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# Construction Quality of Prefabricated Buildings Using Structural Equation Modeling

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**Abstract:** Prefabricated construction has emerged as an inevitable trend in the development of the construction industry due to its numerous advantages, such as safety, energy saving, environmental protection, and sustainability. However, a series of operations and processes, such as prefabricated components, transportation of finished products, and on-site lifting required for fabricated buildings, can affect the quality of prefabricated buildings, especially during the construction process. This study aims to establish a systematic approach to analyzing the factors that influence the construction quality of prefabricated buildings and their interrelationships. A questionnaire was issued based on a literature review, and a model of the factors that influence the construction quality of fabricated buildings was established using structural equation modeling. Results showed that construction organization and management have a significant impact on building quality, prefabricated components, and the construction process. Moreover, they exerted the greatest influence on building quality, unlike the traditional belief that the construction process primarily affects building quality, and identified core factors influencing the quality of prefabricated construction.

**Keywords:** fabricated buildings; construction quality; structural equation model; Influencing factor

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## 1. Introduction

Prefabricated buildings have received significant attention and undergone extensive development due to their numerous advantages, such as heightened construction efficiency, reduced environmental pollution, and effective improvement of building quality [1]. In the 20th century, Europe witnessed the emergence of industrialized prefabrication techniques. This gained traction globally, especially in Europe, Japan, and the US. Urbanization, driven by the Industrial Revolution, prompted a shift of rural populations to cities, resulting in poor living conditions. Prefabrication was developed to address urban housing demands. Post-World War II, severe urban housing damage and labor shortages led to the significant growth of prefabricated modular construction in select advanced European nations during the 1950s. Industrialized assembly methods became a key solution for large-scale residential projects, laying the groundwork for standardized and serialized housing systems that persist today. During prefabricated building construction, diverse factors significantly impact quality—encompassing design, materials, hoisting, and management. Poor oversight at each stage risks accidents, yielding substantial economic losses [2]. Major development challenges encompass the following: limited project planning experience leading to inadequate feasibility studies; design coordination issues due to designers' insufficient grasp of advanced technology meeting production needs; scarcities in advanced manufacturing and transportation techniques and protective measures for finished products; contractors applying conventional concrete-focused quality practices instead of tailored ones; a lack of construction personnel responsibility; and unclear quality management goals among managers [3].

Notably, both project managers and construction personnel often lack experience in fabricated building practices. Issues like improper component lifting, weak connections, lax acceptance scrutiny, and seismic performance assessment hamper quality and industry progress. Hence, exploring factors impacting quality and enhancing performance is pivotal in influencing the prefabricated building sector's advancement.

The design and construction of assembled buildings are closely integrated, necessitating a professional construction team capable of executing the construction with high standards of collaboration among involved parties; moreover, the new process entails unclear sources of hazards and poses significant risks during the construction hoisting [4]. Traditional cast-in-place construction is categorized as on-site wet work, involving a significant amount of manual work with limited specialization among workers. However, in the case of fabricated buildings, the construction phase primarily relies on mechanical hoisting, necessitating a certain level of expertise among workers. Consequently, changes in construction methods and processes and the operation of the construction phase directly influence the construction quality of fabricated buildings. Hence, this work will focus on the construction phase of fabricated buildings.

The process of constructing fabricated buildings by contractors is not conducted in isolation, and the parties involved in the project must be viewed as a system, with the constructor functioning as a subsystem of this system [5]. The efficient performance of the overall system requires the mutual collaboration of its subsystems. The owner or supervision unit is responsible for providing the necessary site facilities and conducting construction acceptance for the contractor. The component supplier collaborates with the contractor to complete the component transportation and inspection. The design unit conducts drawing reviews, technical deliveries, and design changes for the contractor. The contractor supervises the construction quality of the subcontractor at the same time. This close interaction between the contractor and all project participants is at the core of ensuring the construction quality of fabricated buildings. Therefore, this work takes the contractor party as the research object.

## 2. Overview of the Quality of Fabricated Buildings

### *2.1. Construction Technology and Materials of Fabricated Buildings*

The quality of prefabricated components must be ensured to guarantee the quality of the construction of fabricated buildings. Even if the quality of components is improved, quality problems still occur when the components are installed and connected. Fujita Steel Plus Reinforced Precast Concrete (FSRPC) has the advantages of the component method in terms of building production technology [6]. In terms of structural planning, this method has the advantages of reinforced concrete and steel structures, and it can improve the quality of assembled buildings. Low-frequency cyclic load tests on three T-shaped partially precast reinforced concrete shear walls and one cast-in-place specimen of the same size focusing on reinforcement connections showed that partially fabricated reinforced concrete shear walls exhibit excellent seismic performance, effectively fulfilling the same role as cast-in-place members in building structures, and their utilization improves the quality of fabricated building construction [7]. The performance of full-size glass fiber-reinforced polymer concrete shells under concentric compression showed that the longitudinal fibers increased the load carrying capacity of the columns, and the glass fiber-reinforced polymer shells eliminated the need for closely spaced restrained steel, thereby improving the quality of fabricated buildings [8]. Manychova Monika et al. [9] replaced the idealized and simplified models of structural behavior with accurate physical and load models using potential impact echo methods to assess the nodal condition of existing prefabricated structures. Michael J. Louis [10] reviewed the basic principles and concepts for the design of waterproofing systems for prefabricated brick wall panels to enhance the quality of prefabricated components. A construction method that involves tying and forming the steel cage on the formwork of the box beam and lifting them as a whole on the prepared pedestal by using a gantry crane guarantees the accuracy of the tying of the steel cage and effectively controls the size of the slab and beam, thereby ensuring the quality of prefabricated components and assembled buildings [11]. The reconstruction of assembled point cloud geometric models constructed an assembled concrete member model in industrial foundation class format using an isometric segmentation slice mapping method and determined the geometric surface quality of the precast concrete members [12].

### 2.2. Advanced Technical Means to Improve the Quality of Fabricated Buildings

Norman Murray et al. [13] found that a 3D model of the building was imported and used to interactively design the building by creating the design and construction of prefabricated components in a virtual environment. This innovative approach later became known as Building Information Modeling (BIM) technology. Adding progress to 3D BIM can achieve simulation of the construction progress of prefabricated buildings, and this study resulted in an effective improvement in construction quality [14]. In terms of information storage for prefabricated components. BIM and Radio Frequency Identification (RFID) technologies can improve the efficiency of information collection and access in prefabricated construction and further promote the quality of prefabricated buildings [15]. In addition, BIM technology serves as a means to facilitate practical quality management and information sharing [16]. RFID stores construction-quality information through specific encoding. The construction quality information is transmitted and analyzed through BIM technology to achieve comprehensive management of the quality information of manufactured buildings. Cai Zhili et al. [17] introduced countermeasures to address common problems in the construction of prefabricated buildings. They proposed the concept of 5D information technology, which includes the integration of BIM design and construction. The integration of architectural design and construction has been shown to better control project design, construction, information communication, and product quality. This integrated approach also accelerates the construction schedule and ensures construction quality. The quality of construction can be improved by collecting construction data using photogrammetry and laser scanning, comparing the actual data with the design data, and taking corrective action accordingly [18]. In addition, a case study of a prefabricated hotel project in Hong Kong showed that the Ingvar Kamprad Elmtaryd Agunnaryd (IKEA) model based on Virtual Prototyping (VP) can improve the efficiency and safety of prefabricated building construction and reduce costs and construction time [19].

### 2.3. Factors Influencing the Quality of Fabricated Buildings

The feasibility of utilizing prefabricated methods for a certain project must be ascertained prior to exploring the quality factors of assembled buildings. Alistair G. F. Gibb [20] suggested several factors that influence the adoption of prefabricated methods, including cost, time, quality, past experience, design, weather, performance testing, logistics, and safety. Several factors affect the quality of assembled buildings, including the lack of advanced tooling and technology in the production phase, the insufficient involvement of contractors and manufacturing companies in the design phase, the failure to use advanced mechanical equipment during the construction phase, and the absence of effective communication channels among various actors [21]. Some scholars have also subdivided the factors that influence the quality of fabricated buildings in the construction phase into three stages: pre-construction, mid-construction, and post-construction [22]. Other scholars have argued that several influencing factors, such as an immature quality management system, a lack of technical personnel, an inadequate quality inspection mechanism, the need for improvements in the industry environment, an inadequate pre-feasibility study and planning, and an imperfect supply chain in the construction industrialization market, affect construction industrialization project quality [23,24]. It is also argued that strengthening personnel training, enhancing project participation by all parties, and using BIM technology can improve the quality of fabricated buildings [25,26]. Li Dezhi et al. [27] obtained a hierarchical diagram of the factors by using the Interpretative Structural Model (ISM). They concluded that safety, quality, cost, schedule, corporate image, and environmental benefits are direct factors. Meanwhile, the supply capability of the component plant, type of structure, contractor's capability, and transportation of parts are indirect factors, and project size is the basic factor. Chang YF et al. [28] conducted a comprehensive study on quality management, specifically focusing on "project quality planning", "project quality supervision", and "project quality control". They also established 15 criteria to determine the construction quality of assembled buildings. "Project quality planning" has the greatest effect on the quality of assembled buildings. Using the ISM methodology, it was found that the direct factors affecting the quality of fabricated buildings were the substandard production quality inspection of prefabricated buildings and the high rate of component rework. Moreover, the core factors were the lack of drawing review and the absence of measures for stacking and transporting components, and the basic factors were the substandard skills of personnel, the lack of a clear basis for design, and the lack of standardization in the production of components [29]. Taking the assembly building construction phase as a benchmark, the key factors affecting its quality included personnel, machinery, materials, and workmanship [30,31]. In addition, there were measures to improve the quality by reasonably using auxiliary tools [32]. Qing Wei, Xiaojuan Li et al., and Chuanyong Li et al. [2,33,34] proposed that the factors influencing the quality of fabricated construction are process, materials, machinery, equipment, acceptance of the work situation, quality protection of components, prefabricated building construction plan and personnel, and the need to improve the construction, control the quality of materials, and strengthen management efforts to enhance the quality of fabricated construction. The above influencing factors are summarized in Appendix A, Table A1.

In summary, the majority of scholars have examined the factors influencing the quality of fabricated buildings using the qualitative approach, while only a few researchers have adopted the quantitative approach. Therefore, this work will utilize the structural equation modeling (SEM) quantitative analysis method to investigate the factors affecting the quality of fabricated buildings.

## 3. Materials and Methods

### 3.1. Study Process

The first step of this study involved an extensive review of literature pertaining to prefabricated construction and quality, with the subsequent identification of factors influencing the quality of prefabricated construction. An index system for these influencing factors was formulated. Following this, SPSS was utilized for analyzing the reliability and validity of the survey data. Subsequently, hypotheses were formulated, and a structural equation model was established, with subsequent model fitting and refinement to investigate the factors affecting prefabricated construction quality and their interrelationships. The obtained results were subsequently discussed, and strategies for enhancing prefabricated construction quality were proposed. The detailed process is illustrated in Figure 1.

### 3.2. Introduction to the List of Influencing Factors

#### 3.2.1. Principles of Constructing a List of Influencing Factors

The rationality of the factors that influence quality is the basis for investigating the construction quality of fabricated buildings. Therefore, a scientific and reasonable list of influencing factors must adhere to the principles outlined in Table 1.

**Table 1.** Principles of the influencing factor list.

| Principles | Contents |
|---|---|
| Systematic | The construction materials of fabricated buildings are prefabricated and transported to the site for lifting and connection. The factors that influence the quality of later construction must be systematically considered for the links before lifting the components. |
| Objective | The purpose of identifying quality impact factors for fabricated building construction is to allow contractors to quickly screen for matching quality impact factors while being objective. |
| Independence | The identified impact factor indicators should be independent of each other as far as possible to avoid similarity, overlap, and crossover in their meaning. |
| Targeted | This study focused on the quality of the construction of fabricated buildings. Hence, this study differs from the main structural implementation phase of traditional building construction and must have some relevance. |
| Qualitative quantitative combination | Some quality aspects can be measured using specific quality acceptance values, while others must be judged in the context of actual conditions and the practical experience of fabrication engineering professionals. Hence, a combination of qualitative and quantitative analysis is required. |

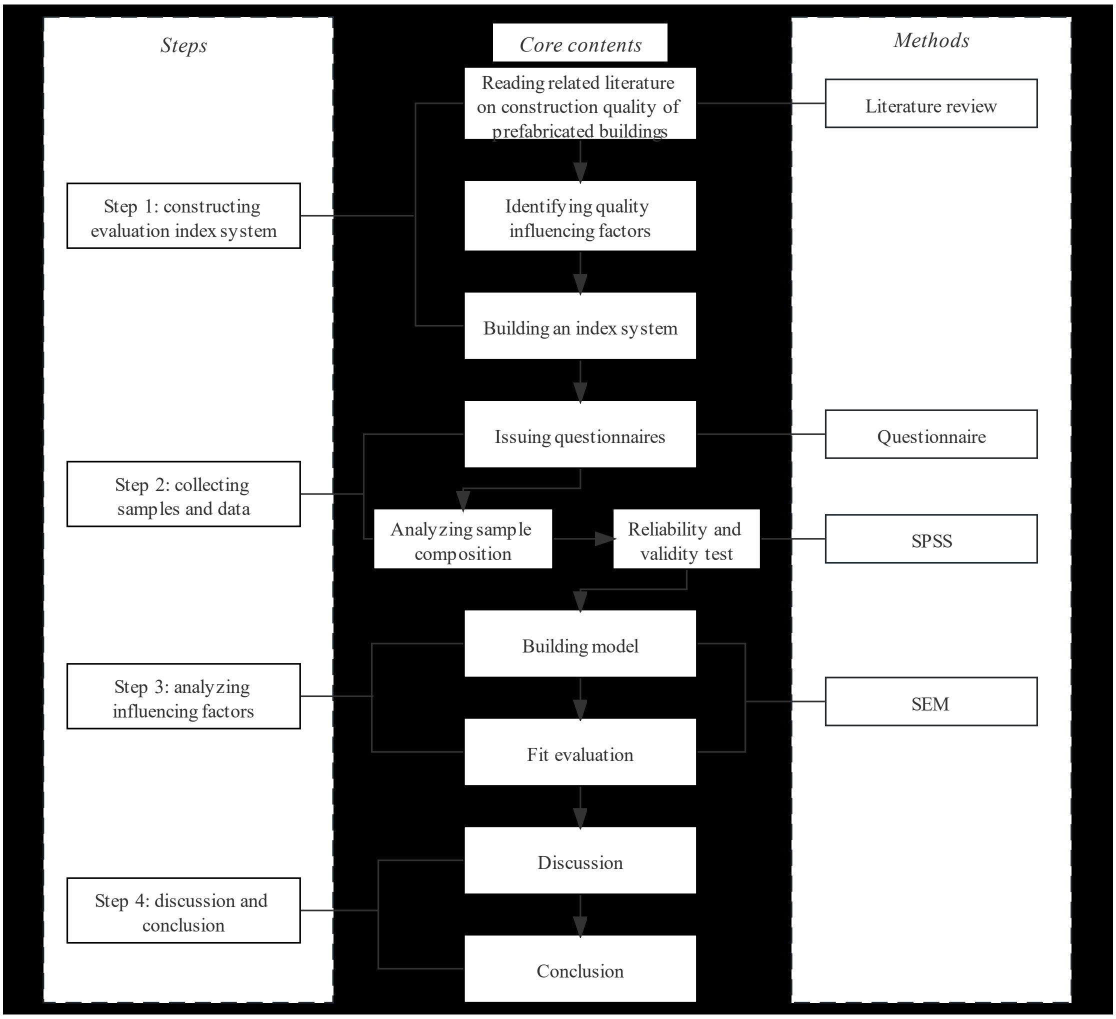


**Figure 1.** Study process.

#### 3.2.2. Steps in Constructing a List of Influencing Factors

A perfect and strong logical process is essential during impact factor identification. Figure 2 depicts the procedure for quality impact factor identification for fabrication and building construction. First, after defining the identification scope and focus, relevant literature on assembly building construction quality was collected, and subsequent screening followed. Thereafter, quality impact factors were collected and listed. Finally, expert interviews were conducted to revise, update, and refine the list of these factors.

A total of 256 articles were searched with the keywords "prefabrication" and "fabricated building quality" using domestic and international databases, such as CNKI, China Science Citation, SCI, ESI, Elsevier SDOL, SpringLink, EI Compendex Web, JCR, and the American Society of Civil Engineers, in the collection of factors that influence the construction quality of prefabricated buildings. Approximately 157 articles were not related to the construction quality of prefabricated buildings, while 48 articles investigated the application of BIM technology. A total of 205 invalid papers were eliminated, and 51 valid papers were obtained. After a comprehensive reading and analysis of these 51 papers, 25 high-quality and representative literatures were selected, and 40 quality influencing factors involved in the construction phase of assembled buildings were extracted.

The initial list of 40 quality influencing factors was further updated and revised to ensure completeness, scientificity, and systematization. The expert interview method was selected as a further supplementary revision, which can effectively compensate for the shortcomings of the literature research method in terms of authority, timeliness, and scientificity. Fifteen experts in the field of quality management of fabricated buildings were selected through questionnaires and interviews to complete the research. Hence, 15 factors that influence the construction quality of fabricated buildings were determined through the experts' recognition rate of the influencing factors and the elimination, merging, and integration of the factors (Table 2).

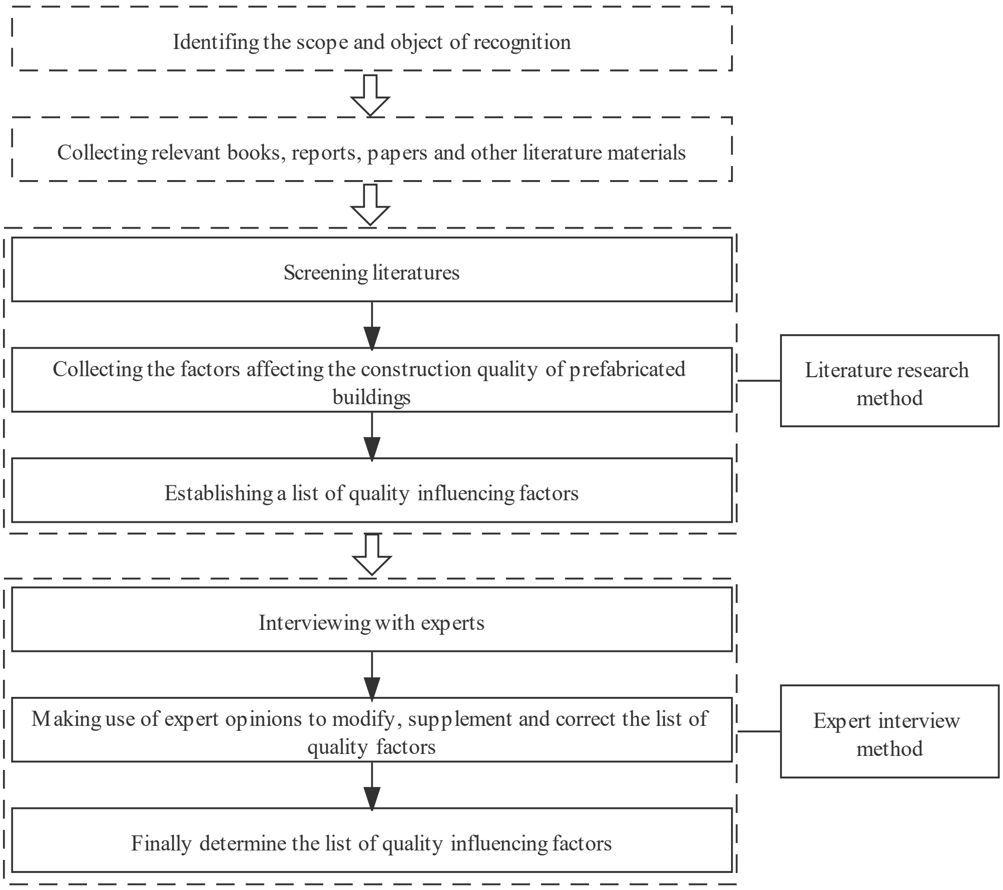


**Figure 2.** Steps for the creation of the influencing factor list.

**Table 2.** List of factors influencing quality.

| Influencing Factors of the Construction Quality | References |
|---|---|
| Q1 Construction site quality management institution | [5,23,35–40] |
| Q2 Technical delivery and training | [29,35,38,41–44] |
| Q3 Reasonable construction organization scheme | [24,35,45–50] |
| Q4 Main structure construction technology | [36,37,39,41,42,44,50,51] |
| Q5 Construction personnel's technical level of quality awareness | [22,29,36,40,42,43,47,49,52] |
| Q6 Construction machinery and equipment quality level | [5,22,44–46,49,52] |
| Q7 Construction measure | [5,35–37,40,47,51] |
| Q8 Supervise communication and coordination | [22,29,38,42–44,46,50] |
| Q9 Component incoming acceptance | [5,24,35,46,47,49,51] |
| Q10 Component stacking protection and environment | [36,39,44–46,48,51] |
| Q11 Component transportation measures | [24,29,37,39,43,44,50,52] |
| Q12 Pre-construction inspection of the components | [5,29,36,37,41,49,52] |
| Q13 Appearance quality and dimensional deviation | [23,35,42,47,50,52,53] |
| Q14 Surface flatness of connection parts | [24,29,43–45,47,51–53] |
| Q15 Structural quality acceptance | [5,23,39,41,42,46,48,51] |

The reasonable construction organization scheme, the construction site quality management institution, and technical delivery and training are categorized under the construction organization and management aspects of construction quality [5]. Meanwhile, construction machinery and equipment quality level, construction personnel's technical level of quality awareness, main structure construction technology, construction measures, and supervision, communication, and coordination belong to the construction process on the construction quality [48]. Moreover, component transportation measures, component incoming acceptance, component stacking protection and environment, and pre-construction inspection of components all contribute to the influence of prefabricated components on construction quality [47]. According to the Technical Standard for Fabricated Concrete Buildings, the Code of Construction Quality Acceptance for Concrete Structural Engineering, and the Evaluation Standard for Industrialized Buildings, appearance quality and dimensional deviation, surface flatness of the connection parts, and structural quality acceptance are the keys to evaluating the construction quality inspection of fabricated buildings [54]. Figure 3 demonstrates the structure of the quality influence factor system.

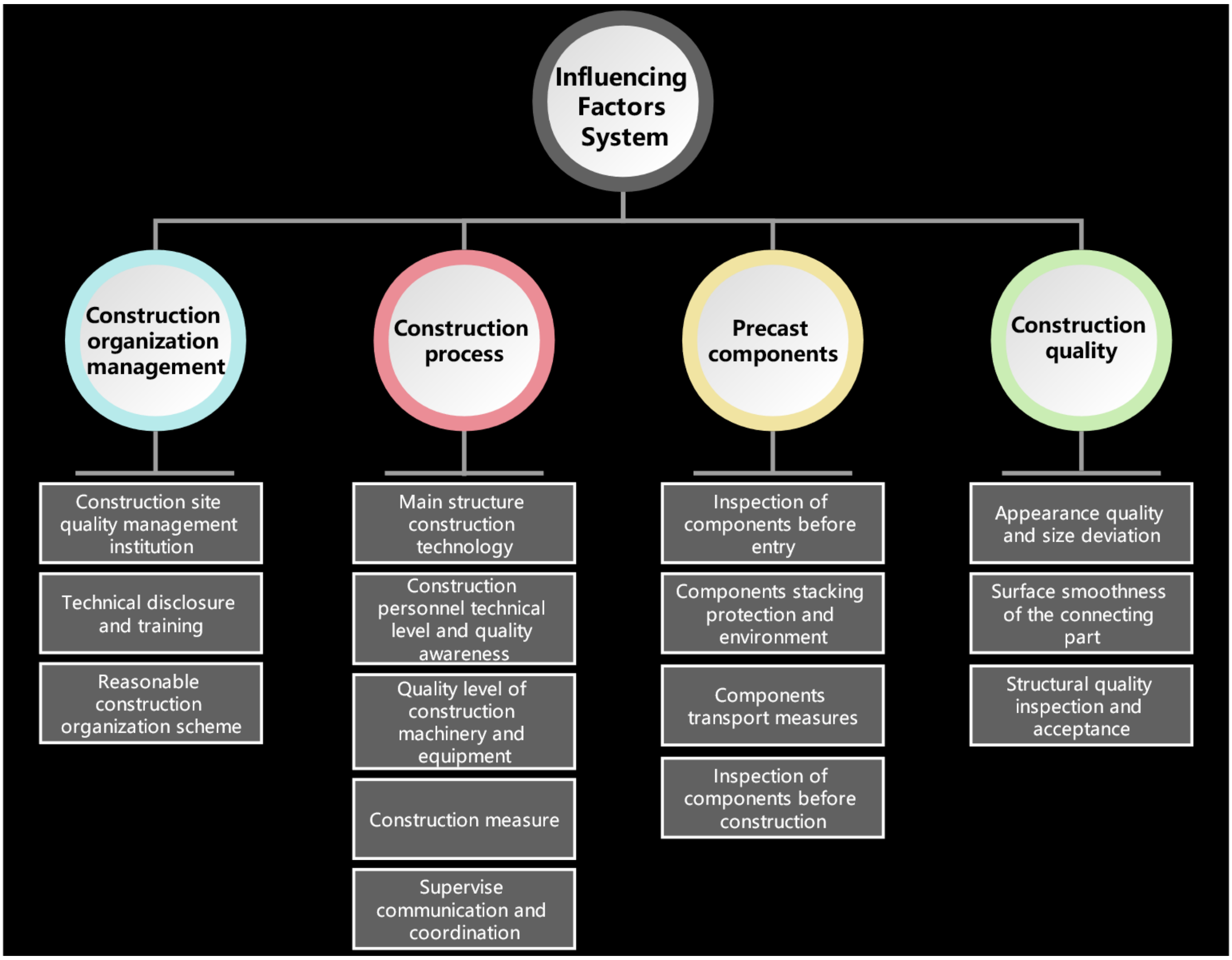


**Figure 3.** Influencing factor system.

### *3.3. Samples and Data Collection*

The data for this work were derived from a questionnaire survey. Considering the complexity of the study objects, the questions were crafted to be concise and easily comprehensible to maintain professionalism in the questionnaire. The questionnaire consisted of 15 questions and was measured using a ten-point Likert scale. A score of 10 represents a very high influence, and a score of 1 indicates no influence. To ensure the objectivity of the research data, the questionnaires were sent to all the participants who had participated in the development of the fabricated buildings and the professionals who conducted the research on the construction quality of the fabricated buildings [55]. A total of 650 questionnaires were distributed, and 530 were collected, with a recovery rate of 81.53%, of which 401 were valid questionnaires with a valid recovery rate of 75.66%. The data are illustrated in Table 3.

**Table 3.** Questionnaire sample data statistics.

| Basic Information | Type | Quantity | Proportion |
|---|---|---|---|
| Work unit type | Government-related units | 15 | 2.83% |
| | Colleges and universities | 49 | 9.24% |
| | Real estate development enterprises | 103 | 19.43% |
| | Component supplier enterprises | 24 | 4.52% |
| | Building construction enterprises | 196 | 37% |
| | Supervisory units | 132 | 24.90% |
| | Other (graduate students) | 11 | 2.08% |
| Years of work/research in a prefabricated building | Less than 1 | 96 | 18.11% |
| | 1–3 | 297 | 56.04% |
| | 4–5 | 128 | 24.15% |
| | Over 5 | 9 | 1.70% |
| Degree of understanding the construction quality of a prefabricated building | Very well known | 102 | 19.25% |
| | Fairly well known | 135 | 25.47% |
| | Generally know | 164 | 30.94% |
| | Very little | 73 | 13.77% |
| | Do not know | 56 | 10.57% |

### *3.4. Introduction of the Reliability and Validity Tests*

Reliability, in an academic context, refers to the dependability and consistency of research outcomes. The Cronbach's $\alpha$ coefficient and CITC value are commonly used indexes for reliability analysis [56]. The reliability of the questionnaire is tested using SPSS 22.0 software. The Cronbach's $\alpha$ coefficient is greater than 0.8, indicating that the data are stable. The CITC value must be greater than 0.2; otherwise, the factor is not strongly correlated with the system. Validity refers to the degree to which a measurement tool accurately measures the object being measured. Moreover, validity refers to how well a measurement reflects the aspect being examined. The more consistent the measurement results are with the measurement content, the higher the validity; otherwise, the validity is low. The Bartlett sphere test is used to determine whether the data are suitable for factor analysis. SPSS 22.0 software is used for KMO and Cronbach's tests.

### *3.5. Introduction of SEM*

SEM is a multivariate statistical method that includes path and factor analyses. This method can analyze the relationship between measurement variables, latent variables, and errors. Moreover, this method can be used to determine the effect on dependent variables from the analysis of independent variables. This method is helpful to analyze the relationship between the factors affecting the construction quality of prefabricated buildings. It can also analyze the effect of this latent variable on its corresponding explicit variable in the construction process, construction organization management, and precast component. SEM uses AMOS (analysis of moment structures) software to draw and browse the model through the visualization module. This method can also fit the data collected through the questionnaire with various indexes of the model and output the best model. The model is considered scientifically valid when the fit indexes meet the established standards. The indexes include relative-fit and absolute-fit indexes. The main indexes and standards are shown in Table 4.

**Table 4.** Main indexes and standards.

| | Fit Index | | Standard | |
|---|---|---|---|---|
| Relative-fit index | Root mean square error of approximation | RMSEA | <0.0.8 | Qualified |
| | Goodness of fit | GFI | >0.9 | Qualified |
| Absolute-fit index | Chi-square degree of freedom ratio | $X^2/df$ | ≤3.00 | Qualified |
| | Comparative fit index | CFI | >0.9 | Qualified |
| | Normed fit index | NFI | >0.9 | Qualified |
| | Incremental fit index | IFI | >0.9 | Qualified |
| | Tucker–Lewis index | TLI | >0.9 | Qualified |
| | Adjusted goodness of fit index | AGFI | >0.9 | Qualified |

SEM can be divided into exploratory factor analysis and confirmatory factor analysis (CFA). CFA is a method for measuring whether the relationship between the measured factors and the measured items is consistent with the researcher's predictions. SEM consists of a measurement model (Equations (1) and (2)) and a structural model (Equation (3)).

$$X = \Lambda_x \xi + \delta \quad (1)$$

$$Y = \Lambda_y \eta + \varepsilon \quad (2)$$

Equation (1) defines the relationship between the explicit observation variable $X$ and the implicit observation variable $\xi$. Equation (2) defines the relationship between the explicit latent variable $Y$ and the implicit latent variable $\eta$. $\delta$ is the residual of the dominant observed variable, $X$. $\eta$ is the residual of the dominant latent variable, $Y$. $\Lambda_x$ is the regression coefficient of $\xi$. $\Lambda_y$ is the regression coefficient of $\eta$.

$$\eta = \beta\eta + \Gamma\xi + \zeta \quad (3)$$

Equation (3) represents the relationship between the implicit observation variable $\xi$ and the implicit latent variable $\eta$. $\beta$ is the coefficient matrix between the hidden and the latent variables. $\Gamma$ is the coefficient matrix composed of hidden observed variables and hidden latent variables. $\zeta$ is the residual of the equation.

## 4. Result

### *4.1. Reliability and Validity Tests*

The data from 401 questionnaires involving 15 factors were preliminarily analyzed. The coefficient values of the four potential variables of construction organization and management, construction process, precast components, and construction quality inspection exceeded 0.8. Moreover, the overall coefficient of the statistical data was 0.961, indicating that the statistical data from each indicator dimension. The overall dimension of this research had good reliability and internal correlation and passed validation (Table 5). In addition, Cronbach's $\alpha$ coefficient of each explicit variable is greater than 0.8, indicating that each latent variable also has good internal reliability and can be analyzed in the next step.

**Table 5.** Reliability analysis.

| Latent Variable | Index | CITC | Cronbach's α Coefficient | |
|---|---|---|---|---|
| F1: Construction organization management | Q1 | 0.818 | 0.957 | 0.882 |
| | Q2 | 0.806 | 0.957 | |
| | Q3 | 0.629 | 0.961 | |
| F2: Construction process | Q4 | 0.82 | 0.957 | 0.962 |
| | Q5 | 0.835 | 0.957 | |
| | Q6 | 0.824 | 0.957 | |
| | Q7 | 0.831 | 0.957 | |
| | Q8 | 0.787 | 0.958 | |

**Table 5.** *Cont.*

| Latent Variable | Index | CITC | Cronbach's α Coefficient | |
|---|---|---|---|---|
| F3: Precast component | Q9 | 0.769 | 0.958 | 0.878 |
| | Q10 | 0.638 | 0.96 | |
| | Q11 | 0.681 | 0.96 | |
| | Q12 | 0.587 | 0.961 | |
| F4: Construction quality inspection | Q13 | 0.89 | 0.956 | 0.947 |
| | Q14 | 0.87 | 0.956 | |
| | Q15 | 0.828 | 0.957 | |
| Total | | | | 0.961 |

Table 6 illustrates that the *p* value (Sig.) is 0, and the KMO value is 0.95, which is greater than 0.6, indicating a high correlation between the indexes established in the questionnaire. Therefore, validity is guaranteed.

**Table 6.** Validity analysis.

| | | |
|---|---|---|
| Kaiser–Meyer–Olkin value | 0.95 | |
| Bartlett sphere test | Approximate chi-square | 6598.803 |
| | df | 105 |
| | *p* value (Sig.) | 0 |

### *4.2. Model Building and Identification*

#### 4.2.1. Model Correction

The pre-model was conducted for four latent variables and 15 observed variables. The pre-model is shown in Figure 4a. The model has six sets of relationship assumptions.

**H1.** *F1 has a positive effect on F2.*

**H2.** *F1 has a positive effect on F3.*

**H3.** *F1 has a positive effect on F4.*

**H4.** *F2 has a positive effect on F3.*

**H5.** *F2 has a positive effect on F4.*

**H6.** *F3 has a positive effect on F4.*

The index fitting results are shown in Table 7. This study focuses on enhancing a structural equation model (SEM) through two distinct strategies. The first involves modifying the relationships between internal and external variables. The second centers on adjusting residual covariances. After applying these methods to refine the initial model, all pathway *p*-values were found to be statistically significant, with values below 0.05, supporting the proposed hypotheses. Consequently, the first method of altering pathway relationships, as outlined in this study, was not necessary.

As an alternative, the Modification Index (MI) method was employed for further refining the model to achieve a better fit. This technique leverages MI values to guide theoretically grounded adjustments. Larger MI values typically indicate a need for more significant model restructuring. When MI values are identified between variables, it suggests a linear relationship between them. Conversely, if MI values are observed between variables and residuals, it implies a lack of independence between those variables.

Analysis results from AMOS indicated the most significant residual difference between e11 and e12. Therefore, to improve the model, a correlated relationship was introduced between these two variables. The revised after-model is shown in Figure 4b.

**Table 7.** Model fitting results.

| Fit Index | Pre-Correction | Pre-Result | After-Correction | After-Result |
|---|---|---|---|---|
| RMSEA | 0.075 | Match | 0.064 | Match |
| GFI | 0.913 | Match | 0.931 | Match |
| $X^2/df$ | 3.238 | Mismatch | 2.662 | Match |
| CFI | 0.971 | Match | 0.979 | Match |
| NFI | 0.959 | Match | 0.967 | Match |
| IFI | 0.972 | Match | 0.979 | Match |
| TLI | 0.964 | Match | 0.974 | Match |
| AGFI | 0.876 | Mismatch | 0.91 | Match |

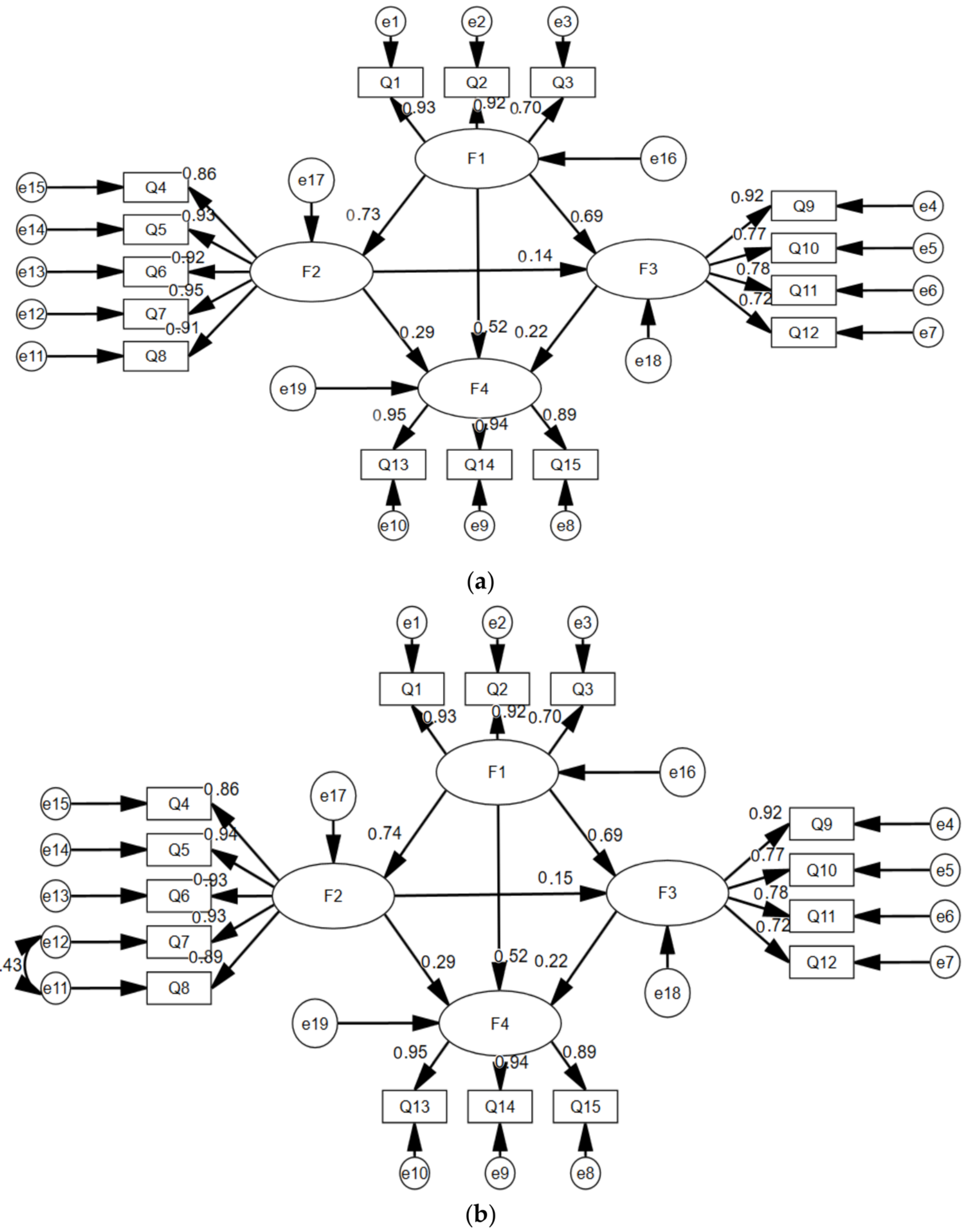


**Figure 4.** (**a**) Pre-model. (**b**) After-model.

### 4.2.2. Confirmatory Factor Analysis (CFA)

According to the six sets of hypothesized relationships between the potential variables in Table 8. The *p*-values of F1 on F2, F3, and F4 are all less than 0.001, indicating that F1 has a significant positive correlation effect on F2, F3, and F4. Meanwhile, the *p*-values of F2 and F3 on F4 are less than 0.001, indicating that they have a significant positive correlation effect on F4. Although the *p*-value of F2 on F3 is 0.01, it is still less than 0.05, indicating that F2 has a significant positive correlation effect on F3. This outcome indicates that the six sets of hypotheses are valid. The standardized path coefficients of the 15 observed variables are all greater than 0.6, indicating a significant correlation between the latent and the observed variables.

**Table 8.** Results of the modified parameter estimation analysis.

| Variable | | Variable | Unstandardized Path Coefficient | Standard Error | CR Value | *p* Value | Standardized Path Coefficient |
|---|---|---|---|---|---|---|---|
| Factor 2 | ← | Factor 1 | 0.936 | 0.056 | 16.754 | *** | 0.738 |
| Factor 3 | ← | Factor 1 | 0.718 | 0.063 | 11.337 | *** | 0.686 |
| Factor 3 | ← | Factor 2 | 0.122 | 0.047 | 2.577 | 0.01 | 0.148 |
| Factor 4 | ← | Factor 3 | 0.217 | 0.045 | 4.824 | *** | 0.217 |
| Factor 4 | ← | Factor 1 | 0.54 | 0.055 | 9.825 | *** | 0.517 |
| Factor 4 | ← | Factor 2 | 0.24 | 0.031 | 7.746 | *** | 0.291 |
| Q1 | ← | Factor 1 | 1 | | | | 0.928 |
| Q2 | ← | Factor 1 | 1.064 | 0.034 | 31.592 | *** | 0.924 |
| Q3 | ← | Factor 1 | 0.822 | 0.047 | 17.537 | *** | 0.7 |
| Q9 | ← | Factor 3 | 1 | | | | 0.92 |
| Q10 | ← | Factor 3 | 0.829 | 0.042 | 19.612 | *** | 0.768 |
| Q11 | ← | Factor 3 | 0.908 | 0.045 | 20.363 | *** | 0.784 |
| Q12 | ← | Factor 3 | 0.801 | 0.045 | 17.81 | *** | 0.725 |
| Q8 | ← | Factor 2 | 1 | | | | 0.888 |
| Q7 | ← | Factor 2 | 1.06 | 0.027 | 39.007 | *** | 0.929 |
| Q6 | ← | Factor 2 | 1.042 | 0.035 | 29.737 | *** | 0.931 |
| Q5 | ← | Factor 2 | 1.087 | 0.036 | 30.477 | *** | 0.94 |
| Q4 | ← | Factor 2 | 0.865 | 0.035 | 24.906 | *** | 0.864 |
| Q13 | ← | Factor 4 | 1 | | | | 0.887 |
| Q14 | ← | Factor 4 | 1.037 | 0.034 | 30.409 | *** | 0.938 |
| Q15 | ← | Factor 4 | 1.009 | 0.032 | 31.504 | *** | 0.951 |

*** $p < 0.001$.

Furthermore, CFA can calculate the convergent validity of the potential variables by calculating the AVE and CR values. In Table 9, the AVE values of the four latent variables are greater than 0.5, and the CR values are greater than 0.7. This result shows that the data of this questionnaire exhibit good convergent validity.

**Table 9.** Convergent validity.

| Latent Variable | AVE Value of the Mean Variance Extraction | CR Value of the Combined Reliability |
|---|---|---|
| Factor 1 | 0.735 | 0.891 |
| Factor 2 | 0.830 | 0.961 |
| Factor 3 | 0.644 | 0.878 |
| Factor 4 | 0.857 | 0.947 |

According to Table 10, the effect of F1 on F4 ranked first, with a total effect value of 0.904; the effect of F1 on F3 ranked second, with a total effect value of 0.795; the effect of F1 on F2 ranked third, with a total effect value of 0.738; the effect of F2 on F4 ranked fourth, with a total effect value of 0.323; the effect of F3 on F4 ranked fifth, with a total effect value of 0.217; the effect of F2 on F3 ranked sixth, with a total effect value of 0.148.

**Table 10.** Effect of the latent variables.

| Latent Variable | | Latent Variable | Standardized Direct Effects | Standardized Indirect Effects | Standardized Total Effects |
|---|---|---|---|---|---|
| Factor 2 | ← | Factor 1 | 0.738 | | 0.738 |
| Factor 3 | ← | Factor 1 | 0.686 | 0.109 | 0.795 |
| Factor 4 | ← | Factor 1 | 0.517 | 0.387 | 0.904 |
| Factor 3 | ← | Factor 2 | 0.148 | | 0.148 |
| Factor 4 | ← | Factor 2 | 0.291 | 0.032 | 0.323 |
| Factor 4 | ← | Factor 3 | 0.217 | | 0.217 |

## 5. Discussion

Construction organization management has the greatest influence on the construction quality of fabricated buildings, with a total effect value of 0.904. This management approach encompasses the entire construction process, serving as a comprehensive rehearsal prior to the project's execution. Moreover, this approach provides systematic guidance for construction projects, enabling optimal allocation of construction resources and playing a vital role in construction management [5]. Accordingly, this mechanism is an important basis and reliable guarantee for effective construction preparation. The construction site quality management institution, especially the system implementation, has the most important influence on the quality of the construction of fabricated buildings. Moreover, technical briefing and construction training have a significant effect on construction quality. The content of the briefing, such as architectural design models, drawings, and prefabricated components, varied due to the prefabricated nature of the assembly itself. When the staff do not undergo systematic learning and training related to the construction process and quality awareness, subsequent construction is prone to operational errors and a lack of awareness, resulting in construction quality problems. In addition, a reasonable construction plan is conducive to improving construction efficiency and ensuring construction quality. For example, if the storage of prefabricated components in the fabricated building is not adequately arranged and planned, it can result in components experiencing wear and tear or colliding with each other, which will give rise to construction quality problems.

The total effect of construction organization management on prefabricated components is 0.795. The construction site quality management system includes the inspection of prefabricated components in construction organization management. Given that the prefabricated components in the production and processing may cause deviations in size due to poor process management, cracks on the surface of the components caused by improper storage in the transportation of the components, missing edges, and corners, a thorough inspection of the components is essential when the prefabricated components are in the field [29]. Thus, whether the quality management system is effectively implemented affects the incoming quality of prefabricated components, which in turn influences the final construction quality acceptance.

The total effect of construction organization and management on the construction process reached 0.738. The effective implementation of a complete quality system in construction organization and management affects the quality level of construction machinery and equipment. In the process of controlling the construction machinery and construction materials involved in the assembly building project, if no personnel are organized to carry out targeted maintenance management of machinery and equipment, the stability and continuity of the operation of machinery and equipment may be reduced [57]. This condition not only results in additional costs but also induces construction quality problems. In addition, the pre-construction training on construction technology and quality awareness of construction personnel also play a significant role in ensuring that the construction process is carried out in accordance with the relevant technology. If the construction workers do not receive professional training before construction, then they cannot operate various machinery and equipment according to the relevant operation process and lift the components according to the assembly process, which will give rise to a series of problems, such as irregular lifting of components and misalignment of installation, and affect the construction quality.

## 6. Conclusions

### 6.1. Measures

Based on the aforementioned analysis, the construction quality of prefabricated buildings is primarily influenced by on-site construction management. Accordingly, elevating the pertinent quality management system requires implementation at the uppermost system level.

1. Deploying relevant standards and norms is essential to establishing an effective quality management system and ensuring adequate attention to structural quality by site managers and construction personnel.
2. Instituting an inspection and acceptance system, particularly for contractors, is vital. This involves establishing a quality acceptance system upon prefabricated components' arrival at the construction site, followed by process and physical quality acceptance systems.
3. Introducing pre-job technical training and delivery systems is crucial.
4. Executing effective technical control encompasses appropriate lifting timing, machinery, equipment, and precise installation.
5. Optimizing digital construction capabilities involves using BIM technology for assembly building models, enabling visualization and realistic quality simulation through modeling to identify latent quality issues on-site.
6. Instituting an information collection system and deploying automated testing tools for construction site data collection, encompassing encountered quality issues, material dimensions, component quality, connections, etc. These data are integrated into a management platform to facilitate systematic analysis by technical personnel based on uploaded data and issues.

### 6.2. Further Action

The quality of prefabricated construction is influenced by various factors with complex relationships. Due to limitations in historical data and survey biases, current research can be improved. Strategies for improving quality have been suggested for key factors, but more strategies for other factors are needed for a comprehensive study.

To address this, future research should involve the following:

1. Explore the intrinsic connections among quality factors, refining the theoretical model.
2. Develop a comprehensive strategy framework for enhancing quality in prefab construction.

In summary, despite challenges, investigating factor relationships and proposing strategies can guide the advancement of prefab construction quality.

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## Appendix A

**Table A1.** Factors influencing the quality of fabricated buildings.

| Factors Influencing the Quality of Fabricated Buildings | |
|---|---|
| The lack of advanced tooling | Technology in the production phase |
| Insufficient involvement of all parts | Failure to use advanced mechanical equipment |
| Absence of effective communication channels | Immature quality management system |
| Lack of technical personnel | Inadequate quality inspection mechanism |
| The need for improvements in the industry environment | Inadequate pre-feasibility study and planning |
| Imperfect supply chain | Personnel training |
| Project participation by all parties | BIM technology |
| The supply capability of the component plant | Type of structure, contractor's capability |
| Transportation of parts | Project quality planning |
| Project quality supervision | The absence of measures for transporting components |
| Project quality control | The substandard production quality inspection |
| The high rate of component rework | Drawing review |
| The absence of measures for stacking | The substandard skills of personnel |
| the lack of a clear basis for design | The lack of standardization in the production of components |

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