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Research on the Construction of Evaluation System for New Building Industrialization Projects

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Abstract: Although new industrialized construction technologies have the potential to improve industry performance by optimizing work processes and improving the working environment, the application of these technologies in the construction industry is still in its infancy, and its technical direction is not yet set. This study aims to put forward a theoretical framework for evaluating the level of new-type building industrialization of construction engineering projects, conduct integrated research on the existing domestic and foreign literatures on new-type building industrialization and intelligent construction, preliminarily construct the index system, and determine the evaluation index system of new-type building industrialization projects through the Delphi method. The index weight is determined by the combination of order relation analysis and entropy weight method. The evaluation model is constructed by matter-element theory and cloud model, and the evaluation grade standard is proposed. The research results will help guide the evaluation of new building industrialization projects, and provide a judgment reference for determining the development trend and direction of new building industrialization technologies in the future, and help formulate data-driven industrial policies to promote the adoption of new industrialization technologies and promote the digital transformation of the construction industry.

Keywords: emerging construction industrialization; intelligent construction; combination weighting; matter-element theory; cloud model

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1. Introduction

New-type construction industrialization is driven by next-generation information technology, primarily through systematic integrated design and lean production and construction throughout the entire life cycle of a project, integrating the entire industrial chain, value chain, and innovation chain of engineering projects to achieve high-efficiency, high-quality, low-consumption, and low-emission industrialized construction [1]. Prefabricated buildings, which represent new-type construction industrialization, serve as the foundation and key carrier for realizing intelligent construction [2]. Intelligent construction marks a new phase of deep integration between new-type construction industrialization and information technology [3], and the two demonstrate a multidimensional, interactive, and mutually empowering relationship [4]. Together, they drive high-quality development in the construction industry [5]. Prefabricated buildings represent the direction of the new technological revolution and industrial transformation in the construction industry. They signify not only a major transformation in the traditional construction industry's building methods but also a key initiative in promoting supply-side structural reforms and a strong support for new urbanization [6].

New-type construction industrialization is not merely equivalent to prefabricated building technology itself [7,8]; it requires the comprehensive application of various new construction engineering technologies and innovative uses in the construction industry to enhance the level of industrialization [9]. At the same time, it is not only a technological issue. New-type construction industrialization is an industrial and comprehensive matter that also involves management issues, such as project organization and management models compatible with the technology, and the cultivation and development of supporting industries in the sector [10]. Therefore, the progression

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from prefabricated buildings to intelligent construction, and from intelligent construction to new-type construction industrialization, reflects a deepening understanding of the construction industry's rules.

In recent years, during China's active exploration of the development of prefabricated buildings, several urgent issues have arisen regarding the top-level design of technical standards and regulations. As a result, China's related standards still lag significantly behind the advanced international standards for sustainable prefabricated construction methods [11]. This project aims to formulate evaluation standards for new-type construction industrialization projects, establish a technical indicator system for project evaluation, and explore scientific and practical evaluation methods. The expected research outcomes will not only provide reference points for national and regional standards for industrialized construction projects and offer technical and management support for project design and construction but also highlight the application of information technology, guiding projects to continually improve labor productivity and construction quality. Furthermore, this research will offer important insights for the development of high-quality policies in the construction industry and for the potential prioritization of policy rewards. Additionally, this research project represents a valuable exploration and extension of the evaluation theory for improving the level of new-type construction industrialization.

2. Literature Review

2.1. Literature Overview

Through the analysis of the literature, it has been found that research on evaluating the development level of new-type construction industrialization is still relatively new. However, studies related to the construction industry and the evaluation of the impact of industrialized construction on the surrounding environment offer significant insights into the evaluation of the development level of new-type construction industrialization.

In terms of research related to the construction industry, Umberto used field surveys to obtain a series of data and compared three widely recognized evaluation indicator systems for construction industry development. The analysis revealed that energy consumption evaluation systems are the most important [12]. Tatarc et al. developed a sustainable development system for the construction industry from an ecological perspective and conducted an evaluation focusing on the United States [13]. Kucukvar et al. constructed an evaluation model from economic, environmental, and social aspects, assessing the sustainable development of the construction industry in the United States from a life-cycle perspective [14]. Zhang Miao et al. found that regional overall development levels, development efficiency in the area, and the potential demonstrated during development should be key areas of focus. By evaluating these three aspects and combining them with Matlab software for indicator weight calculation and model construction, they provided scientific evaluations and practical development suggestions for the construction industry across various regions in China [15]. Ye Haowen introduced the key technology system of intelligent construction and building industrialization and its practical exploration, discussing and forecasting BIM forward design, prefabricated buildings, intelligent factories, intelligent construction, smart construction sites, and their corresponding management models [16].

In terms of evaluating the environmental impact of construction industrialization, Aye et al. conducted a quantitative analysis of the effects of prefabricated components on energy conservation, emission reduction, and resource savings. This was achieved by calculating the energy consumed by prefabricated steel structure buildings [17]. Silva et al. demonstrated the specific application of prefabricated retrofit modules in renovation schemes, aiming to minimize the energy consumption and CO2 emissions of the final building compared to other construction types [18]. Bonamente et al. conducted a field survey of an Italian company and obtained actual data, using the LCA (Life Cycle Assessment) method to study the environmental impact of industrial prefabricated houses, including energy consumption and CO2 emissions at each stage of the life cycle [19]. Ammar et al. performed simulation and analysis to measure the actual energy consumption of traditional and industrial

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building systems in Iraq, finding that IBS (Industrialized Building Systems) reduced energy consumption [20]. Cao et al. studied the similarities and differences between prefabricated and cast-in-situ construction technologies, with results indicating that prefabricated technology causes less environmental damage on-site compared to traditional methods [21]. Hong et al. analyzed the energy use of prefabricated components throughout their life cycle, finding that recycling prefabricated components could achieve energy savings of 16% to 24%, improving quality control and reducing overall life cycle energy consumption by 4% to 14% [22]. Lei Yunxia analyzed the constraints on new-type construction industrialization from policy, technology, personnel, and market perspectives, and proposed ideas for improving new-type construction industrialization in Shenyang [23].

In the evaluation of construction industrialization development, Guangbin Wang et al. adopted a multi-case study method and introduced the Excellence Model developed by the European Foundation for Quality Management (EFQM). They explored a maturity model for industrialized construction based on construction projects, focusing on organizational factors. Through literature reviews and expert interviews, the evaluation system was divided into two aspects: enablers and results. The maturity of industrialized construction was categorized into four levels: Initial, Improvement, Comprehensive, and Optimal [24].

Tao Ma divided the life cycle of new construction industrialization into five stages: decision-making, design, production, construction, and operation and maintenance. By integrating the concepts of new construction industrialization and intelligent construction, he employed various research methods to establish an evaluation index system. He used the Cloud Matter-Element Evaluation Method to construct a cloud matter-element model to evaluate the development level of new construction industrialization from an intelligent construction perspective [25].

Yang argued that the development of construction industrialization should first consider its economic benefits, while also emphasizing the importance of environmental protection. Technological advancements provide the foundation for the development of construction industrialization, and companies should improve their informatization levels in response to environmental changes. Based on this, accurate and reasonable assessments of construction industrialization development can be made [26].

2.2. Issues in Current Research

Currently, under the promotion of central departments and local governments, industry practices in prefabricated buildings, intelligent construction, and new construction industrialization are very active. These practices have become new growth points and development directions in the construction industry, serving as important drivers of high-quality development. However, how to carry out new construction industrialization and how to organically integrate the concepts mentioned above to form synergy is still under exploration in practice, urgently requiring theoretical support and guidance. Through analysis and review of domestic and international literature, it is found that systematic research has been conducted on the construction industry chain, construction supply chain, green building industry chain, and their evaluation systems, yielding rich research results. However, there are still shortcomings in areas such as concept definition and research dimensions, specifically:

1. More Focus on Micro-Level Project Evaluation Systems

Existing research results mainly explain certain aspects or stages of the construction industry chain from a single dimension, lacking systematic analysis of the overall structural characteristics of the construction industry chain. There is little research on measuring the maturity of regional construction industry chain development, and the existing research mainly focuses on single stages or dimensions. Studies on the spatial agglomeration of construction industry chain maturity lack systematic analysis, and factors influencing spatial agglomeration have not yet considered regional spatial levels. The purpose of evaluation is for practical application, using the evaluation system as a benchmark to promote high-quality development in the industry. Therefore, the evaluation system should place more emphasis on the project level to enhance its applicability.

2. Evaluation Standards Should Reflect New Trends in Development

The integrated development of intelligent construction and new construction industrialization has been identified as a strategic direction for the construction industry, with high-quality development concepts elevated to unprecedented levels. The evaluation system for new construction industrialization should focus on the "new," incorporating new ideas and concepts into the evaluation indicators and prioritizing the construction of evaluation systems for new construction industrialization projects in the evaluation standards.

3. Room for Improvement in Evaluation Methods

Current evaluation methods mostly rely on subjective comprehensive scoring methods, with relatively little use of scientific research methods that combine subjective and objective evaluations. In addition, the development of the index system mainly relies on literature reviews and expert interviews, with few cases of multiple rounds of quantitative research being used to scientifically determine the index system and its weights.

This study is divided into three stages: (1) constructing the evaluation index system, (2) determining the weight of the evaluation indicators, and (3) establishing the evaluation model. The construction of the evaluation index system is carried out through methods such as literature review, policy research, and expert interviews. The workflow for determining the weight of evaluation indicators includes using the G1 method to calculate subjective weights, the entropy weight method to calculate objective weights, and the combined weighting method to calculate comprehensive weights. Finally, the cloud matter-element model is established for evaluation research.

3. Construction of the Evaluation Index System

This paper determines the evaluation dimensions for new construction industrialization projects by studying domestic and international literature and relevant regulations and policies. Next, it identifies and summarizes the evaluation indicators, forming a preliminary evaluation index system for new construction industrialization projects. Finally, through expert consultation, the final evaluation index system for new construction industrialization projects is established.

3.1. Selection of Evaluation Dimensions

Using keywords such as “new construction industrialization technology application,” “evaluation of new construction industrialization,” “application effects of new construction industrialization,” and “on-site evaluation of new construction industrialization,” relevant literature was retrieved from databases including CNKI (China National Knowledge Infrastructure) and Fujian Province’s digital library. Over 100 domestic and international academic journal articles with high relevance to the research content were selected for detailed review and summary. Additionally, on the official website of the Ministry of Housing and Urban-Rural Development, a search using the keyword “new construction industrialization” yielded 32 relevant pieces of information and documents as of September 1, 2023.

Through the review and analysis of existing research and related policy documents, the dimensions of evaluation for new construction industrialization projects during the construction phase in domestic and international journal papers are mainly categorized into ten aspects: project management, cost management, quality management, safety management, personnel management, material management, machinery management, method management, environmental management, and information management.

In August 2020, the Ministry of Housing and Urban-Rural Development and nine other ministries issued the “Several Opinions on Accelerating the Development of New Construction Industrialization,” which detailed the concepts of new construction industrialization technologies in design, production, construction, and management, providing direction for the development of new construction industrialization industries and technologies in various regions.

In June 2023, the Fujian Provincial Department of Housing and Urban-Rural Development released the “Work Plan for Accelerating the Development of Intelligent Construction in Fujian Province,” further identifying “system substitution, machine substitution, and factory substitution for on-site work” as new models for the development of new construction industrialization.

Based on the existing research and expert discussions, this study merges dimensions with similar meanings and determines the evaluation dimensions for the application effects of new construction industrialization technology as follows:Whole process BIM application, smart site management, construction robots and intelligent equipment, prefabricated parts.

3.2. Determination of the Evaluation Index System

Based on this foundation, evaluation indicators were identified and summarized through literature research and in-depth interviews with experts, resulting in a preliminary set of 22 evaluation indicators for the application effects of new construction industrialization technologies. To reduce the potential for subjectivity in the selection of these indicators, the Delphi method was employed to refine the initial 22 indicators. A total of 6 experts in relevant fields were selected for this process, with an average age of 48.5 years. Among them, 66.7% hold postgraduate degrees or higher, 83.3% have more than 10 years of experience, and 66.7% hold senior professional titles. The basic information of the experts is shown in Table 1.

Table 1. Basic Information of Experts.

No	Highest Education	Work Experience	Title	Age	Gender
1	Postgraduate and above	10 year or more	Senior	52	Male
2	Postgraduate and above	10 year or more	Intermediate	58	Male
3	Postgraduate and above	10 year or more	Senior	49	Male
4	Postgraduate and above	6-10years	Intermediate	41	Female
5	Bachelor’s Degree	10 year or more	Senior	45	Male
6	Bachelor’s Degree	10 year or more	Senior	46	Male

The authority degree (C) of experts is determined by calculating the arithmetic average of cognitive accuracy (Ca) and criteria standard (Cs). This helps evaluate the experts' understanding of the field and the credibility of the consulting results. When the authority degree (C) is 0.7 or higher, it indicates a higher level of trustworthiness for the experts' judgments. The familiarity levels of the indicators are provided in Table 2, and the basis for expert judgments is detailed in Table 3.

Table 2. Indicator Familiarity Level Scores.

Familiarity Level	Cognitive Accuracy（Ca） Score
Very Familiar	1.0
Familiar	0.8
Average	0.6
Unfamiliar	0.4
Very Unfamiliar	0.2

Table 3. Indicator Judgment Basis Scores.

Judgment Standard（Cs）	Impact Level	Score
Experience Judgment	High	0.5
	Medium	0.4
	Low	0.3
Theoretical Analysis	High	0.3
	Medium	0.2
	Low	0.1
Peer Consultation	High	0.1
	Medium	0.1

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	Low	0.1
Intuition	High	0.1
	Medium	0.1
	Low	0.1

The authority coefficients of the experts in both rounds of consultation were consistently above 0.90, indicating very high expert authority, as shown in Table 4.

Table 4. Expert Authority Coefficients.

Round	Familiarity（Mean）	Judgment Basis（Mean）	Authority Factor（Mean）	Familiarity（Std Dev）	Judgment Basis（Std Dev）	Authority Factor （Std Dev）
First	0.917	0.925	0.921	0.950	0.942	0.946
Second	0.098	0.043	0.071	0.087	0.064	0.076

The importance levels of each indicator and their corresponding scores are shown in Table 5.

Table 5. Indicator Importance Scores.

Assessment Item	Level	Score
Importance	Very Important	5
	Important	4
	Average	3
	Not Important	2
	Very Not Important	1

In the results of the first round of expert Delphi consultation, except for the indicators “BIM-based Construction Management” under the “BIM Application Throughout the Process” dimension and “Prefabricated Electrical and Plumbing Lines” under the “Prefabricated Components and Parts” dimension, the average importance scores of the remaining indicators were all greater than 3, with a coefficient of variation (CV) of less than 20%. The Kendall coefficient passed the consistency test ($p < 0.05$), indicating good consistency. After discussing with experts, it was decided to merge the “BIM-based Construction Management” indicator from the “BIM Application Throughout the Process” dimension with the “Intelligent Construction Management” indicator from the “Smart Construction Site Management” dimension due to overlap. The combined indicator is now placed under the “Smart Construction Site Management” dimension, explained as: through 4D visualization technology, BIM technology, and real-time simulation models linked with on-site construction information, effective dynamic integration management of the construction site is achieved. Considering that the “Prefabricated Electrical and Plumbing Lines” indicator under the “Prefabricated Components and Parts” dimension does not align well with national conditions in practical engineering applications, experts recommended removing this indicator. Therefore, the indicators were revised, and the remaining 20 indicators were included in the second round of expert Delphi consultation. In the results of the second round, the average importance scores of the indicators were all greater than 3, with a coefficient of variation (CV) of less than 20%. The Kendall coefficient passed the consistency test ($p < 0.05$), indicating good consistency. The final evaluation indicator system for new construction industrialization projects, consisting of 20 indicators, is shown in Table 6.

Table 6. Evaluation Indicator System for New Construction Industrialization Projects.

Criterion Layer	Indicator Layer	Indicator Explanation
BIM Application Throughout the Process	Forward Collaborative Design	Uses BIM for forward collaborative design，promoting multi—disciplinary coordination and comprehensive design integration to optimize design processesand improveefficiency.
	Construction DrawingReview	lmplements Al—based review systems using BIM technology for digital and intelligent review of construction drawings.
	Completion Delivery	Develops BIM delivery standards and conducts 3D digital completion acceptance and registration.
Smart Construction Site Management	Intelligent Progress Management	Tracks construction progress in real time using 4D visualization models.
	lntelligent Cost Management	Utilizes BIM technology to create SD models for dynamic cost control.
	lntelligent Construction Management	Constructs real—time simulation models by integrating 4D visualization technology，BIM technology，and on—site construction information for dynamic integrated management.
	lntelligent Safety Management	Monitors safety risk sources and issues automatic alerts using BIM technology.
	lntelligent Environmental Management	Uses loT technology to monitor dust and noise generated on—site，with AI technology for automatic intervention if thresholds are exceeded.
	lntelligent Communication Management	Builds a three—dimensional communication platform using BIM technology to facilitate coordination among all parties.
	Digital Internal Documentation Management	Uses electronic signatures and digital construction documents based on engineering management and construction operations.
BuildingRobots and Intelligent Equipment	Pre—application Planning	Considers the application of building robots in structural，MEP，decoration，and landscaping design to increase their coverage.
	Optimized Construction Plan	Optimizes construction plans to meet building robot requirements and improve construction efficiency.
	BuildingRobot Application	lnnovatively applies robots in material delivery，rebar processing，spraying，fabric laying，tile laying，partition wall installation，floor leveling，and high—altitude welding to assist or replace manual labor in hazardous，complex，dirty，and heavy tasks.
	lntelligent Equipment	Applies automated rebar tying，smart weighing scales，intelligent tower cranes，smart concrete

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	Application	pumping equipment，smart lifting platforms，bridge machines，and intelligent transport equipment to achieve intelligent construction equipment.
	Intelligent Monitoring Equipment	Promotes the installation of intelligent monitoring devices in deep foundations，high formwork，and steel structures for real－time monitoring of structural load conditions.
	Earthwork Measurement Drones	Utilizes drones for earthwork measurement to quickly collect terrain information and calculate soil and rock volumes with a single click.
	Real Measurement Robots	Uses pre－formed rebar and prefabricated components suitable for systemswith no molds or supports in the main structure and temporary facilities.
Prefabricated Components and Parts	Prefabricated Structural Components	Uses pre－formed rebar and prefabricated components suitable for systemswith no molds or supports in the main structure and temporary facilities.
	Prefabricated Decoration	Employs new wall materials，integrated doors and windows，complete kitchen and bathroom units，andintegrated ceilings.
	Tool－based Formwork	Utilizes aluminum formwork，plastic formwork，and other tool－based formworks.

4. Determination of Evaluation Indicator Weights

In this study, a combination of subjective and objective methods is used to assign weights to each level of evaluation indicators. The main steps are as follows:

1.Ordinal Relation Analysis Method This method does not require consistency checks and is simple and convenient for calculations. The ordinal relation analysis method is used to calculate the subjective weights of the indicators.

2. Entropy Weight Method This method is not restricted by the number of indicators, is widely applicable, and involves simple calculations. The entropy weight method is used to determine the objective weights of the indicators.

3. Lagrangian Extremum Method This method is used to calculate the combined weights of the evaluation indicators at each level.

4.1. Order Relation Analysis

The Ordinal Relation Analysis Method is an improved subjective weighting method derived from the Analytic Hierarchy Process (AHP). This method ranks the importance of evaluation indicators and determines their weights based on a specific algorithm. It is simple, convenient, and highly operational, without limitations on the number of indicators. The specific calculation steps are as follows:

Step 1: Determine the Ordinal Relationship of Evaluation Indicators. Assume Indicator Set $I=\{I_1,I_2,\cdots,I_n\}$ contains n indicators at the same level. Experts select the most important indicator from these n indicators, denoted as $I_1^{'}$, and then choose the most important indicator from the remaining $(n-1)$ indicators, denoted as $I_2^{'}$, and so on. This process is repeated for all n indicators.After determining the final order, we obtain the evaluation indicator set, denoted as $I^{'}=\{I_1^{'},I_2^{'},\cdots,I_n^{'}\}$.

Step 2:Determine the Relative Importance of Indicators. Experts assess the importance of adjacent indicators $I_{j-1}^{'}$ and $I_j^{'}$ based on Table 8, It is represented by r_j as:

$$r_j=\frac{W_{j-1}^{'}}{W_j^{'}},j=2,3,\cdots\cdots,n \quad (1)$$

In the formula, $W_j^{'}$ and $W_{j-1}^{'}$ represent the weights of adjacent evaluation indicators $I_j^{'}$ and $I_{j-1}^{'}$, respectively, and r_j represents the relative importance ratio between adjacent evaluation indicators $I_{j-1}^{'}$ and $I_j^{'}$. The assignment of r_j can be referenced from Table 7.

Table 7. Assignment reference table**.**

r_j	Indicators are equally important.
1.0	One indicator is slightly more important than the other.
1.2	One indicator is significantly more important than the other.
1.4	One indicator is far more important than the other.
1.6	One indicator is extremely more important than the other.
1.8	The ratio between indicators falls between two of the significance levels.
1.1、1.3、1.5、1.7	1.0: Indicators are equally important.

Step 3: Calculate Indicator Weights.Based on the values in Table 8, calculate the weights of indicators at each level. The weight value of the n-th indicator, denoted as $W_j^{'}$, is computed as follows:

$$W_j^{'}=\left(1+\sum_{j=2}^{n}\prod_{i=j}^{n}r_i\right)^{-1} \quad (2)$$

$$W_{j-1}^{'}=r_j\cdot W_j^{'},j=2,3,\cdots\cdots,n \quad (3)$$

4.2. Entropy Weight Method

The Entropy Weight Method is an objective weighting approach that determines the weights of evaluation indicators based on their impact on the overall system. It assesses the degree of variability of each indicator, with higher weights indicating more information and greater variability, and lower weights indicating less variability. The calculation process is illustrated in Figure 3. The specific steps are as follows:

Step 1: Generate the Initial Evaluation Matrix. First, classify the indicators into five levels of importance: Extremely Important (5), Important (4), General (3), Not Important (2), and Extremely Not Important (1). Then, invite n experts with relevant work experience to score each indicator. Summarize the scoring results to obtain the evaluation matrix $R=(r_{ij})_{m\times n}$.

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$$R=\left(r_{ij}\right)_{m\times n}=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}_{m\times n} \quad (4)$$

Where:

r_{ij} represents the evaluation score given by the *i*-th expert for the *j*-th indicator,

m represents the number of evaluation objects,

n represents the number of evaluation indicators.

Step 2: Calculate the Scores for Each Indicator P_{ij}.

Due to the varying professional backgrounds of the scoring experts, their perceptions of different evaluation indicators may differ. To eliminate this influence, the evaluation matrix needs to be normalized.

$$P_{ij}=\frac{r_{ij}}{\sum_{i=1}^{m} rij} \quad (5)$$

Step 3: Calculate the Information Entropy e_j for Each Evaluation Indicator.

$$e_j=-\frac{\sum_{i=1}^{m}\left[p_{ij}\bullet\ln\left(p_{ij}\right)\right]}{\ln\left(m\right)} \quad (6)$$

Where:

e_j represents the information entropy of the j-th indicator.

Step 4: Calculate the Entropy Weights for Each Evaluation Indicator d_j.

$$d_j=1-e_j \quad (7)$$

$$W_j^{"}=\frac{d_j}{\sum_{i=1}^{n} d_j} \quad (8)$$

Where: $W_j^{"}$ represents the entropy weight of the j-th evaluation indicator.

4.3. Combination Weight

This study uses the Lagrangian Extremum Method to determine the coefficients for the two types of weights, resulting in combined weights to ensure the accuracy of the evaluation indicator weight calculations. The calculation formula is as follows:

$$\begin{cases} W_j=\alpha W_j^{'}+\beta W_j^{"}, j=1,2,\cdots\cdots,n \\ \alpha^2+\beta^2=1,\alpha>0,\beta>0 \end{cases} \quad (9)$$

In the formula, α is the subjective weight coefficient and β is the objective weight coefficient. The Lagrangian Extremum Method is used to solve this, and the formula is as follows:

$$\begin{cases} \alpha' = \dfrac{\sum_{i=1}^{m}\sum_{j=1}^{n} W_j' r_{ij}}{\sqrt{\left(\sum_{i=1}^{m}\sum_{j=1}^{n} W_j' r_{ij}\right)^2 + \left(\sum_{i=1}^{m}\sum_{j=1}^{n} W_j'' r_{ij}\right)^2}} \\ \beta' = \dfrac{\sum_{i=1}^{m}\sum_{j=1}^{n} W_j'' r_{ij}}{\sqrt{\left(\sum_{i=1}^{m}\sum_{j=1}^{n} W_j' r_{ij}\right)^2 + \left(\sum_{i=1}^{m}\sum_{j=1}^{n} W_j'' r_{ij}\right)^2}} \end{cases} \quad (10)$$

$$\begin{cases} \alpha = \dfrac{\alpha'}{\alpha' + \beta'} \\ \beta = \dfrac{\beta'}{\alpha' + \beta'} \end{cases} \quad (11)$$

By calculating with the above formula, the two coefficients are determined as α= 0.504148 and β = 0.495852. Finally, the weights for each level of indicators are obtained, as shown in Table 8.

Table 8. Weights of Indicators at Each Level.

Criterion Level	Combined Weight	Indicator Level	Ordinal Relation Analysis Weight	Entropy Weight Method Weight	Combined Weight
Whole Process BIM Application	0.2093	Forward Collaborative Design	0.0747	0.0215	0.0484
		Construction Drawing Review	0.0897	0.0917	0.0907
		Completion Delivery	0.0680	0.0158	0.0421
Promoting Smart Construction Site Management	0.2732	Intelligent Progress Management	0.0351	0.0341	0.0346
		Intelligent Cost Management	0.0547	0.0772	0.0659
		Intelligent Construction Management	0.0456	0.0401	0.0429
		Intelligent Safety Management	0.0269	0.0545	0.0406
		Intelligent Environmental Management	0.0350	0.0733	0.0540
		Intelligent Communication Management	0.0350	0.0807	0.0576
		Digital Internal Document Management	0.0385	0.0832	0.0607
Application of Building Robots and	0.3423	Design Application Planning	0.0444	0.0338	0.0391

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Intelligent Equipment		Optimization of Construction Plans	0.0488	0.0436	0.0462
		Application of Building Robots	0.0644	0.0511	0.0578
		Application of Intelligent Equipment	0.0537	0.0442	0.0490
		Intelligent Monitoring Equipment	0.0429	0.0436	0.0432
		Earthwork Measurement Drones	0.0472	0.0511	0.0492
		Real Measurement Robots	0.0330	0.0401	0.0365
Prefabricated Construction	0.1752	Site Assembly	0.0554	0.0338	0.0447
		Prefabricated Decoration	0.0609	0.0611	0.0610
		Tool-Based Templates	0.0462	0.0255	0.0359

5. Construction of the Evaluation Model

The reasonableness of the evaluation model's construction is crucial for the accuracy of the evaluation results. Given the characteristics of evaluating new building industrialization projects, the evaluation model is constructed following these steps:

(1) Introduction of Matter Element Theory: This allows for the quantitative transformation of evaluation indicators using characteristic values. (2) Application of Cloud Modeling: The cloud model addresses the randomness and fuzziness issues that arise during the transformation process through its numerical characteristics. (3) Integration of Cloud Modeling and Matter Element Theory:This study combines cloud modeling with matter element theory to construct a cloud-matter-element evaluation model for comprehensive assessment of new building industrialization projects.

5.1. Cloud-Matter-Element Theory

In matter element theory, a matter element is expressed as R = (N, C, V), where N is the matter element object, C is the matter element characteristic, and V is the measured value of the matter element property.Matter element theory enables the quantitative conversion of qualitative indicators through the analysis of objects, characteristics, and measured values. However, due to the randomness and ambiguity of the problem, the quantitative values in the evaluation process cannot be accurately determined, which results in the inability to guarantee the accuracy of the final evaluation results. Therefore, the introduction of the cloud model into matter element theory allows for the consideration of randomness and ambiguity. By using expectation (E_x), entropy (E_n), and hyper-entropy (H_e), uncertainty can be transformed into certainty, thereby improving the accuracy of the evaluation results [27]. The expression is as follows:

$$R=\begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix}=\begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{bmatrix}=\begin{bmatrix} N & C_1 & (E_{x1} & E_{n1} & H_{e1}) \\ & C_2 & (E_{x2} & E_{n2} & H_{e2}) \\ & \vdots & & \vdots & \\ & C_n & (E_{xn} & E_{nn} & H_{en}) \end{bmatrix} \quad (12)$$

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In the cloud-matter-element model, the level of the evaluation indicators is represented by a fixed interval $[C_{\min}, C_{\max}]$ corresponding to the score for each level. E_x represents the midpoint of the interval, and E_n is calculated based on the "$3E_n$" rule of the normal cloud model. The formula is as follows:

$$E_x = \frac{C_{\max} + C_{\min}}{2} \qquad (13)$$

$$E_n = \frac{C_{\max} - C_{\min}}{6} \qquad (14)$$

$$H_e = s \qquad (15)$$

Where s is a constant that can be adjusted according to the degree of fuzziness of each indicator.

5.2. Construction of the Cloud-Matter-Element Model

By constructing the cloud-matter-element model, the evaluation and analysis of new building industrialization projects can be carried out. The specific calculation steps are as follows:

Step 1: Divide the Rating Standards

Currently, China has not yet developed a standardized evaluation system for new building industrialization projects. However, various provinces and cities have issued related policy documents. The evaluation dimensions mainly focus on areas such as BIM models, intelligent construction and evaluation, smart devices, and prefabricated components.

Based on literature research and expert opinions, the indicators are classified into five levels:One Star (Initial Level)、Two Stars (Promotional Level)、Three Stars(Comprehensive Level)、Four Stars (Next Best Level) and Five Stars (Optimal Level). To reflect the differences between levels, the golden ratio model is used to determine the scoring intervals within domain $[0,1]$. The midpoint of domain 0.5 is set as the score for the evaluation level "Three Stars" E_x.

According to the principle of the "$3E_n$", the smaller value of adjacent clouds $3E_n$ and H_e is 0.618 times the larger value [28]. The standard cloud model parameters for each evaluation level are determined by equations (13) and (14), as shown in Table 9.

Table 9. New Building Industrialization Levels and Their Numerical Characteristics.

Hierarchy	One Star	Two Stars	Three Stars	Four Stars	Five Stars
Score Interval	[0,0.309]	[0.117,0.501]	[0.407,0.593]	[0.499,0.883]	[0.691,1]
Numerical Characteristics	(0,0.103, 0.0131)	(0.309,0.064, 0.0081)	(0.500,0.031, 0.0050)	(0.691,0.064, 0.0081)	(1,0.103, 0.0131)

After determining the numerical characteristics for each evaluation level, MATLAB programming is used to establish the standard cloud model for evaluating new building industrialization projects. To improve accuracy and avoid errors due to high randomness, the number of cloud droplets D is set to 1000. This is illustrated in Figure 5.

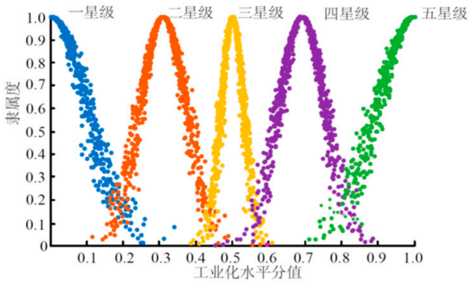

Figure 5. Standard Cloud Model for Evaluating New Building Industrialization Projects.

Step 2: Membership Degree Calculation

(1) Membership Degree Calculation at the Indicator Level

For each evaluation indicator value xxx, treat it as a cloud droplet. Using MATLAB 2016b, calculate the association degree of each indicator value xxx with each evaluation level. The expression for this calculation is as follows:

$$K\left(x_i\right)=\exp\left[-\frac{\left(x_i-E_x\right)^2}{2\left(E_n^{'}\right)^2}\right] \tag{16}$$

Where $E_n^{'}$ is a normally distributed random number determined by the expectation E_x and the standard deviation H_e. Criteria Layer Membership Degree Calculation: By weighting the calculated indicator layer membership relationships, the membership degree for the criteria layer $K_j\left(L_p\right)$ can be determined.

$$K_j\left(L_p\right)=\sum_{i=1}^{n}\omega_{pi}K_j\left(M_{pi}\right) \tag{17}$$

Where $K_j\left(L_p\right)$ is the membership degree of the p-th criterion element with respect to the j-th application effect level.

(2) Objective Layer Membership Degree Calculation: By weighting the calculated membership degrees at the criteria layer, the membership degree for the objective layer $K_j\left(L\right)$ is obtained.

$$K_j\left(L\right)=\sum_{p=1}^{n}\omega_p K_j\left(L_p\right) \tag{18}$$

Step 3: Determine Evaluation Level

Based on the membership degrees of the evaluation indicators calculated using the above formula, the application effect level for the criteria layer, indicator layer, and objective layer can be determined using the maximum membership degree principle. The formula is as follows:

$$K\left(N\right)=\max K_j\left(N\right) \tag{19}$$

6. Conclusions

This paper constructs an evaluation index system for new building industrialization projects and develops a project-level cloud-matter-element evaluation model using a combination weighting method that integrates ordinal relationship analysis and entropy weight methods. By analyzing and building an evaluation model for the application effects of intelligent construction technology, it provides effective guidance for the application of new building industrialization technologies.The transition from prefabricated buildings to intelligent construction, and from intelligent construction to new building industrialization, represents a deepening understanding of the principles of the construction industry. In the context of high-quality development, the evaluation standards and index system for new building industrialization projects need to align more closely with the requirements of high-quality development. Therefore, incorporating new concepts such as integrated design, intelligent construction, refined management, and management information technology as evaluation indicators for building industrialization reflects the new demands of the era.

Future research will focus on the following areas:

1. Research Perspective: While this study primarily evaluates the effects of intelligent building technologies during the construction phase, future research will extend to assess the application effects of these technologies during the decision, design, and post-operation stages, covering the entire lifecycle.

2. Evaluation Standards: Given that China has yet to fully establish a comprehensive evaluation standard system for intelligent buildings, future research will aim to compile the latest domestic and international policy documents related to intelligent building evaluation standards and work towards refining this evaluation system.

3. Indicator System: As the integration of information technology into new building industrialization becomes the industry's overall trend, future research will track new developments in informatization, intelligence, and high-quality development. This will involve continuously updating and adjusting the evaluation indicator system to align with national strategies and improve implementation conditions and methods.

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