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Improve Integrated Material Handling (IMH) Efficiency of Local High-Rise Building Projects by IMH Framework Optimization and Empirical Analysis

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Abstract

Fast urbanization and economic development lead to a prosperous high-rise building industry with high material handling efficiency (MHE). However, the integrated material handling (IMH) framework optimization and empirical studies on Chinese high-rise buildings are not in-depth. Here, the IMH practice in Chinese Chongqing high-rise building projects (CHBPs) was researched, and the effect factors of MHE were discussed to propose improvement strategies. A questionnaire survey (191 participants), qualitative topic analysis, quantitative descriptive statistics, reliability/correlation analysis, an independent sample t-test, analysis of variance (ANOVA), and regression analysis were performed. As a result, the understanding of the IMH concept, effectiveness of training projects, and positive effect of regulations were found to favor an improved MHE. Moreover, a weak positive correlation between work experience and MHE was found. Through the proposed model development framework, the combination of theoretical analysis and empirical research can provide comprehensive tools and knowledge resources for IMH practices in CHBP to improve MHE. Through quantitative indicators such as the material handling efficiency index (MHEI), the training project impact score (TPIS) and the regulation perception index (RPI), this framework offers an objective basis for continuous monitoring and improvement.

Keywords: integrated material handling; efficiency; building project; research framework; empirical analysis

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Academic Editor: Antonio Caggiano

Received: 19 May 2025
Revised: 21 June 2025
Accepted: 26 June 2025
Published: 29 June 2025

Citation: Xiong, P.; Mohamed, G.F.E.; Lee, Y.S. Improve Integrated Material Handling (IMH) Efficiency of Local High-Rise Building Projects by IMH Framework Optimization and Empirical Analysis. *Buildings* **2025**, *15*, 2286. https://doi.org/10.3390/buildings15132286

1. Introduction

Quick urbanization and economic development have boosted the development of the high-rise building industry in Chongqing, in China [1]. The unique geographical location and climatic conditions in Chongqing can result in a significantly improved complexity in the architectural design and construction, leading to hard material handling (MH), high cost, slow progress, and high security risk [2,3]. The material handling efficiency (MHE) can directly affect the schedule, cost and quality of a building project [4]. An effective MH strategy can greatly reduce the work hours, lower the safety risk, and improve the overall efficiency of the construction site [5]. At present, in the high-rise office building construction in Chongqing, the MH has become one of the key factors which can affect the schedule and quality of the project. Due to large dosages and multiple kinds of building materials, combined with a small construction space, the effective organization and management cannot be easily achieved [6,7]. The traditional MH style has failed to meet the needs of modern construction projects, especially in the construction of high-rise buildings, in which the MH has faced the double challenges of space limitation and efficiency. Therefore, integrated material handling (IMH), with the merits of systematization and integration, should be adopted to improve the construction efficiency, decrease the cost and ensure construction safety.

To handle the aforesaid double challenges, many strategies and techniques have been raised for improving the MHE. In the reported work, the complexity of building material logistics was discussed [8,9], the effect of the low-efficiency MH on the environment and the economy was analyzed [10–13], and the models and methods for maximum improvement of the logistics efficiency, removing the wastes, and increasing the security in construction projects, were summarized [14–19]. Based on the building information modeling (BIM) technology, the MH path and construction program can be optimized, reducing the chaos and resource waste on the construction site [20]. The empirical research and effective evaluation were conducted using the sustainable construction methods, advanced equipment and robot construction technology, and sustainable construction was proposed [21]. Using modern technology and automation, the MH complexity and environmental damage can be lowered, enabling the high-efficiency project implementation [22–26].

For examples, the researchers [27] conducted extensive surveys and statistics towards the carbon release of Chinese residential buildings, confirming a remarkable effect of carbon release on environmental protection. The low-carbon buildings in China were also studied, showing that the green low-carbon materials should be used in buildings to reduce the carbon release. To boost the sustainable development, the government regulations should be emphasized, for enlarging the department of green and innovative building materials (GIBMs), and the IMH mode should be employed in material purchasing. The methods for reducing carbon release were proposed [11,28,29]. In addition, researchers [30] studied management and utilization of wastes, giving insights into the sustainable public building design. Various MH techniques and methods can be effectively integrated using the IMH framework. By optimizing the MH process and using automation technology, the MH capacity in the construction of high-rise buildings can be notably improved [31–33]. Lastly, researchers [16] reported the cases of high-rise building construction projects, where empirical analysis was adopted to verify the contribution of the IMH framework to a high MHE.

Nowadays, the theoretical studies on the green building materials and sustainable development have been widely reported. Researchers have raised resilience-oriented multi-stage and coordinated restoration frameworks for clarifying the related problems [34,35], which can boost the development of the IMH practices in high-rise construction projects combined with empirical methods. Researchers have proposed risk-averse and cooperative decision-making strategies for studying the integrated energy systems in buildings [36,37], addressing practical challenges and dealing with uncertainty. The effect of MH on the duration, cost and safety was also clarified. In the light of architectural design, as well as construction material treatment and selection, the MHE was well improved. Although the application of the IMH framework in the MH of high-rise buildings has achieved some good results, the empirical studies on the novel IMH frameworks (taking the high-rise buildings in Chinese Chongqing as the study objects) are fewer, and lack depth. In this work, the application of IMH practice in Chongqing high-rise building projects (CHBPs) was explored, and various factors that affect the implementation effect were expounded. First, the demographic characteristics of participants were analyzed (e.g., the role in the construction project, MH experience, and previous understanding of IMH), building a foundation for deeply understanding study results. Then, by a combination between qualitative and quantitative data, the complexity of IMH practice was fully assessed, including the cognitive attitude and understanding level of IMH's global and local practices (particularly in Chongqing). Ultimately, the key factors inducing success or failure of IMH practice were identified and evaluated, and the corresponding measures were raised. The goal was to optimize the MH process in CHBPs. As a result, a better IMH model framework was successfully developed to offer the strategy guidance and solutions for IMH practice in the CHBP, addressing the challenges from specific geographical, cultural and economic environments. The full understanding of IMH practice, in this work, will offer a set of integrated strategies and tools for the building industry, improving the efficiency and safety of MH, along with facilitating the sustainable development of the building industry.

While great progress has been made in MH for construction projects, there are knowledge gaps in prior studies in addressing the challenges of high-rise office building construction in rapidly urbanizing cities like Chongqing in China. Those reported works focused on MH in construction, but most pertained to low-rise and mid-rise building practices. High-rise projects need a more comprehensive approach, due to the increased complexity. Globally, the studies used technologies like BIM, drones and automation in MH. However, there is a lack of applicability to Chongqing's high-rise construction. Chinese research has often focused on the broad construction management, overlooking MH optimization. Moreover, the studies are insufficient in terms of integrating material flow, cost, logistics efficiency, and safety constraints into one framework. The lack of an IMH framework for high-rise office building construction in Chongqing can be deemed as a knowledge gap. Existing approaches cannot effectively meet the increasing demand for better construction solutions without the coordinated strategies. These gaps have inspired the objective of this work, which is to develop and validate a good IMH framework for enhancing material flow and reducing waste, as well as improving safety and logistics performance. Therefore, the present work can enrich the understanding of high-rise construction challenges and propel the use of related advanced technologies.

2. Data and Methods

2.1. Data Collection

Figure S1 gives a methodology flowchart of the evaluation of effective implementation of the IMH framework in CHBPs. Firstly, the questionnaire design is described in detail, as follows. The process of developing the questionnaire is shown in Figure 1. The selection and definition of variables were made based on the study purpose, theoretical basis and reported literature, followed by problem design, to form the original code to be repeatedly studied. According to the specific situation of current high-rise building construction, the above code was constantly revised to achieve the initial code. The experts and team reviewed the preliminary interview results to give the feedback, followed by a further optimization of questionnaire content to assure clear and unambiguous expression. Before issuing the formal scale, it was necessary to collect the data of related parties on a small scale. The reliability and validity of the questionnaire were tested to further revise the questionnaire, finishing the development of the questionnaire. The resultant interview questionnaire is exhibited in Table S1.

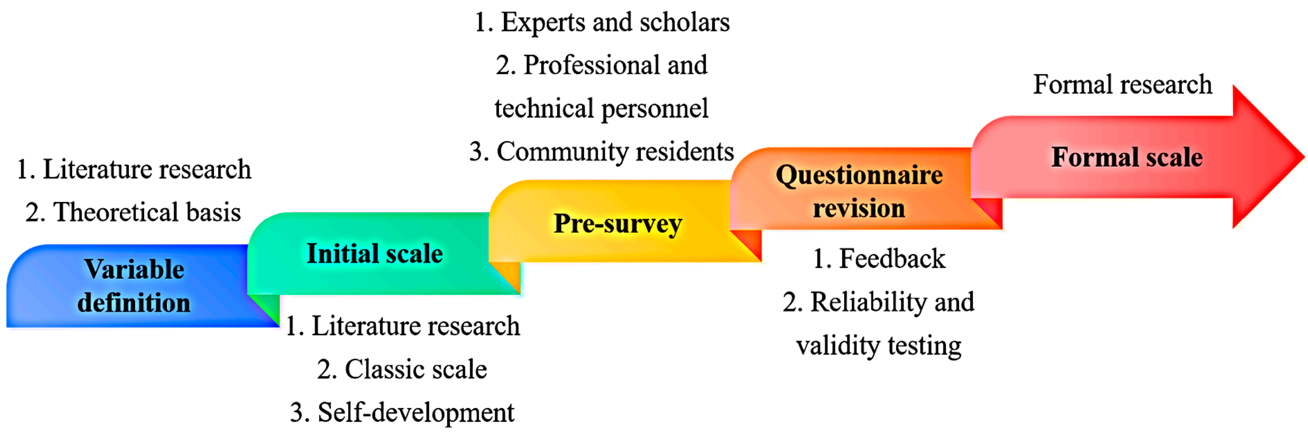

Figure 1. Process of questionnaire development.

Secondly, the data collection is described in detail, as follows. To effectively collect the data, a standardized questionnaire was developed in advance, where the questionnaire content was obtained via the issuing of the online questionnaire. Moreover, all the respondents were the personnel related to the Chinese building construction industry (CBCI), including developers, logistics personnel, suppliers, contractors, consultants, architects, engineers, site supervisors, and related researchers. They have various working experiences, practice years, and ages. After surveying 191 respondents, the data saturation was achieved.

2.2. Data Description

This section is given in the Supporting Information document.

2.3. Reliability Analysis

Through reliability analysis, the internal consistency of a set of items in a survey or questionnaire can be assessed. The Cronbach's alpha (α) is a commonly used measure. If the α value is higher than 0.7, the reliability can be acceptable. It was calculated using Equation (1):

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum_i V_i}{V_t}\right) \tag{1}$$

wherein n is the number of items, V_i is the average covariance between pairs of items, and V_t is the average variance of items. A larger α value can indicate that the same underlying structure is measured for survey items, increasing the data reliability [38].

Table S2 shows the Cronbach's reliability analysis. Here, the Cronbach' α was verified to be 0.971 (>0.7), and the number of items was 9. This α value can indicate a high level of variables' internal consistency or reliability for all variables. Thus, the questions/items used to measure the structures in this work should be highly reliable. Using the items, the same underlying construction can be consistently measured.

2.4. Correlation Analysis

This section is given in the Supporting Information document [39]. The variable pairs were abbreviated (see Table S3).

2.5. Independent Sample t-Test

This section is shown in the Supporting Information document.

2.6. Analysis of Variance (ANOVA)

The goal of ANOVA was to explore the cognitive differences of IMH practice of participants with various roles, years of experience, and understanding levels in the CHBP environment. By analyzing these differences, the key factors that have a significant impact on MHE and IMH practice can be obtained, offering the data support for developing more targeted and effective IMH implementation strategies. Figure 2 gives the ANOVA across different roles of construction workers (the abbreviations are given in Table S5). Figure 3 shows the ANOVA across different years of experience (YE) [40]. Figure 4 displays the ANOVA across different levels of understanding. In these figures, the definitions for key metrics of F and D.f are as follows. The F-value is a statistical measure of the F-test to be used to measure the ratio of between-group differences to within-group differences. The F-value can determine whether different levels of processing factors have a significant impact on the observed values. Moreover, D.f is degrees of freedom, which refers to the number of variables whose values are not restricted when calculating a unified metric. Usually, D.f is the numerical difference between the number of samples and the number of restricted conditions. The D.f is used to determine the relationship between the range of statistical values and the number of samples, which affects the degree of sample variation and the size of estimation error. The D.f can affect the degree of variation within each group and the comparison of inter-group dispersion.

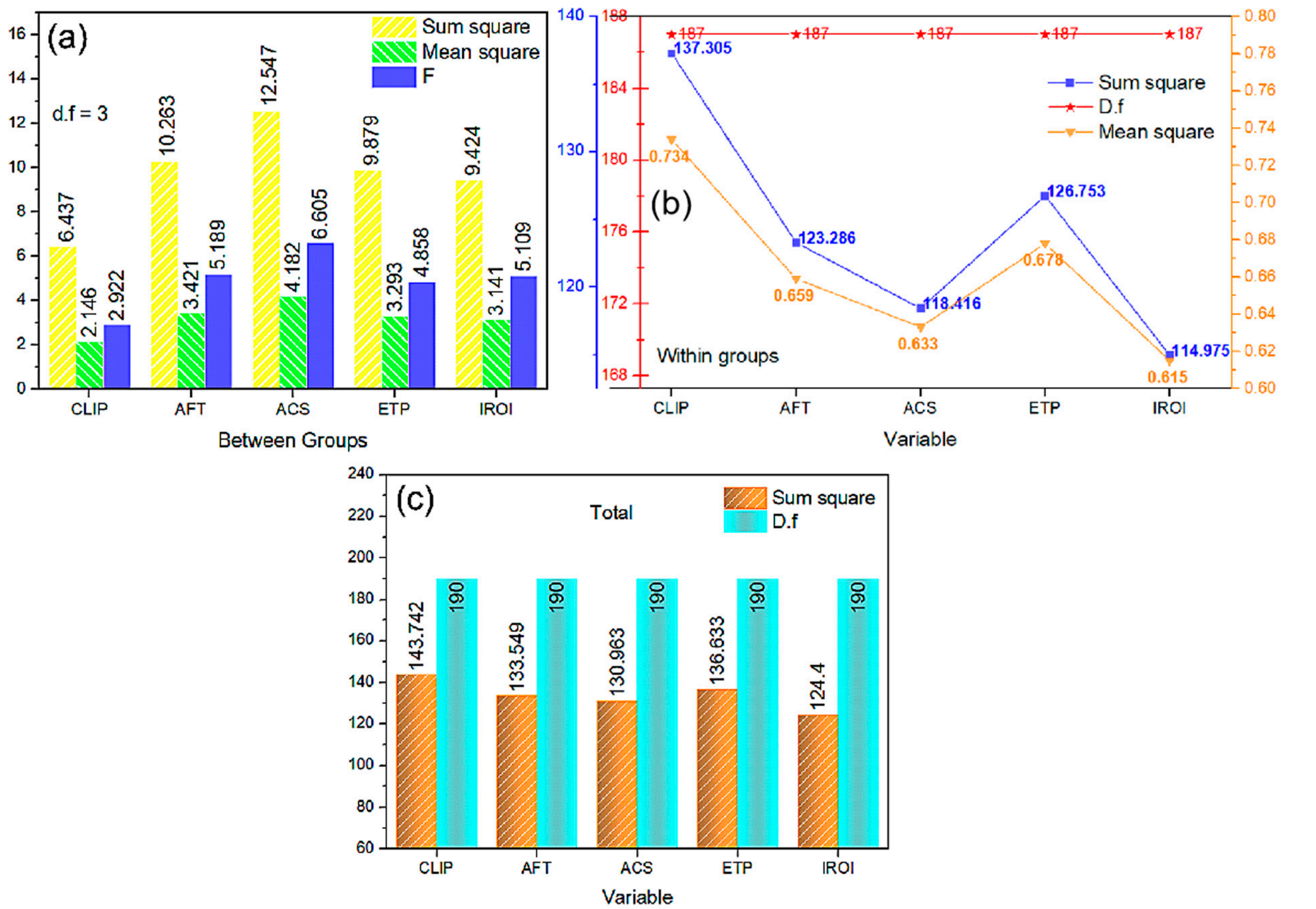

Figure 2. ANOVA across different roles of construction workers: (**a**) between groups, (**b**) within groups, and (**c**) total.

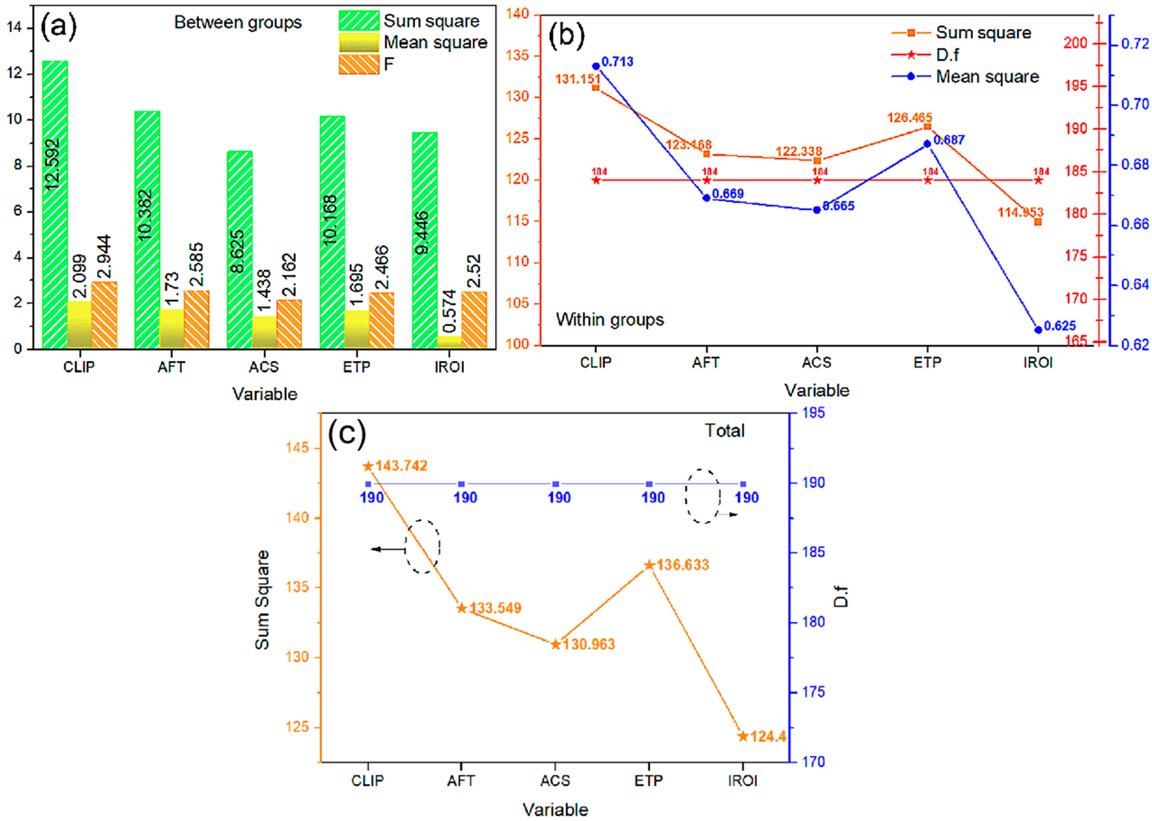

Figure 3. ANOVA across different years of experience: (**a**) between groups, (**b**) within groups, and (**c**) total.

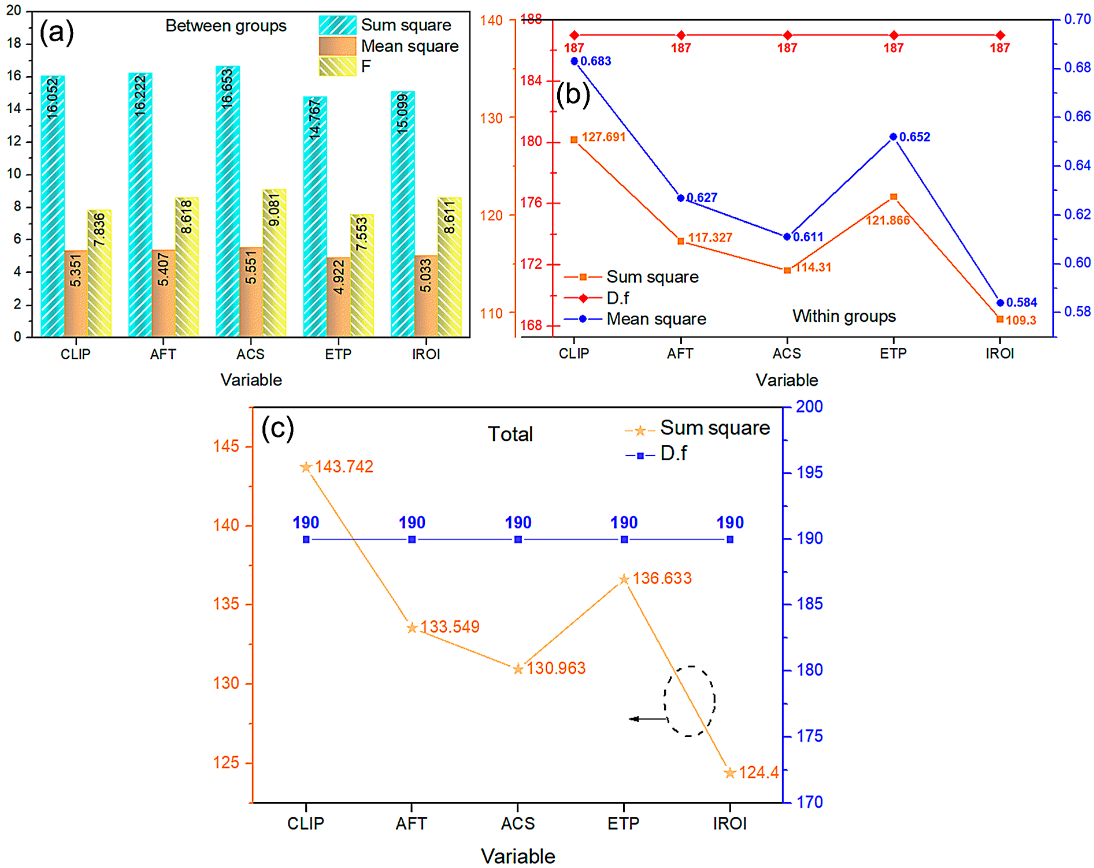

Figure 4. ANOVA across different levels of understanding: (**a**) between groups, (**b**) within groups, and (**c**) total.

Based on ANOVA (see Figures 2–4), the significant effects of various roles, years of experience, and understanding levels of IMH practice cognition can be disclosed. Thus, the industry implementation recommendations are as follows. Firstly, the order and style of training programs should be implemented by priority. According to various roles, years of experience, and understanding levels, the customized training programs can be offered. Through the seminars, online courses and on-the-job training, the MHE can be improved comprehensively. Secondly, the flexible IMH implementation strategy should be developed. The implementation strategy of IMH should be flexible enough to meet the needs of different roles, promoting a wide application of IMH in the construction industry. Then, the experience evaluation criteria should be reassessed. The traditional experience-evaluation criteria should be re-examined, and more attention should be paid to the type and diversity of experience, rather than only years of work. After that, the effectiveness of the training should be ensured. The training content should be adjusted according to the actual needs, ensuring the favoring of the actual operation of the staff (being effectively applied in the work). In the end, the policies and industry standards should be aligned. The policies and practices should agree well with the industry requirements. The regulatory environment that is conducive to an increase in the efficiency and safety should be established, further promoting the successful implementation of IMH.

In the above ANOVA, the degrees of freedom (D.f) can remain unchanged (e.g., D.f = 3, 187, and 190) across different dependent variables, because D.f values were determined by study design—specifically, the fixed number of groups (k = 4 roles→between-group D.f = 3) and total sample size (N = 191→within-group D.f = 187, total D.f = 190)—which do not vary when analyzing different questions (e.g., training effectiveness, regulation impact) for the same participants. The consistency in D.f confirms a properly structured analysis, while changing F-values (e.g., 2.922 vs. 6.605) reflect differences in variance between variables, ensuring statistical validity.

2.7. Regression Analysis

The regression analysis method was used to identify the key factors affecting the MHE in CHBPs. The independent variables included the understanding of the IMH concept, years of experience in MH, training program effectiveness [41], and impact of IMH regulations. It was supposed that these independent variables all show positive correlation with MHE. The linear regression model used is given in Equation (2):

$$y = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \varepsilon \quad (2)$$

wherein y is dependent variable, X_1~X_n are independent variables, β_0 is $\overline{y}$ intercept, β_1~β_n are coefficients of independent variables, and ε is an error term. In Figure 5, the descriptive statistics can be gained, where YE refers to years of experience. Moreover, in Figure 6, the obtained correlations are shown. Figure 7 shows the obtained regression coefficients. In Figure 7, the definitions for key metrics of B, t and Sig. are as follows. At first, B is the regression coefficient (beta coefficient). It represents the degree of influence of the independent variable on the dependent variable. The standardized B value represents the correlation between the independent and dependent variables, and the standardized units are unified to make the results more accurate. Then, t-value is the t-test result of the regression coefficient. It is used to test the significance of regression coefficients. In the end, the Sig. (the significance level) is a *p*-value used to determine the significance of a coefficient. Generally, if the absolute value of the t-value is greater than 2 and the Sig. value is less than 0.05, the coefficient is considered statistically significant. Table 1 shows the results based on ANOVA. Table 2 shows the model summary.

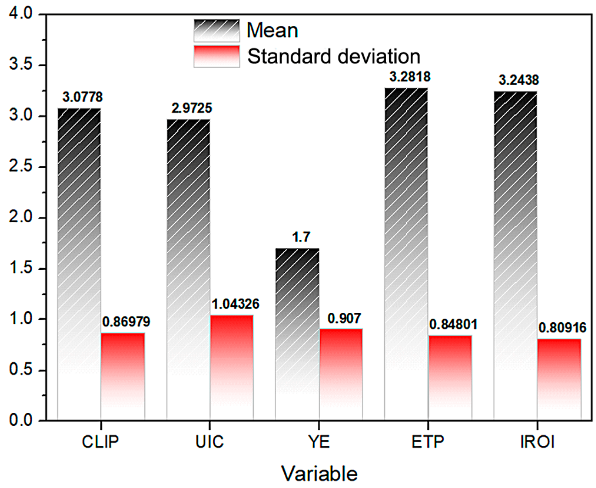

Figure 5. Descriptive statistics: mean values and standard deviations of variables.

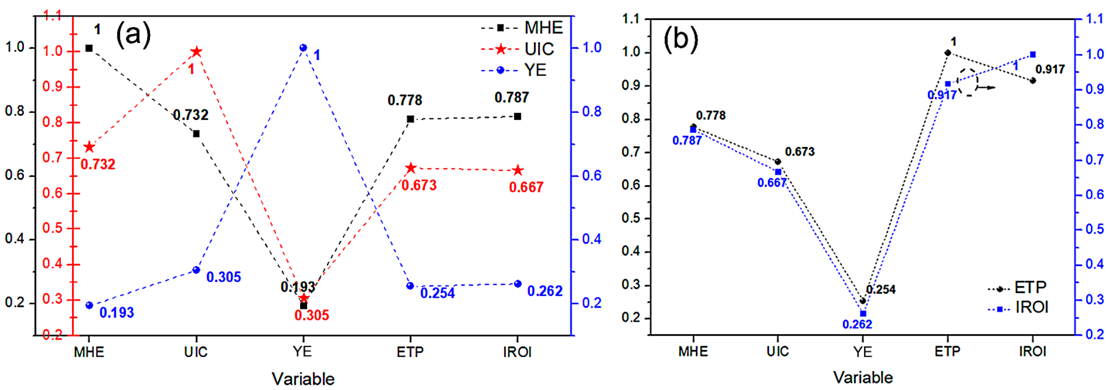

Figure 6. Obtained correlations: (**a**) focusing on MHE/UIC/YE, and (**b**) focusing on ETP/IROI.

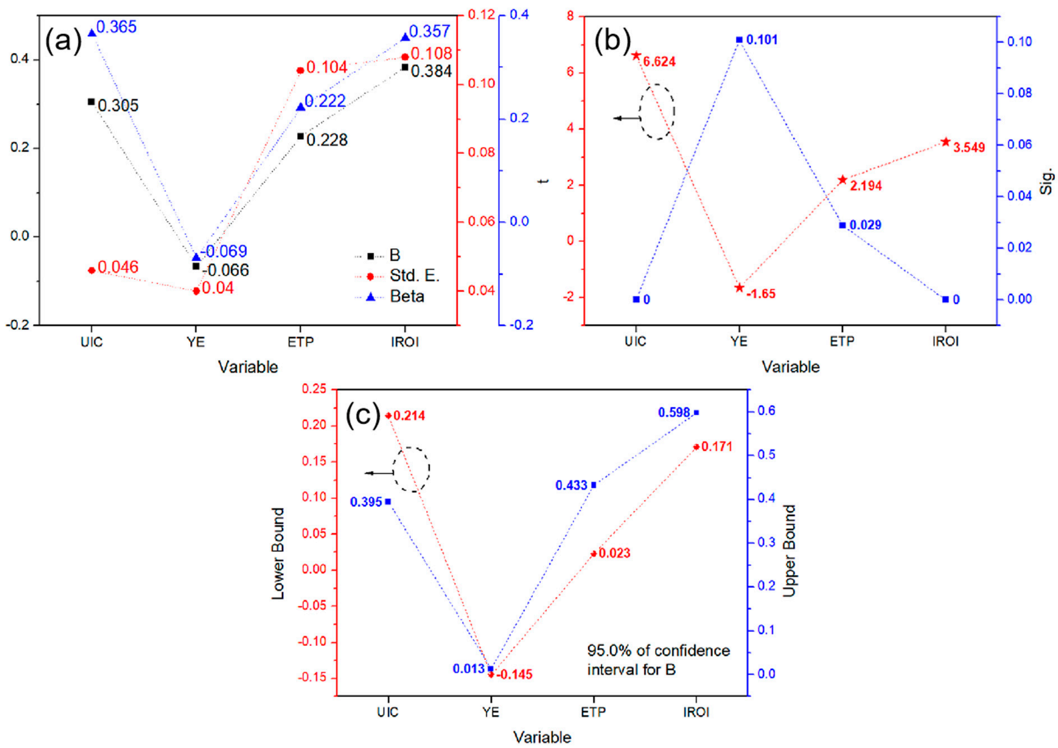

Figure 7. Regression coefficients: (**a**) B/standard error/Beta, (**b**) t/Sig., and (**c**) lower and upper bounds of various variables.

Table 1. Results based on ANOVA.

Model	Sum of Squares	D.f	Mean Square	F	Sig.
Regression	101.873	4	25.468	113.140	0.000
Residual	41.869	186	0.225	-	-
Total	143.742	190	-	-	-

Dependent variable: MHE. Predictors: constant, impact of regulations on IMH, years of experience, understanding of IMH, effectiveness of training programs.

Table 2. Model summary. (Sig. means significance.)

Model	R	R^2	R^2 Adjusted	Standard Error	ΔR^2	ΔF	D.f1	D.f2	Sig.
1	0.842	0.709	0.702	0.47445	0.709	113.14	4	186	0.000

Predictors: constant, impact of regulations on IMH, years of experience, understanding of IMH, effectiveness of training programs. Dependent variable: MHE.

As shown in Table 1, the significance of this model can be expressed as F = 113.140 and $p < 0.001$, suggesting that the predictive effect of independent variables on MHE can be significant. Based on the above regression analysis, the conclusions gained are as follows. At first, the understanding of the IMH concept has a significant positive effect on MHE. The deep understanding of the IMH concept can obviously improve MHE (B = 0.365; $p = 0.000$), manifesting that mastering and applying IMH knowledge and methods can favor an optimization of the MH process, as well as an improvement in overall efficiency.

Therefore, the effect of MH years of experience is not significant. Although the years of experience were assumed as the positive influence factor, the analysis results can show that the effect of years of experience is not statistically significant (Beta of −0.069; $p = 0.101$). This study result contradicts the traditional belief that experience accumulation can inevitably enhance skills. In fact, the relationship between experience and efficiency from dimensions such as the technological iteration, industry characteristics and learning modes, should be re-examined. In detail, the automation and intelligent transformation in the field of material handling may weaken the value of the repetitive physical operation experience. The processes that rely on the manual operation in traditional experience (such as manual sorting and route planning) have shifted from the core efficiency driving factor to the ability to master new technological tools (such as system operation and equipment maintenance) after the penetration of digital technology, rather than simply accumulating over time. If practitioners fail to continuously update their skills and they repeat old operating modes for a long time, it may result in experience solidification and a decrease in acceptance of new technologies, leading to the dilution of the correlation between years and efficiency through the technological gap. Moreover, in traditional cognition, experience is often simplified as length of time, but in fact the quality rather than quantity of experience is the core. If the practitioners only repeat the fixed processes instead of accumulating strategic knowledge through retrospective analysis and problem-solving (such as optimizing transportation paths and predicting equipment failures), the increase in years may only result in a marginal decrease in proficiency benefits, rather than an essential improvement in abilities. The material handling scenario often changes, due to fluctuations in orders, adjustments in warehouse layout, and updates in safety regulations. Efficient practitioners need to have the ability to quickly adapt to new rules, rather than relying on past successful cases. This dynamic adaptability relies more on the willingness to continue learning, rather than the length of service itself. Therefore, the years of experience alone are not enough to significantly improve MHE, especially in the context of complex modern high-rise buildings. The results suggest that the people should pay more attention to the qualitative factors related to experience, not only the years of experience.

Subsequently, the effectiveness of the training program has a significant positive effect on MHE (Beta of 0.222; $p = 0.029$). Thus, the importance of improving employees' ability through effective training should be recognized, and the training program is an important means of improving MHE.

After that, the effectiveness of regulations also shows a significant positive effect on MHE (Beta of 0.357; $p = 0.000$). The reasonable supervision and regulations can improve the standardization and efficiency of MH practice. Thus, great importance should be attached to the design and implementation of regulations.

Finally, the comprehensive effects are as follows. Using this model, the variance of MHE (~70.9%; from Table 2) can be well explained, indicating that the selected independent variables can have significant predictive capacity for MHE. Based on the regression analysis, the understanding of the IMH concept, training program effectiveness, and regulation impact [42], are key factors in improving MHE. Although years of experience did not show a significant effect, these findings suggest that the people should pay more attention to the training and regulations to achieve overall improvement in the efficiency. This provides an important basis for CHBP's MH practice and related policy-making.

The rationale for not including other potential confounders such as organizational culture, firm size, and technology adoption, is as follows. First, the impacts of the organizational culture on high-rise building MH can show opposite aspects. The positive impacts can include the improvement in MH efficiency, the enhancement of employees' sense of responsibility, the promotion of innovation and improvement, and the enhancement of corporate image. However, the negative influences can include the resulting rigid MH, employee resistance, and information blockage. Then, the impacts of the firm size on high-rise building MH are rather complex. The positive impacts are the resource and capability advantages, economies of scale effects, and risk management capability. But the negative influences are the increased MH difficulty, poor information transmission, and lack of flexibility. In the end, technology adoption can have multiple impacts on MH in high-rise buildings, as follows. The positive impacts are the improved MH efficiency, optimized resource allocation, enhanced quality control, enhanced safety management level, and realized information sharing and collaboration. However, the negative influences are the increased cost of technical training, the system maintenance and update pressure, the increased difficulty in data security and management, and the limitations of technology application.

The summary of key tests in this work is shown as follows. At first, in terms of the descriptive statistics, the variables were age, gender, education level, role, experience, IMH understanding, etc. The outputs were means/Std. Dev. (such as IMH understanding: mean = 2.97, Std. Dev. = 1.04), frequency tables (categorical variables such as 74.9% male and 25.1% female), and visualizations (pie/bar charts for demographics in the Supporting Information document).

Then, in the light of the reliability analysis, namely Cronbach's Alpha, the scales showed high reliability for IMH-related constructs ($\alpha = 0.953$~0.972). The exception was negative α (-0.351) for demographic variables, due to non-scale items (expected).

Subsequently, in terms of inferential tests (ANOVA), the purpose was to compare IMH perceptions across roles/experience levels. The key results were role differences (significant for IMH understanding with $F(6184) = 6.08$ and $p < 0.001$; post hoc Tukey highlighted "Construction Workers" vs. Others with $p = 0.008$), and experience impact (significant for future trends with $F(3187) = 5.19$ and $p = 0.002$). The assumptions were normality (Shapiro–Wilk $p > 0.05$), and homogeneity of variance (Levene's $p > 0.05$).

After that, for the regression analysis, the model was based on the predictors of IMH implementation level ($R^2 = 0.709$, $p < 0.001$). The key coefficients were IMH understanding (β = 0.365, $p < 0.001$), and the regulatory and policy landscape (β = 0.357, $p < 0.001$). The assumptions were residual plots (random scatter with linearity; Q-Q plot with normality), and multicollinearity (VIF < 5, tolerance > 0.2).

In the end, in terms of the correlation matrix, the strong correlations were IMH understanding↔current practices (r = 0.732, $p < 0.01$), and training↔policy landscape (r = 0.917, $p < 0.01$).

There are two points that need special explanation here. On one hand, the statistical software used was IBM SPSS Statistics (v28.0). On the other hand, the handling of missing data was clarified as follows. In the light of missing data, the minimal missing values (<5% per variable) were identified via descriptive analysis. For the handling method of missing data, listwise deletion was used for ANOVA/regression, as Little's MCAR test confirmed the data were missing completely at random ($p > 0.05$). Sensitivity analyses showed no bias.

3. Results and Discussion

3.1. Construction of IMH Model Framework

In Section 2, using regression analysis, the key points for improving MHE are IMH concept understanding, training project effectiveness, and regulation effect. From the correlation analysis among variables, the relation between variables is significant. From the ANOVA, the industry implementation strategy was attained. As a result, a new model framework was built herein (Figure 8), aiming at improving the IMH practices in high-rise office building construction in Chinese Chongqing.

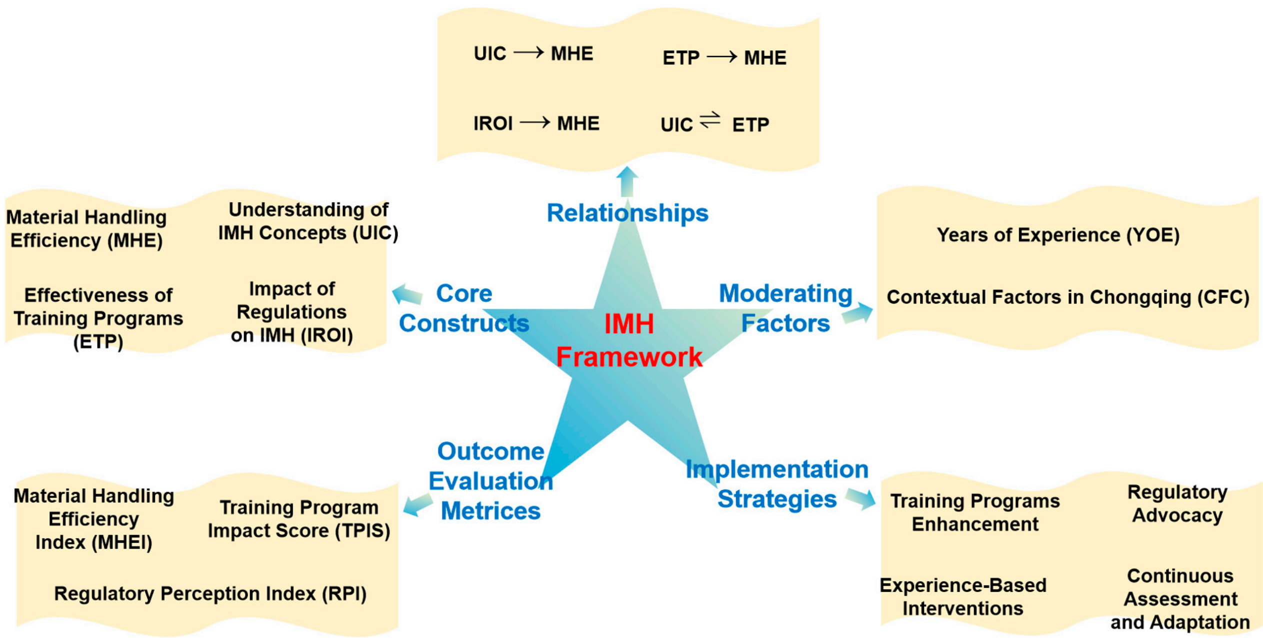

Figure 8. Model framework for improving IMH practices in high-rise office building construction in Chongqing.

3.2. Components of the Model

In Figure 9, the core building blocks of the above new framework model are exhibited. This proposed IMH model framework is compared with the best practice in the similar urban high-rise construction environment in Chinese Shanghai in the Supporting Information document.

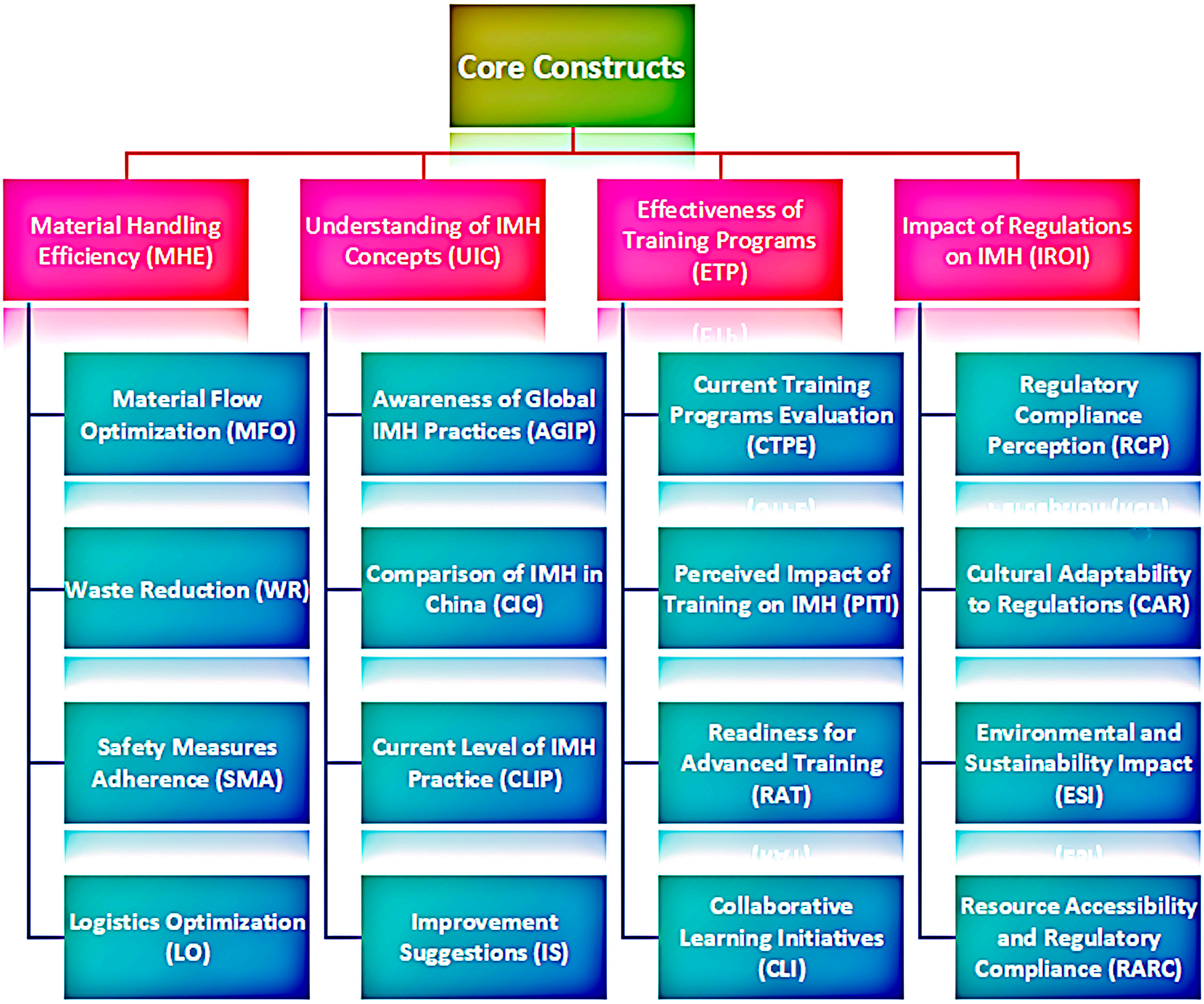

Figure 9. Core building blocks of the new framework model.

First, the MHE is discussed, as follows. The MHE as a core index can realize the comprehensive evaluation. As a key benchmark, it can evaluate the effectiveness of IMH practices in CHBPs. The goals of MHE include a shortening of construction time, improvement in sustainability, and increase in safety. As shown in the figure, the MHE mainly consists of four parts. In detail, the material flow optimization (MFO) can ensure the smooth movement of materials at all stages of construction. Through optimizing the MH system, the waste reduction (WR) refers to a reduction of waste generation in construction projects. The waste amount can be decreased by material recycling, material reuse and sustainable methods. The safety measures adherence (SMA) can check for the safe operation, including a review of safety training, introduction of security mechanisms, and comprehensive construction-site safety culture. In terms of logistics optimization (LO), the effectiveness of the logistics strategy in warehousing can be examined, including the planning for transportation efficiency, storage, distribution, and distribution of materials at a construction site.

For MHE, the quantitative evaluation indicators are the MH cycle time, inventory turnover, and percentage reduction in waste. The qualitative evaluation indicators are the stakeholder feedback, safety incident report, and logistics coordination evaluation. In the light of its importance, the multi-dimensional properties of MHE allow for a full assessment to provide actionable insights, improving specific areas within the MH framework. To achieve the quantified baseline-to-improvement estimate for MHE, the empirical benchmarks and projected targets should be integrated. For example, current industry data from Chongqing's high-rise construction sector can suggest a baseline MH cycle time of 8~12 h per delivery, along with an inventory turnover ratio of 3~4 times per month, indicating inefficiencies in flow optimization. By implementing IoT-enabled tracking and lean logistics, a 30~40% reduction in cycle time (to 5~7 h) and a 20~25% increase in inventory turnover (to 4~5 times/month) could be achieved within 12 months. Similarly, construction waste (currently at 50~70 kg/m^2) could be reduced by 35~40% via prefab recycling hubs, while safety incidents (averaging 5~8 per 100 workers/month) might drop by 50% with the enhanced training and AI hazard monitoring. These estimates can align with the regional pilot studies (e.g., Shanghai's digitized material tracking saw 25~50% efficiency gains), providing a data-backed foundation for MHE improvement. Moreover, the absence of precise baseline data can be mitigated by adopting sector-wide benchmarks or conducting a preliminary audit of Chongqing sites. For example, logistics delays (on-time delivery: 75~80%) could be improved to over 90% via route-optimization software, as demonstrated in Shenzhen's high-rise projects. Such quantified targets can bridge the conceptua–practical gap, enabling the stakeholders to gauge the ROI of MHE interventions.

Afterwards, the understanding of IMH concepts (UIC) is discussed as follows. The UIC is the understanding of CHBP practitioners with regard to IMH principles, techniques, methods, and construction process impact. The UIC focuses on the education and refers to the global requirements, continuously improving the culture. It is of great importance. The primary components of UIC include the awareness of global IMH practices (AGIP), comparison of IMH in China (CIC), current level of IMH practice (CLIP), and improvement suggestions (IS). The assessment indicators of UIC can include the questionnaire survey (practitioners' understanding of the IMH concept), comparative analysis (local practices versus global benchmarks), and recommended assessment (improving the feasibility and desirability of the proposal). In the light of its importance, the knowledge level of IMH can be evaluated by UIC to direct follow-up interventions, boosting the continuous improvement of the Chongqing construction industry.

Next, the effectiveness of training programs (ETPs) is discussed, as follows. The ETPs can measure the impact and benefits of IMH education programs in improving the knowledge and skills of practitioners. The main components of ETPs include the current training programs evaluation (CTPE), perceived impact of training on IMH (PITI), readiness for advanced training (RAT), and collaborative learning initiatives (CLIs). In terms of specific examples of existing training programs, Fujian Road Port Group in China has implemented the "Safety Education and Training Management System" to provide safety management training for employees, including safety knowledge and skills training in high-altitude operations, operations near live electrical objects, blasting equipment and operations, and water operations. Through training, employees' safety awareness and perception of safety risks in MH have been significantly improved. The employees can better identify and prevent the safety hazards, ensure the safety of MH processes, and reduce the possibility of accidents. Moreover, a construction company in Nantong, in China, provided one-on-one guidance to new employees with coaches, as well as professional skills and management training. By training, the new employees can quickly familiarize themselves with MH processes and requirements in the construction industry (improving their perception and understanding of MH). New employees can better adapt to the work environment, improve work efficiency, and reduce errors and waste caused by unfamiliarity with MH. The assessment indicators should include the evaluations before and after training (knowledge assessment), a participant questionnaire (quality and satisfaction of course content), qualitative interviews (the practical impact of training), and results of collaborative projects. In a word, the ETP can ensure that the practitioners have the skills needed to implement the advanced IMH practices, improving overall capability.

Finally, the impact of regulations on IMH (IROI) is discussed as follows. The IROI can assess the impact of the current regulatory framework applied in CHBPs on the development and utilization of IMH. It can measure the impact of regulation on IMH practice methods, exhibiting a key role. The main components of IROI include the regulatory compliance perception (RCP), cultural adaptability to regulations (CAR), environmental and sustainability impact (ESI), and resource accessibility and regulatory compliance (RARC). Here, the assessment indicators include the following four parts. The analysis of a legal gap can clarify the deviation point between the IMH practice and regulatory framework. The environmental impact assessment focuses on the ecological footprint of MH practices. The stakeholder interviews should focus on the practical impact of regulations on IMH practices. The resource allocation surveys should focus on the impact of resources on regulatory compliance. Because of its importance, the IROI studies the impact of regulations on IMH practices to favor an improvement in the management strategies, enhancing the compliance and innovation capability of the industry.

To sum up, the systematic analysis and evaluation of the above core elements can offer the scientific management framework and specific improvement measures for IMH practice in CHBPs, improving the overall MHE.

In the following discussion, the influence of core factors on MHE in CHBPs, based on empirical analysis, is emphasized. Here, for the IMH analysis, the core factors can include the UIC, YE, ETP and IROI, and a positive correlation between any core factor and MHE was supposed. The obtained analysis data are given in Table 3. In this table, the UIC in IMH has a significant positive effect on MHE ($\beta = 0.42$, $p < 0.05$), and the UIC variable can explain the variance of MHE (29%). Moreover, the effect of YE on MHE is nearly significant ($\beta = 0.18$, $p = 0.07$), and thus the sample amount should be increased. Moreover, the ETP can significantly positively affect the MHE ($\beta = 0.35$, $p < 0.01$), explaining the variance of MHE (24%). Ultimately, the IROI was found to significantly positively affect the MHE ($\beta = 0.29$, $p < 0.01$), interpreting the variance of MHE (21%). Therefore, the UIC, ETP and IROI in IMH can have positive influences on MHE with larger influence weights. The supplementary content for this section is given in the Supporting Information document (S3.2. Components of the model (supplementary)).

Table 3. Data from empirical analysis model.

Predictor Variable	Beta Coefficient	*p* Value	R-Squared
UIC	0.42	<0.05	0.29
YE	0.18	0.07	0.13
ETP	0.35	<0.01	0.24
IROI	0.29	<0.01	0.21

The survey data in Table 3 can suggest the building application of the IMH model proposed. The reasons are as follows. YE can be abandoned, due to $p > 0.05$. The beta coefficients are greater than 0, indicating positive impacts of predictor variables. A larger beta coefficient means a stronger effect of the predictor variable on MHE. Thus, the improvements in UIC, ETP and IROI can lead to the improved MHE. The magnitude of MHE improvement can be ordered as UIC > ETP > IROI. Moreover, based on *p* values (Sig. values), the probability of occurrence can be ordered as ETP $\approx$ IROI > UIC. To sum up, to greatly improve the MHE in the building application of this IMH model, the most noteworthy factor is the effectiveness of training programs, while the negligible factor is the years of experience. At the same time, the understanding of IMH concepts, and the impact of regulations on IMH both have equal importance. The IMH model here can present a comprehensive framework for improving MHE in high-rise construction projects, and was constructed from the synthesis of the literature, expert input, and multi-phase survey data. It integrated critical components in building application, such as material flow planning, equipment selection and scheduling, workforce coordination, and risk management.

3.3. Implementation Strategies

Firstly, the project training should be enhanced, strengthening the knowledge and level of skill training for professionals who are engaged in IMH jobs. The main measures are as follows. The highly specific course design should be customized, and the course should cover the technological advances, security protocols, and collaborative practices relevant to the local context. The technology integration space should be set up, covering the advanced technologies and devices such as robotics, internet of things, and radio frequency identification (RFID). The IMH application-oriented integration space can enhance practical experience and improve application capability. The shared collaboration platforms should be built. Through the forums, seminars and related events, the best practices, case studies and innovative solutions in the IMH area can be learned and shared among the practitioners. For a continuous improvement of the plan, the corporate culture should be continuously improved, including the regular assessments and feedback mechanisms. The incorporation of emerging trends into training content can ensure that the practitioners always master the newest technologies.

In terms of implementation and evaluation, the implementation of the training programs requires cooperation with the education industry experts and relevant government departments. The continuous effective training can be assured through the regular audit and feedback mechanism. Here, the performance indicators include the participation rate, skills proficiency, number of collaborative projects, and MHE. With regard to the implementation results, the success of the training-program upgrade components will be assessed through qualitative and quantitative models. At the beginning and end of the implementation period, the improvements in IMH practices in Chongqing will be compared, obtaining the valuable information about the impact of better education on IMH in Chongqing.

Secondly, the advocacy of policies and regulations should be highlighted. The objective is to ensure that the existing regulations and standards can improve the IMH efficiency. Through the evaluation and practice, the IMH practice mechanisms can be established and perfected. The key measures include the analysis of the present situation of laws and regulations, and stakeholders' participation in advocacy. For the former, the comprehensive review of the existing legislation on high-rise building materials should be conducted, identifying the barriers to development and giving the corresponding improvement suggestions. For the latter, the advocacy activities to gain the support of key stakeholders should be initiated, including government agencies, industry leaders and the public. The effective policies to promote the local IMH implementation should be developed.

In terms of the implementation and evaluation, the success of the strategy is measured by the adoption of the recommended policies, as well as its impact on IMH practices. The adaptability of advocacy work is ensured, based on regular monitoring and feedback mechanisms. The performance indicators are as follows. The policy adoption rate refers to the percentage of recommended policies adopted by regulators. As for the stakeholders' support, through the survey and feedback, the perception effect of industry stakeholders on regulatory changes can be understood. With regard to the regulation compliance, the compliance of the construction industry with the new or revised regulations is assessed. As for public awareness, the awareness levels are measured by the public preaching activities and feedback mechanisms.

Subsequently, the experience-based intervention measures should be stressed. These aim to improve the practical knowledge and skills of practitioners involved in the IMH work in the construction of high-rise office buildings in Chongqing. The specific measures are as follows. Based on virtual simulation learning projects, the practical training programs for simulating real IMH scenarios can be developed and implemented. By building the collaborative platforms and workshops, the collaboration among the practitioners, experts, and technical experts, can be facilitated, and the platform for sharing experiences, challenges, and best practices, can be provided to promote the learning within the industry. By constructing the training bases, the practitioners can be trained in the training bases, attaining the cognition and experience to favor IMH practices. With regard to the tutor project system, the tutor responsibility system between the experienced professionals and new practitioners can be established, performing the knowledge teaching and practical experience guidance.

As to the implementation and evaluation, the implementation content can include the virtual simulation experience, training base, and instructor guidance. through the continuous feedback cycles and evaluations, the consistency of the intervention measures with needs can be ensured. The performance indicators include the participation rate (the virtual simulation learning and training base learning), skills development, feedback, satisfaction, and safety performance.

Lastly, the continuous assessment and adaptation should be highlighted. The mechanism of continuous evaluation and adaptation should be established, to ensure the relevance and effectiveness of Chongqing high-rise building IMH practices. The critical elements are as follows. Considering the real-time monitoring system, the real-time data tracking system can provide relevant real-time information, including the efficiency, security, and compliance information. As to the key performance indicator (KPI), the regular KPI evaluation can measure the efficiency of the IMH practices. The KPI can refer to the indicators related to material flow, safety measures, logistics performance, and compliance with global sustainable development goals. In the light of a construction mechanism and professional committee, the mechanism of the continuous feedback from all levels of personnel should be established, and the committee composed of representatives of the various roles should be set up (data analysis; trend forecast; information feedback; making suggestions; cooperating to improve).

Regarding the implementation and evaluation, the implementations should include the integration of monitoring systems, a periodic review of KPI, and the establishment of feedback mechanisms. The professional committee should meet regularly to analyze data and make recommendations for revision. The performance indicators include the adaptation rate, KPI achievement rate, employee satisfaction score, and safety incident trend.

The implementation proposals which it is realistic to implement under current market conditions in Chongqing are as follows. First, the implementation of training programs requires a cooperation with the education industry experts and relevant government departments. As one of the “old eight schools” in China, the Department of Architecture in Chongqing University enjoys a high reputation in the construction industry. Its graduates have strong competitiveness in the job market and are widely recognized and welcomed by major architectural design units, real-estate enterprises, planning departments, etc. The education industry experts from Chongqing University and relevant government departments such as the planning department can cooperate well with the professionals who are engaged in IMH jobs. Second, the implementation of the advocacy of policies and regulations is connected with the adoption of the recommended policies. In Chongqing, the policy-adoption rate is very high, due to the local culture. Finally, for the implementation of the experience-based intervention measures, the content can include the virtual simulation experience, training base, and instructor guidance. For example, the Chongqing University Architecture Science Popularization Education Base has the virtual simulation experimental systems to simulate the real IMH scenarios. It can bring the public an immersive virtual simulation experience. As for the implementation of continuous assessment and adaptation, the barriers under current market conditions in Chongqing are in existence. Firstly, the integration of monitoring systems, a periodic review of KPI, and the establishment of feedback mechanisms is very difficult, due to complexity. Secondly, the formation of a professional committee lacks experience, at present.

3.4. Effectiveness Assessment Indicators

This part is shown in the Supporting Information document. To sum up, the combination of the framework model, questionnaire analysis, the core construction, and empirical research, can furnish theoretical support for IMH practices. This framework covers the training optimization, regulation advocacy, experiential intervention, and continuous adaptation, combined with quantitative effectiveness assessment indicators, namely, MHEI, TPIS and RPI. MHEI can be improved by improving the material flow rate, resource utilization ratio, safety event rate and environmental impact score. TPIS can be improved by improving the knowledge promotion score, behavior change index, performance improvement ratio, and participant satisfaction score. RPI can be improved by improving the scores of compliance difficulty, alignment, impact and adaptability. This framework can lay a foundation for an improvement in the MHE of high-rise office buildings in Chongqing and other areas.

4. Conclusions

Here, a novel model framework based on IMH practice evaluation in CHBPs was proposed, giving the determinants of MHE, as well as improvement strategies. The IMH concept, the actual effects of training programs, and related laws and regulations, were covered. The implementation strategies of transforming theory into practice were raised, including the improvement of existing training programs, regulation support, experience-based approaches, and ongoing evaluation. In the stage of data analysis, the empirical methods such as factor, contingency, causality and demographic characteristics analyses were adopted, disclosing the relationship between different variables and MHE. The empirical regression, correlation, reliability and demographic analyses, along with ANOVA, were used to reveal the primary factors for improving MHE, MH practice awareness, attitude to training programs and regulations, and future technology trends. The understanding of the IMH concept, effectiveness of training projects, and the positive effect of regulations can improve the MHE. Moreover, the weak positive correlation between work experience and MHE can be verified. through the model development framework, a combination of theoretical analysis and empirical research can provide comprehensive tools and knowledge resources for IMH practices in CHBPs, to improve the MHE. Throughquantitative indicators such as MHEI, TPIS and RPI, this framework can offer the objective basis for continuous monitoring and improvement. The results achieved in this work can help the stakeholders identify the existing deficiencies, optimizing the MH process to improve the MHE.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings15132286/s1, Figure S1: Methodology flowchart of evaluation of effective implementation of IMH framework; Table S1: The resultant interview questionnaire; Figure S2: Descriptive statistics of demographic characteristics: (a) age distribution, (b) education level, (c) roles in construction projects, (d) years of experience in MH, (e) previous exposure to IMH projects, and (f) standard deviations for various sections with N = 191; Table S2: Cronbach's reliability analysis; Figure S3: Results of correlation analysis among variables; Table S3: Abbreviations of variable pairs; Table S4: Independent sample t-test results based on analysis; Table S5: More abbreviations; Figure S4: Moderating factors of the raised framework model; Table S6: Regulation effect of YOE on various relationships; Table S7: Interaction effect of CFC based on regression model.

Author Contributions: Conceptualization, P.X.; Methodology, P.X.; Software, P.X.; Validation, P.X.; Formal analysis, P.X.; Investigation, P.X.; Resources, G.F.E.M.; Data curation, G.F.E.M.; Writing—original draft, G.F.E.M.; Writing—review & editing, G.F.E.M.; Visualization, G.F.E.M.; Supervision, Y.S.L.; Project administration, Y.S.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [Research Project on Higher Education Teaching Reform in 2023 by Chongqing Education Commission, China] grant number [233403], and [2023 Chongqing Education Commission Humanities and Social Sciences Research Planning Project, China] grant number [23SKGH326].

Data Availability Statement: The data that support the plots within this paper and other findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors express gratitude to Chongqing Engineering Research Center of Structure Health Monitoring and Disaster Prevention in Full-Life-Cycle in Yangtze Normal University in China.

Conflicts of Interest: The authors declare no conflict of interest.

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