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Research Article

Critical Success Factors for Safety Management of High-Rise Building Construction Projects in China

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This study aims at identifying the critical success factors (CSFs) for safety management of high-rise building construction projects and exploring interactions among such CSFs. Study data were sourced from semistructured interviews and a questionnaire survey administered in China. The study constructs a third-order CSFs system containing six CSFs: management measures, management organization, technical and management plan, worker safety behavior, safety environment, and worker safety quality. Among these, management organization is found to be the key factor affecting construction safety management performance, while worker safety behavior is a factor with a direct impact. Implications for practice are proposed. This study enriches the existing literature on the CSFs and performance evaluation of construction safety management in high-rise building construction projects. Safety performance of high-rise building construction projects can be effectively enhanced by improving the professional competence of safety management organizations.

1. Introduction

The construction industry remains one of the world's most dangerous industrial sectors, accounting for 30–40% of fatal injuries despite only accounting for around 7% of employment [1]. In Korea, it accounts for the highest proportion (25.3%) of workplace fatalities [2, 3], the third-highest in the U.S. [4], and the fourth-highest in Australia [5]. In China, only the coal-mining industry is more dangerous than construction [6].

Safety performance is a serious challenge in high-rise building construction with high-altitude operation and excavation of deep foundation pits resulting in much higher accident rates and more severe injuries than found in medium- and low-rise buildings. Injuries and fatalities resulted from falls and the impact of falling objects are constant threats. Booming economies and rapid urbanization in East Asia, and in China in particular, have massively increased the volume of high-rise construction in the region. According to the Council on Tall Buildings and Urban Habitat [7], in 2017, China alone accounted for 53% of the world's 200-meter-plus buildings, thus issues related to improving safety performance of high-rise building construction are an urgent concern in China.

This research seeks to identify critical success factors (CSFs) in construction safety management practices for high-rise buildings and to determine mutual interactions between these factors. The remainder of this paper is organized as follows. Section 2 systematically reviews the literature related to CSFs, construction safety management for high-rise buildings, and factors affecting construction safety management. Section 3 reviews research methods using semistructured interviews and a questionnaire survey. Section 4 reports the results and corresponding discussion. Section 5 clarifies the relationships among CSFs. Conclusions and recommendations for future studies are provided in Section 6.

2. Literature Review

2.1. Critical Success Factors. The concept of "success factors" was first developed by Daniel [8] in the context of the importance of information systems. Generally, success in most industries is determined by three to six factors. Rockart [9] wrote that "*CSFs are, for any business, the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organization.*" Thus, CSFs are areas of activity that should receive constant and careful attention from management.

Studies in the field of construction have adopted the CSF approach to examine safety issues. For example, Aksorn and Hadikusumo [10] investigated the CSFs of safety program implementation in medium- and large-scale construction projects in Thailand. Al Haadir and Panuwatwanich [11] explored the critical factors influencing the implementation of safety programs among construction companies in Saudi Arabia. The CSF approach has also been widely adopted in construction partnering [12–14], PPP/PFI [15, 16], knowledge management [17], value management [18], and green building researches [19].

2.2. High-Rise Buildings. No internationally agreed definition exists for "high-rise building." For instance, the *International Conference on Fire Safety in High-Rise Buildings* defined a high-rise as "*any structure where the height can have a serious impact on evacuation*" [20]. In the U.S., the *National Fire Protection Association* regarded a high-rise as being higher than 75 feet (23 meters) or about 7 stories [21]. In China, according to *Technical Specification for Concrete structures of Tall Buildings*, a high-rise building is a residential building of 10 floors or more, or 28 meters or more in height, and other commercial buildings exceeding 24 meters, including mega-high-rise buildings (commercial buildings at least 100 meters tall) [22]. This research adopts China's local definition, which is a wide range of tall buildings including mega-high-rise buildings. The absolute height of high-rise buildings gives rise to a wide range of challenges to construction safety management, including extreme environments on high-altitude floors [23, 24] and complex physiological and psychological impacts on construction workers from working at such elevations [25–27].

Despite the impacts of such issues on the complexity of construction safety management for high-rise buildings, the relevant literature is sparse. Hinze and Raboud [28] examined large building construction projects in Canada (mostly high-rise buildings), seeking to assess the degree to which corporate or project policies and practices influence worker safety, and to identify factors affecting safety performance. Ismail et al. [29] sought to identify safety factors that determine the success of safety management systems for high-rise building construction sites. Prior studies into safety management mechanisms fell short of drawing distinctions between high-rise buildings and medium- and low-rise buildings, and common influential factors and CSFs for the construction safety management of high-rise buildings are yet to be identified.

2.3. Factors Affecting Construction Safety Management. A great deal of construction researches has sought to identify factors impacting the success of safety management.

Table 1: Construction safety management regulations and standards.

Region	Title	Abbr.
China	Standard of construction safety inspection (JGJ59-2011)	[30]
	Regulations on safety production management of construction projects	[31]
	Technical code for safety of temporary electrification on construction site (JGJ46-2005)	[32]
	Standard for the work safety assessment of construction company (JGJ/T77-2010)	[33]
	Technical scheme of high-place construction operation (JGJ80-2011)	[34]
Hong Kong	Factories and industrial undertakings ordinance (FIUO-Cap. 59)	[35]
	Occupational safety and health ordinance (OSHO-Cap. 509)	[36]
Singapore	Code of practice for safety management system for construction worksites (CP79:1999)	[37]
	Factories (building operations and work of engineering construction) regulations	[38]
Japan	Construction occupational health and safety management system (COHSMS) guidelines and COHSMS external system evaluation	[39]

Regulations and standards (Table 1) for construction safety management are also major sources for the identification of influential factors. Table 2 summarizes various factors affecting construction safety management identified in past researches and the corresponding regulations and standards. Previous qualitative and quantitative attempts have been made to determine CSFs for the construction industry, with various authors identifying positive or negative relationships between them. However, to date, no research has sought to identify CSFs for high-rise building construction project safety management, constituting a serious gap in the literature.

3. Research Methodology

This study applies a two-pronged research design. First, expert interviews were conducted to develop and validate the initial questionnaire to identify the success factors (SFs) of safety management for high-rise building construction projects based on the factors summarized in Table 2. Second, a questionnaire survey was administered to quantitatively identify CSFs and their interactions.

3.1. Expert Interview. Expert interviews were carried out to validate the constructed questionnaire for SFs for high-rise building construction project safety management. Seven experienced practitioners were interviewed including four safety officers, two engineers, and one project manager, each with at least ten years of work experience in the field of high-rise building construction safety management (Table 3). To guarantee interview comprehensiveness, each lasted 40–60

Table 2: Factors affecting construction safety management.

Number	Factor	Source	Description
1	Safety production liability system	[30, 31]	Safety production liability system is a compulsory system in the Chinese construction industry used to stipulate responsibilities of the leadership, management, and labor layers. Clear assignment of responsibilities enables all involved parties to perform specific tasks to meet safety requirements.
2	Special construction plans for safety of danger subprojects	[30, 31]	High-risk subprojects, such as high-altitude construction, high formwork, and deep foundation pits, need special safety construction plans prior to work. Appropriate special construction plans are essential technical documents used to guide management and operations.
3	Safety inspection	[28, 30, 31, 35, 37, 40–45]	Safety programs may require safety managers (e.g., safety supervisor, project manager, and safety officer, etc.) to conduct adequate inspection during construction to protect workers from workplace hazards. Safety inspections are also an effective way to discover potential safety problems and correct them to reduce the accident rate.
4	Safety education and training of workers	[10, 11, 30, 31, 35, 37, 40, 42, 43, 43–48, 48, 49–52]	Safety management performance can be improved if all workers are educated and trained properly. Education and training are used to improve worker safety awareness and knowledge and skills to prevent accidents.
5	Emergency response plan	[30, 35, 37, 39]	In the event of an accident, emergency rescue is the most efficient way to minimize loss. Thus, construction projects should have scientific emergency response plans in place prior to work.
6	Employment with certificates	[30, 31]	The Chinese construction industry has implemented an occupational certificate system to guarantee worker quality and competence. Safety managers (e.g., project manager, supervisor, and safety officer) and technical workers (e.g., welder, scaffolder, and concreter) are required to obtain professional certification to perform work.
7	Accident reports and investigation	[30, 31, 35, 37, 39, 43, 44, 46, 47, 53]	Accident reports and investigations ensure that accidents are handled appropriately and prompt reflection and improvement. Accident analysis identifies root causes to improve future accident prevention.
8	Safety environment	[30, 31, 37]	Safety environment covers a wide scope including physical environment (e.g., light and temperature), site layout, and safety protection. A good safety environment guarantees safe conditions to reduce potential onsite hazards.
9	Control of subcontractor	[30, 35, 37, 44, 46, 47, 53]	Safety management is not assigned to a single party, but rather is the common purpose of all stakeholders. Subcontractor management entails ensuring subcontractor qualification and performance to ensure safe work practices at all levels.

Table 2: Continued.

Number	Factor	Source	Description
10	Safety committee	[31, 35, 37–39]	Safety committee comprises of the project manager, safety officers, and other relevant management personnels. As the key leader and decision-maker for safety management, the safety committee plays an important role in improving safety performance.
11	Safety incentive	[42–49]	Safety incentives are widely used to incentivize workers to play an active role in safety management and effectively encourage good safety behavior.
12	Regular safety meetings	[28, 41–43, 45, 47]	Regular formal safety meetings allow all relevant parties to review safety records and discuss safety problems. Detailed safety management plans and safety goals should be discussed and determined through such meetings.
13	Management support	[10, 11, 40, 45, 48, 51, 54–57]	Management support can ensure that sufficient resources are allocated for safety management, and proper actions are conducted to improve safety performance. Support from management is also an important dimension of safety climate and safety culture to encourage workers to attach more importance to safety.
14	Provision of personal protection equipment (PPE)	[44, 49, 54, 55]	PPE is essential for routine construction works, and for high-altitude works in particular. In practice, managers should provide adequate PPE to each worker and require its usage.
15	Detailed safety management plan	[42, 46, 47, 53]	The safety management plan is a formal safety management document including safety goals, strategies, measures, rules, and schedules.
16	Safety investment	[40, 42, 48, 55]	Safety investment entails the distribution and allocation of key resources for construction safety management. Safety management cannot be effective without adequate investment. Thus, a certain proportion of engineering costs should be allocated to safety management.
17	Personal attitude	[10, 11, 51, 56, 58]	Personal attitude entails the intrinsic motivation of workers to actively participate in safety management practices. One of the main purposes of safety management is to cultivate positive safety attitudes among workers.
18	Suitable supervision	[10, 11, 51, 56]	Appropriate supervision from government agencies should guarantee the provision of adequate safety resource and standardized management. Supervising departments will regularly inspect construction sites to ensure safety management conforms to relevant regulations and standards.
19	Safety equipment	[10, 51, 52, 56]	The procurement, maintenance, and operation of safety equipment must all be emphasized. The safety of construction site equipment, including cranes, welders, and rebar cutters, must all be strictly controlled.

Table 2: Continued.

Number	Factor	Source	Description
20	Personal competency	[10, 51, 52, 59]	Personal competency means that people can complete tasks properly based on his/her knowledge, experience, and skills. To avoid accidents, tasks must be assigned to qualified individuals.
21	Clear and reasonable objective	[10, 11, 51, 60]	Clear and reasonable safety goals are the main directions for safety management of a project. Safety management strategies, such as plans, schemes, and detailed measures, all should aim to achieve the project safety goals.

minutes and proceeded through three steps: a brief introduction of the research background and objectives, followed by comments on the complexity of construction safety management for high-rise buildings, and verification of each listed variable and proposed modification suggestions.

Feedback gathered from the expert interviews was used to revise the initial questionnaire. Additional influential factors were added including electrical safety, coordinator of special operations (e.g., hoisting and grouting), safety and technology disclosures, daily safety records, adjustable timetables, efficient rectification and reform, worker compensation insurance, safety awareness, sufficient quality of material and equipment, worker awareness and behavior, labor-management relations, and safety climate. Factors that did not fit the Chinese high-rise building construction context were removed, such as extra compensation for high-risk work. Some factors were subdivided. For example, safety environment was divided into safe monitoring, site layout, and physical environment; worker behavior was broken down into stability, peer cooperation, and compliance.

3.2. Questionnaire Survey. A questionnaire survey was designed to collect data. The final questionnaire comprised three parts: (1) project background, used to collect project information, such as building height, type, and safety performance; (2) demographic information of respondents including service experience, qualification certificates, and number of high-rise building construction projects worked on to ensure respondents qualification; and (3) SFs of construction safety management for high-rise buildings. The final questionnaire of part (3) alone included 38 structural questions representing 38 SFs for the safety management of high-rise building construction projects. The questionnaire was constructed using a five-point Likert scale where 1 stands for no influence, 3 stands for moderate influence, and 5 stands for very high influence.

The questionnaire survey was administrated to construction safety personnels who had qualification certificates for safety management and experience in high-rise building construction projects. Construction safety personnels are those with responsibility for overall construction site safety, including safety directors, managers, supervisors, officers, and foremen. In the Chinese construction industry, qualification certificates for safety management include Certified Safety Engineer, Safety Officer (including level A, B, and C), Constructor (including Constructor and Associate Constructor), Technician Certificate, and Supervising Engineer (including Registered Supervisor Engineer, Professional Supervisor Engineer, and Supervisor). Prior to the distribution questionnaire, item analysis was applied to the pretest questionnaire to assess the discriminability of questions. As a result, 36 structural questions representing 36 SFs were retained.

Table 3: Experts profile.

Number	Role	Service company	Service years
1	Project manager	Contractor	16~20
2	Safety officer	Contractor	11~15
3	Safety officer	Contractor	≥21
4	Safety officer	Contractor	≥21
5	Safety officer	Contractor	16~20
6	Engineer	Owner	11~15
7	Engineer	Supervision department	11~15

A total of 410 questionnaires were distributed to safety management personnels of high-rise building construction projects in person, by post or by email. One hundred and ninety-seven valid questionnaires were collected, giving a response rate of 53.53%. Referring to Figure 1, 90.29% of the valid questionnaires were from male respondents. More than half of the respondents had at least six years of high-rise building construction work experience, and about 30% had been involved in more than five high-rise building construction projects. About 60% of the respondents work primarily on residential high-rise building construction projects, of which more than four-fifths exceeded 17 floors. Forty of the valid questionnaires were received from project owners, while another 40 were from consultants, and the remaining 114 were from contractors. Over 40% of the respondents had received various professional licenses (i.e., qualification certificates) from the relevant Chinese authorities.

4. Extracting Success Variables

4.1. Exploratory Factor Analysis. Exploratory factor analysis (EFA) was applied to uncover the underlying structure of

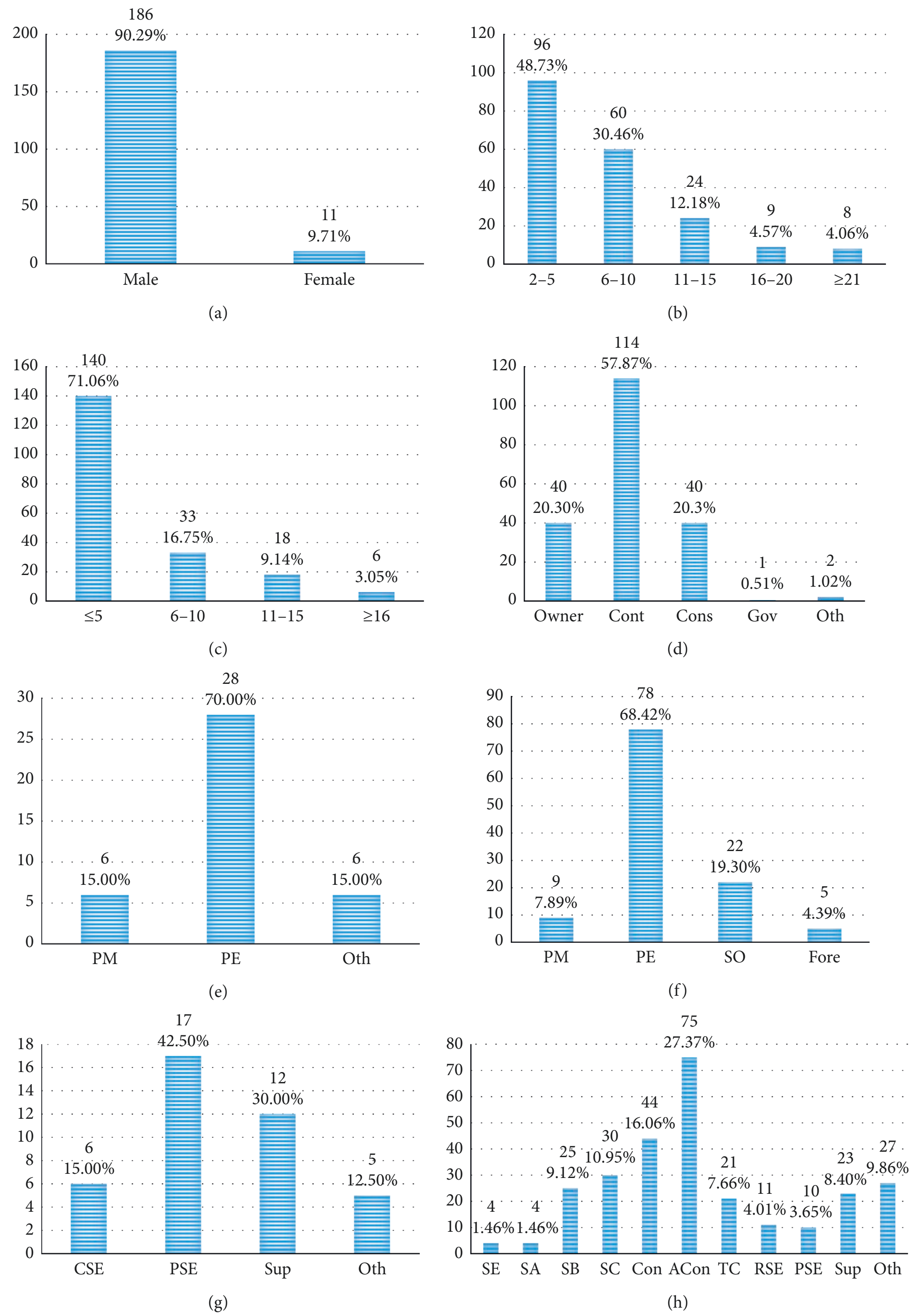
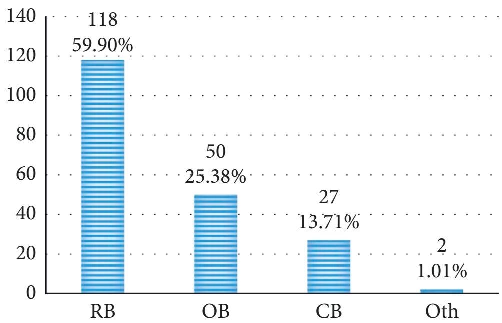


Figure 1: Continued.



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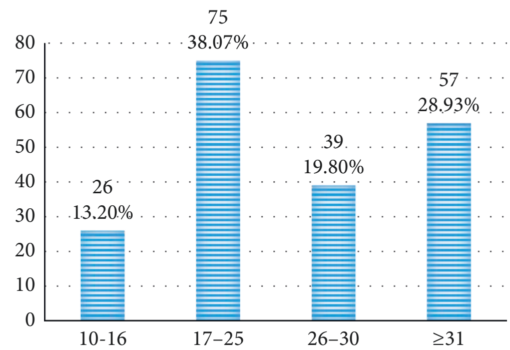

(j)

Figure 1: Respondent demographic data. (a) Gender. (b) Working experience (year). (c) Number of projects involved in. (d) Firm. (e) Owner. (f) Contractor. (g) Consultant. (h) Qualification certificates. (i) Building type. (j) Building height (floors).

variables within questionnaire to identify initial CSFs. Various tests were required to check whether the data could meet EFA requirements, and a correlation matrix was generated to determine correlations among variables. The relationships with high-correlation coefficients (greater than 0.5) were summarized as follows: *Safety committee established* with *Professional competence of safety committee*, *Professional competence of safety committee* with *Safety committee establishes good safety climate*, *Labor-management safety communication* with *Labor-management trust relationship* and *Safety committee establishes good safety climate*, *Labor-management trust relationship* with *Safety committee establishes good safety climate*, *Safety committee establishes good safety climate* with *Safety propaganda*, *Labor-management trust relationship* with *Safety committee establishes good safety climate*, *Worker safety awareness* with *Worker safety knowledge*, *Worker safety knowledge* with *Worker experience*, *Workers obey management* with *Worker cooperation on safety*, *Safety technical measurements in construction organization plan* with *Special construction plans for safety of danger subprojects* and *Detailed safety management plan*, *Worker compensation insurance* with *Emergency response plan* and *Accident/incident reports and investigation*, *Daily safety records* with *Regular safety meetings*, and *Emergency response plan* with *Accident/incident reports and investigation*.

The Bartlett's score for questionnaire sphericity is 3288.275, and the associated significance level is 0.000, indicating that the correlation matrix is not an identity matrix [61]. The Kaiser-Meyer-Olkin (KMO) measure of all the variables is 0.858, which is significantly greater than 0.5 and can be considered highly acceptable. Test results confirmed that the sample data are appropriate for processing EFA. EFA was processed using principal component analysis and promax rotation to identify the initial CSFs (iCSFs), where items exhibiting low communality value (<0.5), low factor loadings (<0.45), and cross-loading were candidates for elimination [61]. The promax rotation is an oblique rotation approach capable of obtaining solutions using correlated components. This approach is commonly applied in almost all fields of social science, as typically each factor is to some extent related to other factors [62]. The promax rotation was realized mainly because the success factors proposed by this study (classified in the social sciences) are mutually dependent to some degree. Table 4 shows the results of final stage EFA. Through the rule of eigenvalue greater than one, the seven-factor solution was considered the most appropriate. The Cronbach's α values for all seven iCSFs exceed 0.65. Every iCSF is named according to its associated success factors as follows: *management measures* (iCSF1), *management organization* (iCSF2), *technical and management plan* (iCSF3), *worker safety behavior* (iCSF4), *guarantee and supervision mechanism* (iCSF5), *safety environment* (iCSF6), and *worker safety quality* (iCSF7).

4.2. Confirmatory Factor Analysis. Confirmatory factor analysis (CFA) was used to determine the final CSFs framework. Overall model fitness is examined using goodness-of-fit (GOF) indices. According to Table 5, the final measurement model fits the data exactly. Figure 2 shows the final CSF system with path coefficients. As shown in Figure 2, at the third-order level, there were two groups (*Organizations and Strategies, Environment and Workers*) including six CSFs which were measured by 12 observed variables.

The second-order groups were structured according to first-order data statistical characteristics (correlation coefficients), existing research results, and practical experience. In the first-order measurement model, the correlation coefficients of *worker safety behavior (CSF4)* with *worker safety quality (CSF7)* and *safety environment (CSF6)* are 0.53 and 0.45, respectively, exceeding the moderate correlation level. Thus, we grouped CSF4, CSF6, and CSF7 into one second-order structure named "*Environment and Workers.*" Furthermore, the correlation coefficients of *management measures (CSF1)* with *management organization (CSF2)* and *technical and management plan (CSF3)* (0.51, 0.50) and *management organization (CSF2)* with *technical and management plan (CSF3)* (0.41) exceed the moderate correlation level. In practice, safety committees are responsible for compiling and auditing technical and management schemes, as well as for implementing management policies. Thus, CSF1, CSF2, and CSF3 were grouped together and named "*Organization and Strategies*."

Table 4: Initial CSFs.

Cluster	Success factor	Communality value	Factor loading	Cronbach's α	Factor label
iCSF1	SF27. Daily safety records	0.694	0.833	0.835	Management measures
	SF28. Regular safety meetings	0.610	0.772		
	SF29. Safety education and training of workers	0.514	0.767		
	SF25. Safety and technology disclosure	0.626	0.608		
	SF32. Emergency response plan	0.713	0.519		
	SF33. Accident/incident reports and investigation	0.665	0.513		
iCSF2	SF7. Safety committee established	0.673	0.778	0.751	Management organization
	SF9. Management support	0.619	0.739		
	SF8. Professional competence of safety committee	0.684	0.713		
iCSF3	SF20. Special construction plans for safety of danger subprojects	0.684	0.859	0.792	Technical and management plan
	SF19. Safety technical measurements in construction organization plan	0.744	0.825		
	SF21. Detailed safety management plan	0.692	0.710		
iCSF4	SF18. Worker cooperation on safety	0.644	0.791	0.717	Worker safety behavior
	SF16. Low worker mobility	0.625	0.776		
	SF17. Workers obey management	0.613	0.658		
iCSF5	SF5. Electrical safety	0.583	0.771	0.663	Guarantee and supervision mechanism
	SF6. Equipment safety	0.565	0.702		
	SF24. Safety investment	0.605	0.586		
	SF34. Safety-related rewards and punishments	0.595	0.479		
	SF23. Worker compensation insurance	0.634	0.451		
iCSF6	SF2. Tidy worksite	0.593	0.746	0.658	Safety environment
	SF3. Good physical environment	0.549	0.632		
	SF4. Sufficient quality of material and equipment	0.624	0.586		
	SF1. Provision of PPE	0.609	0.523		
iCSF7	SF13. Worker safety awareness	0.771	0.819	0.806	Worker safety quality
	SF14. Worker safety knowledge	0.743	0.806		

In the group *Organizations and Strategies* (group 1), *management measures* ($\lambda = 0.804$) play the greatest role, followed by *technical and management plan* ($\lambda = 0.670$) and *management organization* ($\lambda = 0.648$). This is attributed to the complexity of high-rise building construction requiring corresponding measures and strategies to manage workers and the worksite. *Management measures* was measured by safety meetings ($\lambda = 0.702$) and safety training ($\lambda = 0.663$), showing that safety meetings and training are basic management measures. *Technical and management plan* refers to the detailed safety technical measurements ($\lambda = 0.788$) and management plan ($\lambda = 0.762$) in construction organization scheme. Some complex subprojects of high-rise buildings, such as foundation pit, formwork, and scaffold, may require appropriate technical and management planning for guidance. *Management organization* entails the establishment of a safety committee ($\lambda = 0.794$) and the professional competence of committee members ($\lambda = 0.837$). This result is consistent with the work of Sawacha et al. [54], who identified safety committee policy as a significant influence factor on construction safety performance.

In the group *Environment and Workers* (group 2), *worker safety behavior* ($\lambda = 0.912$) is found to have the greatest influence, followed by *safety environment* ($\lambda = 0.577$), while *worker safety quality* ($\lambda = 0.549$) is the least influential factor. The high impact of *worker safety behavior* is consistent with the findings of Blackmon and Gramopadhye [63] who argued that 98% of construction accidents could be attributed to unsafe human behavior. *Worker safety behavior* was measured according to worker safety cooperation ($\lambda = 0.723$) and low worker mobility ($\lambda = 0.655$). Fang et al. [42] and Ismail et al. [29] both highlighted the significant role of cooperation played in construction safety, including cooperation among workers, as well as cooperation between workers and managers. In addition, relatively stable worker status could lower the likelihood of accidents. The positive relationship between worker stability and safety performance has been verified by Fang et al. [42] and Cheng et al. [40]. *Safety environment* requires tidy worksite ($\lambda = 0.650$) and sufficient quality of material and equipment ($\lambda = 0.618$). *Worker safety quality* comprises safety awareness ($\lambda = 0.794$) and safety knowledge ($\lambda = 0.854$), which form workers' intrinsic motivation to operate safely.

Table 5: GOF indices of CSFs measurement model.

GOF indices	Suggested level	CSF measurement model	Results
χ^2 (p)	The least ($p \geq 0.05$)	67.888 (0.082)	OK
χ^2/df	≤3	1.281	OK
GFI	>0.9	0.948	OK
AGFI	>0.9	0.923	OK
RMR	<0.05	0.036	OK
RMSEA	<0.05	0.038	OK
NFI	>0.9	0.901	OK
CFI	>0.9	0.976	OK

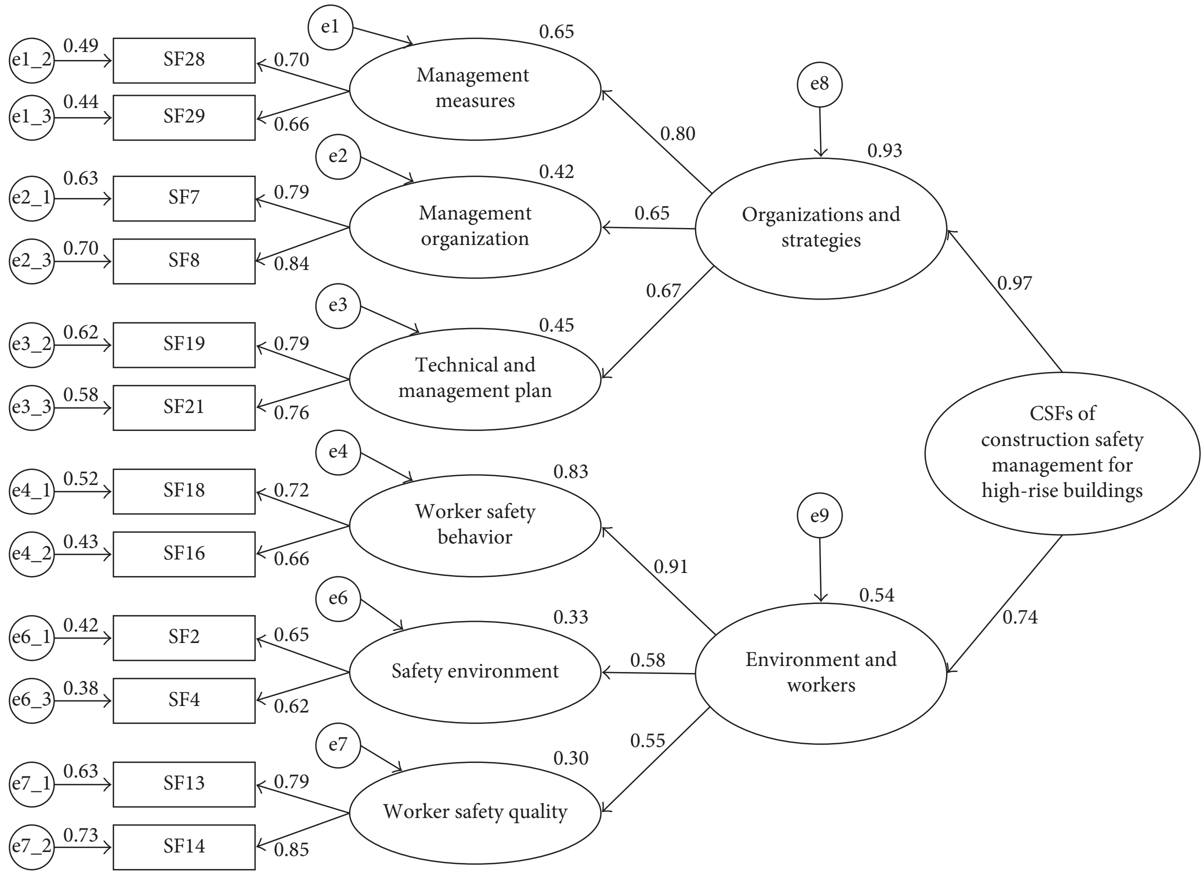

Figure 2: CSF measurement model.

5. Clarifying the Relationships among CSFs

The SEM structural model was used to test interactions among CSFs. To construct the basic framework, the hypotheses describing relationships among CSFs should first be set up on the basis of theoretical expectations and past empirical findings.

5.1. Hypothesis Development. Accident causation theories provide a theoretical basis for hypotheses development. At the early stage, several domino theories were used to analyze accident causation and their relations, including those proposed by Heinrich and Granniss [64] and Bird et al. [65]. Heinrich and Granniss [64] argued that deficiencies in human behavior might lead to accidents, whereas unsafe behavior was caused by worker shortcomings and failure, stemming from both nature (e.g., impertinency, stubbornness, and nervousness) and nurture (e.g., lack of safety knowledge and poor safety awareness). This argument was supported by Bird et al. [65] whose domain theory considered personal reasons that lead to inappropriate behavior. Lack of safety knowledge, safety awareness, and work skills could be regarded as personal reasons. Thus, we develop a hypothesis that *worker safety quality* (CSF7) positively affects their *safety behavior* (CSF4).

In Bird et al.'s domino theory [65], the direct causes of accidents are unsafe conditions and unsafe human behavior, whereas the root cause of accidents is management defects. This suggests that management deficiencies may negatively impact the safety environment and human safety behavior, resulting in accidents. Therefore, the following hypotheses are proposed regarding relations between management factors, the safety environment and safety behavior: (a) *management measures* (CSF1) positively affects *worker safety behavior* (CSF4); (b) *management measures* (CSF1) positively affects *safety environment* (CSF6); and (c) *technical and management plan* (CSF3) positively affects *worker safety behavior* (CSF4).

Trace intersection theory states that workplace accidents are the result of a combination of unsecure environment and unsafe behavior, meaning the traces of the safety environment and worker behavior may intersect to cause accidents. Thus, we propose that *safety environment* (CSF6) positively affects *worker safety behavior* (CSF4).

In addition to accident-causing theories, a large number of empirical studies have modeled the relations of influential factors of construction safety performance. Xing et al. [66] found that organizational factors, such as safety culture and leadership capacity, along with regulator and personnel arrangements, have a direct effect on management measures (e.g., safety checks and safety protection). Consequently, it is hypothesized that *management organization* (CSF2) positively affects *management measures* (CSF1).

In practice, safety committees take charge of compiling and auditing the technical and management scheme, as well as the

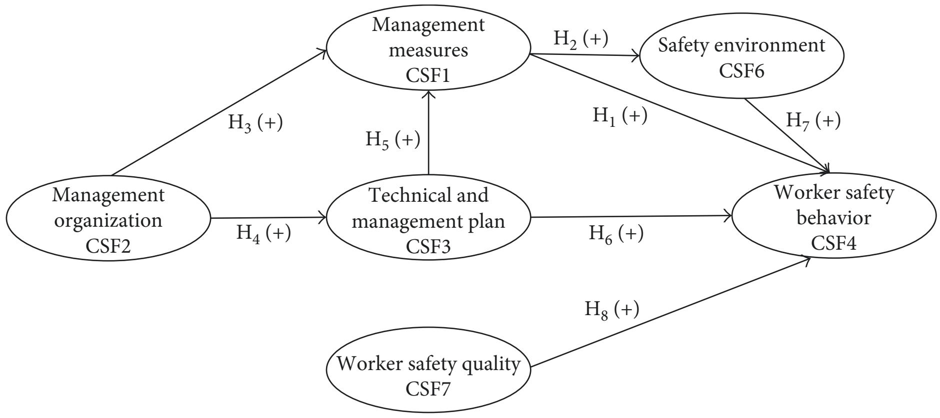

Figure 3: Initial CSF structural model.

Table 6: GOF indices of CSF structural models.

GOF indices	Suggested level	Initial model	First revised model	Second revised model (final)
χ^2 (p)	The least ($p \geq 0.05$)	*81.236 (0.006)*	67.781 (0.058)	68.235 (0.065)
χ^2/df	≤3	1.562	1.329	1.312
GFI	>0.9	0.939	0.948	0.948
AGFI	>0.9	0.909	0.921	0.922
RMR	<0.05	*0.055*	0.038	0.038
RMSEA	<0.05	*0.054*	0.041	0.040
NFI	>0.9	*0.881*	0.901	0.900
CFI	>0.9	0.953	0.973	0.974

Number italicized means it fails to meet the suggested levels.

implementation of management measures. Thus, the following hypotheses are established: (a) *management organization* (CSF2) has a positive impact on *technical and management plan* (CSF3); and (b) *technical and management plan* (CSF3) has a positive impact on *management measures* (CSF1).

As shown in Figure 3, the hypotheses proposed in this study are summarized as follows:

H_1: *management measures* (CSF1) positively affects worker *safety behavior* (CSF4).

H_2: *management measures* (CSF1) positively affects *safety environment* (CSF6).

H_3: *management organization* (CSF2) positively affects *management measures* (CSF1).

H_4: *management organization* (CSF2) has a positive impact on *technical and management plan* (CSF3).

H_5: *technical and management plan* (CSF3) has a positive impact on *management measures* (CSF1).

H_6: *technical and management plan* (CSF3) positively affects *worker safety behavior* (CSF4).

H_7: *safety environment* (CSF6) positively affects *worker safety behavior* (CSF4).

H_8: *worker safety quality* (CSF7) positively affects their *safety behaviors* (CSF4).

5.2. Structural Model Evaluation and Hypothesis Testing. The structural model was tested by SEM path analysis. GOF indices were used to examine the overall fitness. If the GOF indices do not reach the recommended levels, model modification was required to improve overall fitness according to the modified index (MI). Model refinement was also performed in response to insignificant correlation coefficients.

Table 6 summarizes suggested levels of GOF indices and the indices of the initial and final structural models. Four indices of the initial model, χ^2, RMR, RMSEA, and NFI, failed to meet the suggested levels, indicating the need for model modification. The first revised model added the relation path of *management organization* (CSF2) and *worker safety quality* (CSF7). Although GOF indices of the first revised model met the requirements, the model should also be modified because of the insignificant path (standardized weight = 0.14; $p = 0.498$) between *management measures* (CSF1) and *worker safety behavior* (CSF4). As shown in Figure 4, after deleting the relation path of CSF1 and CSF4, the GOF indices of the final structural model reached the threshold levels. Referring to Table 7, in addition to the nonoriginal hypothesis (CSF7 ← CSF2), seven path coefficients have a p value lower than 0.01, indicating they are statistically significant at the 0.01 level, suggesting that seven of the hypotheses (i.e., H_2, H_3, H_4, H_5, H_6, H_7, and H_8) are supported. One of the eight hypotheses (H_1) was dismissed, and the other seven proved meaningful.

The rejection of H_1 was unexpected. Generally, construction safety management personnels govern the worker safety behavior through certain safety management measures. In most cases, CSF1 should have a direct impact on CSF4. However, in this study, the two observed variables (SF28 and SF29) included in CSF1 are mainly intended to

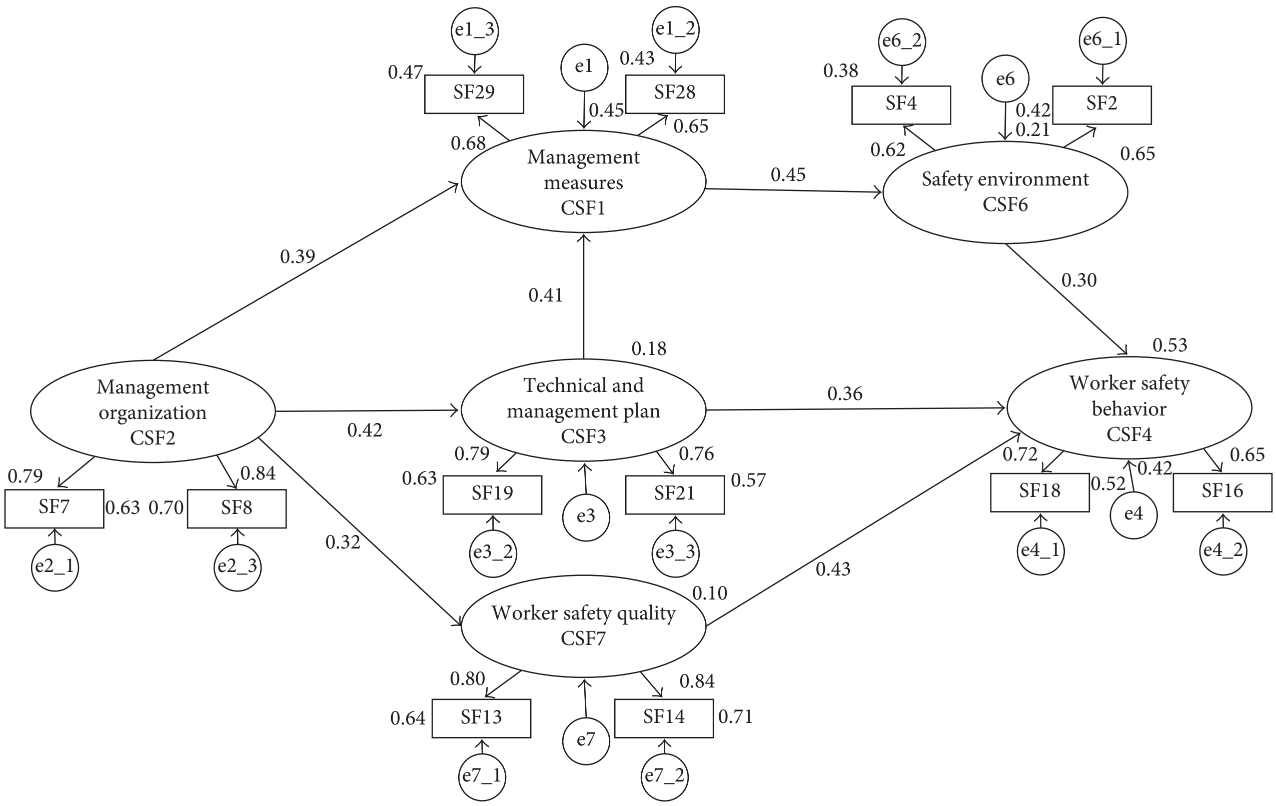

Figure 4: Final CSF structural model.

improve worker safety awareness and safety knowledge. Such measures aim to create a better jobsite safety environment, and further create a good safety climate, rather than directly regulate worker behavior. Due to the characteristics of high-rise building construction, CSF4 also affects the direct interaction between CSF1 and CSF4 to a certain extent. Although path analysis showed no direct effect between CSF1 and CSF4, it does not necessarily mean that CSF1 does not regulate CSF4. In fact, CSF1 indirectly affects CSF4 via *safety environment* (CSF6), as shown in Figure 4.

5.3. Analyzing the CSFs

5.3.1. Management Organization (CSF2). Management organization (CSF2) is considered to be the fundamental factor that has both direct and indirect relationships with other CSFs. Three significant correlation paths between *management organization* (CSF2) and *management measures* (CSF1), *technical and management plan* (CSF3), as well as *worker safety quality* (CSF7) indicate that management organization has direct effects on management measures, technical and management plans, and worker safety quality. The safety committee, as the implementer and supervisor of safety management, exerts decision-making power over the technical and management plan and management measures.

As the implementation of concrete measures should comply with the technical and management plan, and be supervised by safety committee, *management organization* (CSF2) also has an indirect effect on *management measures* (CSF1) through the *technical and management plan* (CSF3). One of novel results of this study is that *management organization* (CSF2) is found to directly influence *worker safety quality* (CSF7). Since the safety management committee provides workers with resources to control accidents and achieve safety goals, the education and training organized by safety committee enable workers to enhance safety quality, competency, and skills [67].

As for indirect effects, *management organization* (CSF2) affects *safety environment* (CSF6) through *management measures* (CSF1) and the *technical and management plan* (CSF3), thus improving management measures, and the technical and management plan will allow safety management organizations to enhance construction environment safety. Through the *technical and management plan* (CSF3), *management organization* (CSF2) indirectly impacts *worker safety behavior* (CSF4). Ultimately, the main purpose of construction safety management is to control worker behavior and protect them from accidents. Thus, safety management organization will control human behavior by providing the scientific, technical, and management plan.

5.3.2. Technical and Management Plan (CSF3). The relationships between the *technical and management plan* (CSF3) with *management measures* (CSF1) and *worker safety behavior* (CSF4) are shown to be significant. As the basic guideline for safety management, the technical and management plan may stipulate detailed management measures, such as training schemes and safety meeting systems. Since

Table 7: Path coefficients and significant test of the final model.

Hypotheses	Relationship	Standardized weight	Estimate	S.E.	C.R.	p value	Test result
H_1	CSF4 ← CSF1	0.104	0.120	0.178	0.678	0.498	Reject
H_2	CSF6 ← CSF1	0.463	0.484	0.124	3.896	***	Support
H_3	CSF1 ← CSF2	0.393	0.305	0.080	3.796	***	Support
H_4	CSF3 ← CSF2	0.423	0.413	0.086	4.821	***	Support
H_5	CSF1 ← CSF3	0.405	0.323	0.085	3.800	***	Support
H_6	CSF4 ← CSF3	0.361	0.335	0.091	3.661	***	Support
H_7	CSF4 ← CSF6	0.302	0.337	0.130	2.598	**	Support
H_8	CSF4 ← CSF7	0.429	0.441	0.092	4.813	***	Support
Nonoriginal	CSF7 ← CSF2	0.320	0.283	0.076	3.727	***	Support

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

human behavior is a main direct cause of safety accidents, the technical and management plan will also directly stipulate modes of work operations and behavior.

The results found that the *technical and management plan* (CSF3) indirectly affects *safety environment* (CSF6). In practice, a construction organization scheme provides detailed management measures, some of which will influence onsite conditions, which accounts for the indirect impact of the *technical and management plan* (CSF3) on the *safety environment* (CSF6). In addition, the technical and management plan might also implement measures to effectively control human behavior and enhance worksite safety.

5.3.3. Management Measures (CSF1). *Safety environment* (CSF6) is directly influenced by *management measures* (CSF1), indicating that appropriate safety management measures can improve the worksite safety environment. Through safety meetings and trainings, quality requirements can be made explicit for workers using plans and proper locations of material and equipment. *Management measures* (CSF1) slightly affects *worker safety behavior* (CSF4) through the *safety environment* (CSF6). This indicates that implementing safety management measures will influence worker behavior through enhancing the worksite environment.

5.3.4. Worker Safety Quality (CSF7). *Worker safety quality* (CSF7) directly impacts *worker safety behavior* (CSF4). As Heinrich and Granniss [64] and Bird et al. [65] suggested, human factors (e.g., lack of appropriate safety knowledge, awareness, and talent) are the underlying causes of misconduct which can result in accidents. Thus, it is reasonable that worker safety awareness and knowledge will directly impact their worksite behavior.

5.3.5. Safety Environment (CSF6). *Safety environment* (CSF6) is found to significantly influence *worker safety behavior* (CSF4), which is consistent with the findings of Chi et al. [68] who indicated an interrelationship among safety behavior and safety environment through a review of 9,358 construction safety accidents in the US. Chi et al. [68] explained that, combined with certain unsafe working conditions, unsafe worker behavior is the major root cause of accidents. In other words, the negative consequence of unsafe behavior can be intensified by unsafe conditions.

5.3.6. Worker Safety Behavior (CSF4). Safety behavior means personal actions taken for self-protection, such as following safety regulations to prevent danger to oneself or others and wearing protective gear [69, 70]. Safety behavior is not only directly affected by sincerity, openness, and extroversion but also is indirectly affected by stress reactions, safety motivation, and safety knowledge [71]. Unsafe behavior is the leading direct cause of safety accidents, and safety behavior has a negative effect on the frequency of occupational injury [72]. In fact, over 98% of construction accidents could be attributed to unsafe behavior [63]. This study found that *worker safety behavior* (CSF4) is directly and indirectly influenced by each of the proposed CSFs in high-rise building construction projects in China. Thus, *worker safety behavior* (CSF4) can be seen as the leading direct impact factor for determining construction safety performance in high-rise building construction projects.

6. Conclusions

High-rise building construction is a complex process, influenced by numerous and variable factors. Excellent safety management performance plays an essential role in construction project success. This study identified CSFs for safety management of high-rise building construction projects (objective one) and explored interactions among them (objective two). Expert interviews and a questionnaire survey were used to collect data for high-rise building projects in China. This study differs from previous work by focusing on the CSFs for safety management of high-rise building construction projects and their interrelationships. The study also provides an important reference for safety management personnels on high-rise building construction projects.

For objective one, this study established six third-order CSFs including *management measures* (CSF1), *management organization* (CSF2), *technical and management plan* (CSF3), *worker safety behavior* (CSF4), *safety environment* (CSF6), and *worker safety quality* (CSF7). Among these, the first three are grouped into *Organizations and Strategies* (group 1), and the latter three are grouped as *Environment and Workers* (group 2). In terms of impact, *management measures* (CSF1) has the strongest effect in group 1, and *worker safety behavior* (CSF4) is the strongest in group 2. *Management measures* (CSF1) is the most representative CSF, followed by *worker safety behavior* (CSF4). In terms of objective two, interactions among the CSFs show that *management organization* (CSF2) is the fundamental factor affecting construction safety management performance of high-rise buildings because it has the largest total effect on the other CSFs. Conversely, *worker safety behavior* (CSF4) is influenced by other CSFs but does not impact others, indicating that CSF4 is a direct-acting factor for the construction safety management performance of high-rise buildings.

The research findings have both theoretical and practical implications. In terms of theoretical contributions, this study enriches the existing literature on the CSFs and performance evaluation of construction safety management in high-rise buildings. The practical implication is that safety performance of high-rise building construction can be effectively enhanced by improving the professional competence of safety management organizations. Project owners and contractors should assign professional safety management personnels to establish a safety committee. At the same time, managers should adopt measures including safety training and safety meetings to enhance worker safety awareness and promote correct safety behavior.

This study takes a broad view of high-rise building construction projects (including mega-high-rise building construction); thus, further investigation is needed to identify specific characteristics of different types of high-rise building construction projects. Future work could seek to differentiate CSFs for construction of general high-rise buildings and mega-high-rise buildings. In addition, case studies for high-rise building construction projects could be conducted to extend the research findings.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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