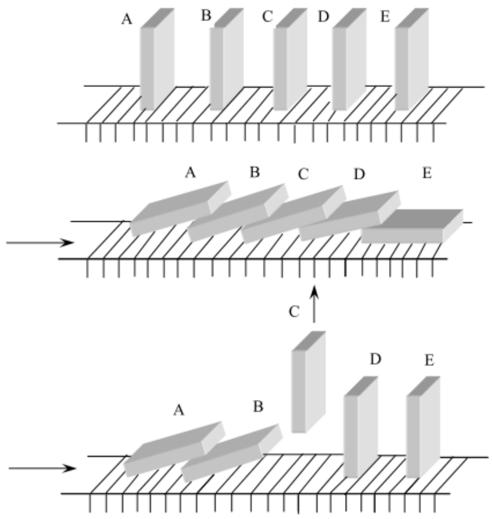
Many scholars around the world have studied accidents and realized that every accident, though more or less accidental, has a variety of inevitable causes without exception(Tariq and John, 2000). Therefore, the key to preventing and avoiding accidents lies in finding out the laws of accidents, identifying, discovering, and eliminating the inevitable causes of accidents, and controlling and reducing the accidental causes so that the possibility of accidents is minimized(Carrillo et al., 2017). In order to take effective preventive measures against safety accidents in building construction projects, it is necessary to first gain an in-depth understanding and knowledge of the causes of accidents. According to the characteristics of safety factors in industrialised buildings, this paper considers Accident Theory as the main theory of this study. Its related theories and developments include Domino Theory， Energy Release Theory，Trajectory Crossover Theory，Trajectory Crossover Theory， Trajectory Crossover Theory,“4M1E” Theory.

1.6.1. Domino Theory

The American engineer Heinrich (1941), in his book "Prevention of Industrial Accidents", first proposed the famous chain reaction diagram of accident occurrence, as shown in Figure 1.7. The theory is that the occurrence of an accident is not an isolated event, although the accident may occur in a moment, but is the result of a series of mutually causal cause events occurring one after another. W.H. Heinrich introduced the important concept of chains of events, where injuries and causes have a chain relationship with each other. Park (2016) think that the chain process of accidents is influenced by five factors: genetic and social environment, human error, human unsafe behavior or physical unsafe condition, accidents, and injuries (Lingard, 2013). Just like the famous dominoes, once the first one falls, it will lead to the second, third and up to the fifth domino in turn, eventually leading to accidents and corresponding losses, hence the name Domino Theory (Heinrich, 1950).

Figure 1.7

Domino Theory



Heinrich also pointed out that the key link to control the possibility of accidents and reduce injuries and losses is to eliminate the unsafe behavior of people and the unsafe state of things, like in a domino series, if a domino in the middle is removed, the chain is broken and the accident process is aborted (Liang, 2017), as shown in Figure 1.7. As long as the unsafe behavior of people or unsafe state of things is eliminated, casualties will not occur, and the resulting personal injuries and economic losses will not be discussed. This theory has been widely used in safety work since its inception and is regarded as the classic theory of safety production, which has had a great and far-reaching impact on subsequent safety production. domino theory mainly explains that the causes of unsafe accidents are related to people and things (materials, equipment).

According to domino theory, the safety management of construction projects should focus on preventing unsafe behavior of construction site participants, eliminating mechanical or material unsafe conditions, and interrupting the process of accidents to avoid them. Therefore, the construction site requires that construction machinery and construction materials must be carefully checked before the start of each day's work and that construction personnel are in a stable working condition, which is precisely the application and embodiment of this principle in the safety management of engineering construction(Man et al., 2021).

1.6.2. Energy Release Theory

Energy Release Theory believes that accidents originate from abnormal or unwanted energy being released accidentally and acting on the human body or mechanical equipment, when various forms of accidental release of energy exceeds the range of the receptor can withstand will be the cause of injury, so this is the direct cause of accidents (Zhou and Irizarry, 2016). The energy contained in process materials or mechanical equipment that may cause injury or property damage commonly found in human production activities contains thermal, force, electrical, and mechanical energy (Ghiyasi et al., 2022), such as burns from chemical reactions that can easily occur in chemical plants, and wind energy generated by nature that can cause injury to people or equipment at construction sites through unfixed components (Shaun, 2007).

1.6.3. Trajectory Crossover Theory

Trajectory crossover theory believes that the trajectories of both human and physical factors are included in the development process of various accidents (Hulme et al., 2019), and the unsafe behavior of people and the unsafe state of things belong to two trajectories respectively (Salmon et al., 2020). Accidents occur in this space-time is due to the intersection of two trajectories of motion in a system in this space-time. The trajectory intersection theory summarizes the sequential development of the basic cause (social factors), indirect cause (management factors), direct cause (human unsafe behavior and object unsafe state), accident, and damage as the accident development process(Hopkins, 2014). With the progress of science and the improvement of production technology, the safety requirements of production equipment and production environment have increased (Chinda and Pongsayaporn, 2020), so the role played by both human and material causative factors in accidents has been re-examined, and it is further emphasized that both human and material related factors are equally important in the cause of accidents (Forsythe, 2014). Trajectory Crossover Theory indicates that it is the environment, technical ability, and management level that makes human unsafe behaviors occur or objects produce unsafe conditions.

1.6.4. Managing the Risks of Organizational Accidents Theory

Managing the risks of organisational accidents theory was proposed by Reason, a member of the British Academy of Sciences, in 1997, to describe the causes of accidents in organisations, and he believed that accidents were generally classified into two situations, one of which occurred in individuals and the other in organizations (Reason, 2016). Individual accidents tend to cause serious injuries to those involved, but they did not spread further and the nature of the accident did not change (Leflar and Siegel, 2013). Organisational accidents, on the other hand, generally occurred due to a combination of multiple causes and tended to occur less frequently (Goh et al., 2010), but when they did, they could be catastrophic, involve multiple people at different organisational levels, and have additional repercussions, and the situation would be very serious (Enya et al.,2018). The safety protection of the organisation would gradually decrease over time, and when a low-loss accident occurred, the organisation would be prompted to improve the prevention process, but it would often be neglected again because of production factors, and the organisation's safety protection would be completely disintegrated in a catastrophic accident. Therefore, the factors of organizational accidents included organisational factors, local operational factors and unsafe behaviors, and the root cause of accidents lies in the organization's own defects, not only in the unsafe behavior of front-line employees (Umar and Wamuziri, 2016). When investigating the causes of accidents, it is possible to use human unsafe behaviors as the starting point for accident investigation, to understand the causes of unsafe behaviors at the workplace level, and then to go deeper into the causes at the organisational level. In addition to human factors, all organisational factors, including managers, regulations, procedures, and preventive measures, must be considered when conducting accident prevention.

1.6.5. Hazard Source Theory

1980 W. Hamer defined a hazard as a potential unsafe factor that could lead to an accident with loss of life or material damage (Yuebing Zhang et al., 2011). According to Liang et al.(2011), a source of danger was a situation or a potential or inherent characteristic of the environment that had the potential to cause injury, illness, or financial loss. Its main emphasis was on hazardous substances, easily confused with the concept of the state of existence of system safety, danger (ZhuWu Zhu et al., 2011). Hazardous sources were the inherent physical and chemical properties and hazardous substances that had the potential to damage humans, property, and the environment, the operating environment, and accidental disaster-causing events (Liang et al., 2011). This definition did not take into account all the factors that led to the occurrence of various hazards, and only considers the external material impact. Krausmann et al. (2017) thought hazardous sources were various substances that existed in a production system and could produce and release energy that, under certain trigger conditions, might lead

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to injury or illness, property damage, work environment damage, or a combination of these conditions as a root cause or condition. Ignore the impact of human factors on the production system. These definitions showed that sources of danger were objective and were the root cause of accidents (Mihić, 2020).

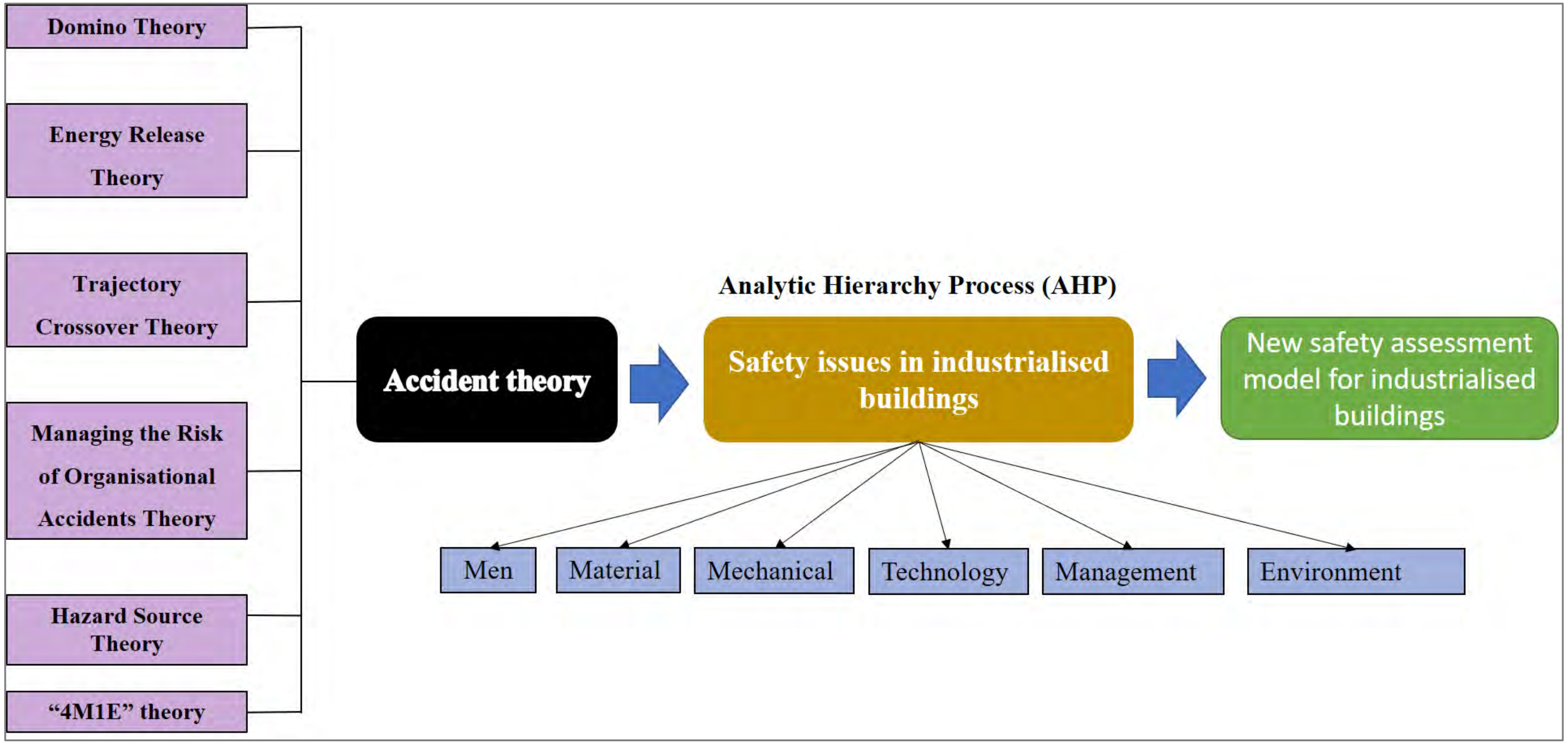
1.6.6. “4M1E” theory

Japanese scholar Shigeo Nishijima summarized the chain reaction theory and proposed that the four major causes of safety accidents are Man, Machine, Media, and Management, and then added the environmental factor, and named it "4M1E" (Pillay, 2015). 4M1E to the emergence of safety problems for the analysis of the impact factors, should be based on different specific situations five elements according to its degree of impact on engineering safety, that is, the five elements according to their degree of impact on different combinations of arrangements, and then be able to find the key factors affecting engineering safety issues more accurately, accurately develop countermeasures to ensure the safety of engineering projects (Zhu et al., 2011).

Based on the above description of safety theory, this research identified the issues affecting safety into six areas: man, material, machinery, Technology, Management, and environment (Figure 1.8)

Figure 1.8

Theoretical Framework



1.7. Conceptual Framework

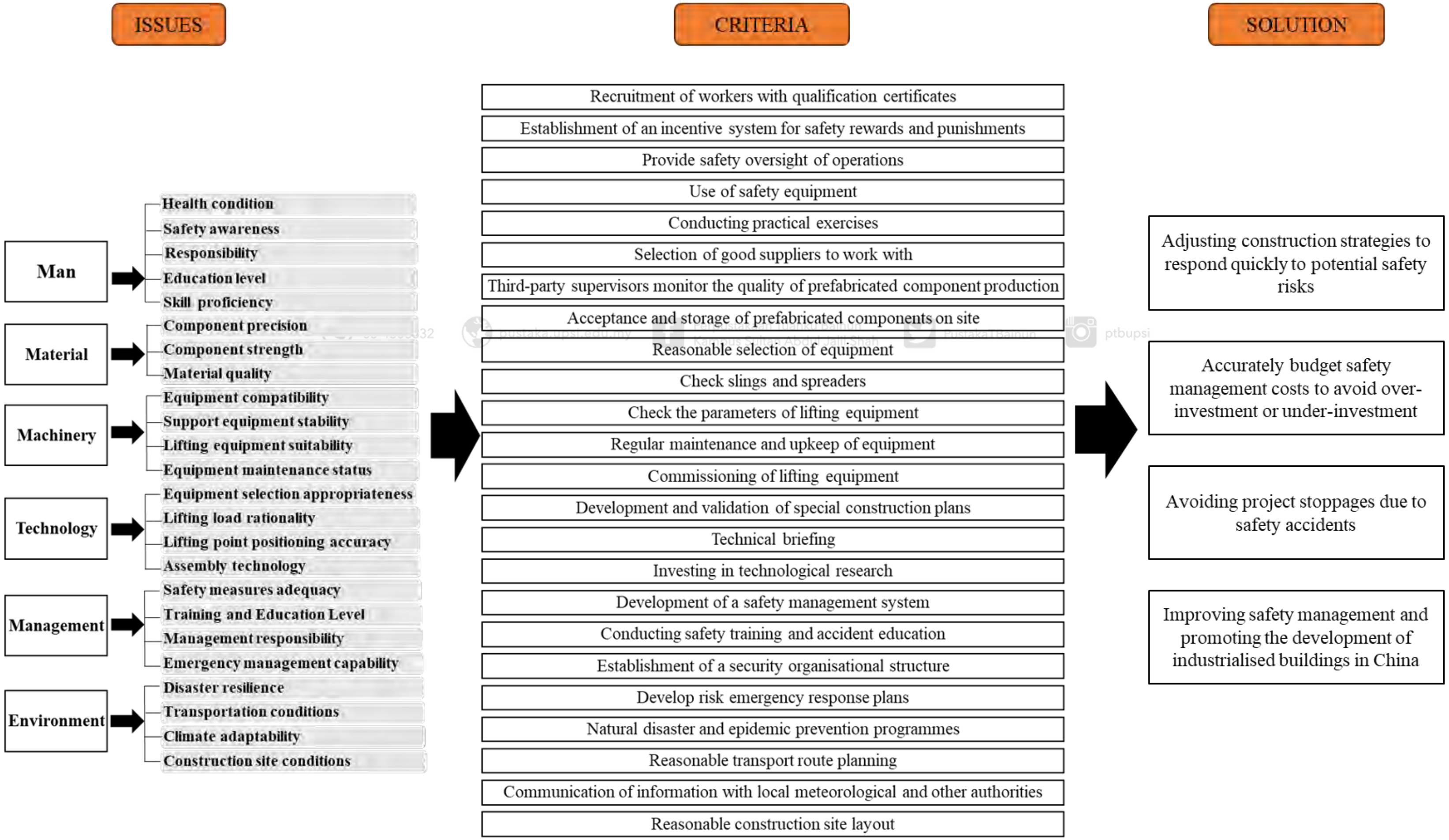
The conceptual framework of this study as Figure 1.9 shows. In Figure 1.9, The six safety issues concerning industrialised buildings, man, material, machinery, technology, management and environment, are listed according to the accident theory for the root causes of safety accidents. In this study, 32 risk factors that can affect the safety of industrialised buildings were identified through literature research and interview around these six safety issues, and the more similar safety factors were finally combined to form 24 safety risk factors for industrialised buildings after expert discussion. The new safety assessment criteria are derived from the safety risk factors in the

industrialised construction industry.

The final outcome of this study was the development of a safety assessment methodology for industrialised buildings based on new safety assessment criteria. The ranking is done from the most important indicators to the least important indicators. The new assessment approach is expected to solve the safety assessment problem of industrialised buildings in China. In addition, it can guide hazard source monitoring and accident prevention to achieve the lowest accident rate, the least loss and the best safety investment benefit, and provide a scientific basis for developing preventive measures and management decisions

Figure 1.9

Conceptual Framework



1.8. Scope and Limitation of the Research

This study focuses on the respondents involved in industrialised buildings projects, project contractors, scholars, prefabricated manufacturer, and government policy makers. The industrialised buildings research in this paper mainly refers to the process of construction projects using industrial production methods for engineering and construction, and the specific scope of the study refers to the whole process of safety risk issues when using industrial production methods for engineering and construction projects.

The project object of the study is mainly to start the study with the prefabrication rate reaching a high degree project (exceed 30%). At this stage, a large number of industrialised projects under construction in China have already reached a high prefabrication rate and industrialization degree, and prefabricated floor slabs, prefabricated facades, prefabricated stairs, prefabricated balconies, prefabricated columns, prefabricated beams and other components are used in industrialised projects under construction. However, there are still a small number of projects with only one kind of prefabricated components such as balconies or exterior wall panels, and for the "semi-industrialised projects" where the prefabrication rate is low and most of the processes still adopt the traditional construction mode. The high or low assembly rate also directly affects the identification and assessment of safety risk factors. Therefore, the respondents were mainly involved in projects with high levels of prefabrication. Therefore, the industrialised buildings in this paper must meet the criteria of industrialised building as defined in GB/T 51129-2017, the evaluation standard of industrialised buildings in China developed by MOHURD, namely, "The assembly rate of projects using industrialised concrete buildings should be not less than 30%; and the prefabrication rate of individual buildings should be not less than 40% when the building height is below 60 meters (inclusive), and the prefabrication rate of individual buildings should be not less than 30% when the building height is above 60 meters (inclusive).

The industrialised building projects selected in this study are Xi'an, Ankang and Yan'an cities in Shaanxi Province. Shaanxi Province has three regions: central, southern and northern. One city in each region was selected for the survey. In the central region, Xi'an is the capital city of Shaanxi Province, with the most developed economy and population, and the highest level of industrialised building development. Therefore, Xi'an has the highest percentage of industrialised building projects in the survey. In the southern and northern regions, Ankang and Yan'an were chosen as the study cities, respectively, mainly because the construction scale of industrialised buildings in both cities is at the front of their own regions.

During the survey, all of the industrialised building projects were completed between 2018 and 2023, this is due to the fact that these projects were completed over a stronger period of time and are therefore likely to be more accurate for the results of the survey. At the same time, the people involved in the projects were also more knowledgeable about the information related to industrialised buildings.

The enterprise object of the study is mainly the industrialised construction enterprise with prefabricated component production, component transportation and construction. There are many kinds of enterprises involved in the whole production process of construction industrialization, such as the whole industry chain production enterprises, construction general contracting enterprises, component processing enterprises, transportation enterprises. However, because a large number of industrialised buildings projects in practice are construction general contracting enterprises plus prefabricated component factory mode and the production mode of the whole industry chain enterprises, which is not only a major feature of the development process of China's construction industrialisation at this stage, but also a development mode that is in line with Therefore, this study does not include the combination of other construction units in the scope of the study, and intends to conduct a special study in the future.

Therefore, this study need to understand the safety risk factors of industrialised buildings through literature review and survey the contractors, prefabricated manufacturers, scholars and policy makers who have been involved in completed industrialised building projects in Shaanxi Province from 2018 to 2023.

1.9. Significance of the Research

This paper studies an important stage in the whole life cycle of industrialised buildings, whose construction safety or not directly determines the construction schedule, construction cost and quality of the project, and is crucial to the future development of industrialised buildings in China. A scientific and perfect construction safety assessment system for industrialised buildings can effectively identify and analyze the risk factors in the construction process, pre-control the risks, effectively reduce the possibility of construction risks, and thus reduce the losses caused to the project when construction risk events occur; at the same time, the reasonable control of risks can effectively guarantee and improve the quality of the project, which has a positive impact on promoting the development of the industrialised construction industry.

The study sorts out and screens industrialised construction safety risk factors, constructs a list of industrialised construction safety risk factors, analyses the importance of each risk influencing factor and the mutual influence between them, and performs analysis on risk factors to rank different risk factors. It strengthens the project managers' understanding of industrialised buildings and enables them to clearly understand the necessity of conducting industrialised building construction safety risk management and control. The study gives targeted countermeasures based on the important risk factors obtained from the analysis. These recommendations and measures not only construct a basis for project managers to plan safety in industrialised building construction, but also provide theoretical guidance for various emergency contingencies that may arise during construction.

The primary methods used in this study were quantitative methods through surveys and qualitative methods supported by interviews and focus groups. This study developed a new assessment of industrialised building safety, which was derived from a literature review and data collection from both quantitative and qualitative methods. The information needed for the paper was first summarized by reviewing a large amount of literature to gain a comprehensive understanding of the current state of industrialised building safety risk research and to dig deeper into what is lacking in China's industrialised building safety risk assessment system so that an appropriate method can be selected to solve the problem. Then, by visiting existing assembly component production bases, industrialised building construction sites, universities conducting research on industrialised buildings, conduct talks and interviews with relevant technical personnel, construction workers, managers, and scholars to fully understand the operational processes of the component transportation stage, component incoming acceptance stage, support system setting stage, and component construction stage in the industrialised building construction process. Based on the experience of professionals, risk categorisation during construction can be understood. Finally, in the process of evaluating the safety risks of industrialised buildings, the hierarchical analysis method (AHP) is used to establish a scientific and perfect assessment model to

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter describes previous research on safety management issues involving industrialised construction projects in the Chinese construction industry. This section also includes an explanation of perspectives related to the global construction industry and China. This chapter includes a list of prior research that will explain the research gaps in this thesis study. This chapter also explains the development of the industrialised construction industry in China. The chapter explains the comparison between traditional construction projects and industrialised construction projects, including the mechanisms of traditional and industrialised construction projects, productivity levels, and the advantages of industrialised construction projects over traditional construction.