



PROJECT COST CONTROL AND STANDARDIZED CONSTRUCTION  
MANAGEMENT OF A HEALTH TOURISM CENTER  
CONSTRUCTION PROJECT



A Thesis Submitted in Partial Fulfillment of the Requirements  
for Master of Engineering ENGINEERING MANAGEMENT  
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT

Silpakorn University

Academic Year 2024

Copyright of Silpakorn University



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาการจัดการงานวิศวกรรม แผน ก แบบ ก 2

ภาควิชาวิศวกรรมอุตสาหกรรมและการจัดการ

มหาวิทยาลัยศิลปากร

ปีการศึกษา 2567

ลิขสิทธิ์ของมหาวิทยาลัยศิลปากร

PROJECT COST CONTROL AND STANDARDIZED  
CONSTRUCTION MANAGEMENT OF A HEALTH  
TOURISM CENTER CONSTRUCTION PROJECT



By  
Mr. Lei KUN

A Thesis Submitted in Partial Fulfillment of the Requirements  
for Master of Engineering ENGINEERING MANAGEMENT  
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT  
Academic Year 2024  
Copyright of Silpakorn University

Title                   PROJECT COST CONTROL AND STANDARDIZED  
CONSTRUCTION MANAGEMENT OF A HEALTH  
TOURISM CENTER CONSTRUCTION PROJECT  
By                       Mr. Lei KUN  
Field of Study       ENGINEERING MANAGEMENT  
Advisor               Associate Professor Choosak Pornsing, Ph.D.

Faculty of Engineering and Industrial Technology, Silpakorn University in  
Partial Fulfillment of the Requirements for the Master of Engineering

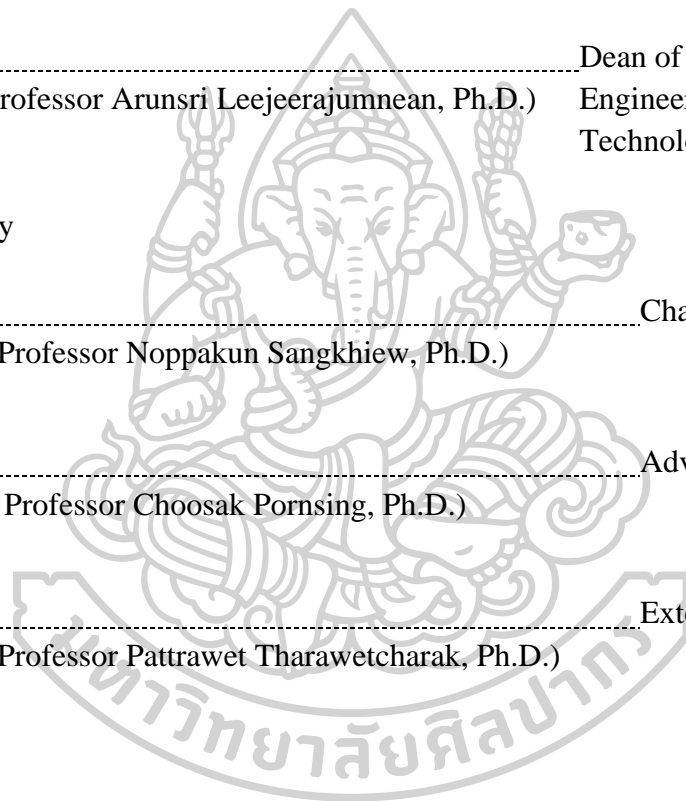
..... Dean of Faculty of  
(Assistant Professor Arunsri Leejeerajumnean, Ph.D.) Engineering and Industrial  
Technology

Approved by

..... Chair person  
(Assistant Professor Noppakun Sangkhiew, Ph.D.)

..... Advisor  
(Associate Professor Choosak Pornsing, Ph.D.)

..... External Examiner  
(Assistant Professor Patrawet Tharawetcharak, Ph.D.)



650920033 : Major ENGINEERING MANAGEMENT

Keyword : health tourism center, construction project cost control, construction standardization management, entropy weight method, normal cloud model, comprehensive evaluation model

Mr. Lei KUN : PROJECT COST CONTROL AND STANDARDIZED CONSTRUCTION MANAGEMENT OF A HEALTH TOURISM CENTER CONSTRUCTION PROJECT Thesis advisor : Associate Professor Choosak Pornsing, Ph.D.

This study aims to construct an integrated evaluation framework that combines the Entropy Weight Method and Normal Cloud Model to achieve scientific quantitative analysis of cost control and construction standardization management in the development of health tourism centers. The research begins by reviewing the historical progress and existing studies on construction project cost control and construction standardization management from both international and Chinese perspectives. Based on this, a multi-level indicator system has been established, encompassing six dimensions-construction costs, construction progress, construction safety, construction quality, energy management, and environmental impact-comprising a total of 22 specific evaluation indicators. This system is designed to provide a systematic assessment standard for the construction standardization of health tourism centers.

The primary academic contributions of this study are twofold: First, from a technical and economic perspective, a multi-level indicator system influencing construction project cost control has been established, ensuring a high degree of alignment between the evaluation indicators and actual engineering design requirements. Second, the study delves into the multi-dimensional factors affecting construction standardization management and constructs a construction standardization evaluation indicator system closely aligned with practical operations. Additionally, the research innovatively applies the mathematical theories of the Entropy Weight Method and Normal Cloud Model to project management practices, offering new insights and methodological support for addressing engineering management challenges in similar construction projects.

Despite the use of diverse methods, including literature review, entropy evaluation, cloud theory-based assessment, comprehensive evaluation, and empirical analysis, the study's limitation lies in its specific case study, which is based on data from the health tourism center construction project at the Dongfeng Yun International Health and Tourism Resort in Mile City, Yunnan Province, China. Therefore, the generalizability of the findings requires further validation. To enhance the applicability of the research, future studies could consider cross-regional and cross-project comparative analyses to strengthen the external validity of the conclusions.

On the methodological front, this study provides a detailed exposition of the theoretical foundation and operational procedures of the entropy evaluation method, including the construction of uncertainty indicator measurement models, data standardization, determination of indicator peaks, allocation of comprehensive weights, selection of confidence level  $\lambda$ , and calculation of comprehensive evaluation values. The study also systematically introduces the theoretical framework, numerical characteristics, generation algorithms, and 3En rules of the normal cloud model, providing a robust theoretical foundation for the effective application of the Entropy Weight Method-Normal Cloud Model.

Through empirical research, the study conducted an in-depth analysis and evaluation of the construction proposals of four construction companies involved in the aforementioned health tourism center project. The results confirmed the effectiveness and practicality of the integrated evaluation model. The findings demonstrate that the combination of the Entropy Weight Method and Normal Cloud Model can significantly enhance the precision and efficiency of project cost control and construction standardization management. This provides scientific evidence for decision-makers, aiding in the optimization of resource allocation, cost reduction, quality improvement, technological innovation, user rights protection, and the promotion of green and sustainable development. This research not only enriches the theoretical framework of construction project management but also offers a powerful tool for practical engineering management.

## ACKNOWLEDGEMENTS

Upon completing this thesis, I am filled with profound gratitude. Here, I would like to express my deepest thanks to all those who have supported, encouraged, and assisted me throughout my academic journey.

First and foremost, I would like to extend my heartfelt gratitude to my supervisor. With his profound academic expertise and rigorous research attitude, he has provided invaluable guidance for my research. From selecting the topic, developing research methods, analyzing data, to the final writing, my supervisor has consistently offered patient and detailed advice and inspiration, helping me refine my thesis. His teachings and support are an indispensable part of my academic journey.

I am also grateful to all my teachers and fellow students, who have provided selfless help and support during my academic exploration and daily studies. Discussions and exchanges with them have greatly enriched my academic life and sparked many new ideas and inspirations. I owe a special debt of gratitude to my family, who have been my strongest support system. Throughout my research, they have provided unconditional love and support, creating a warm and comforting haven for me. Their encouragement and understanding have been instrumental in helping me overcome difficulties and setbacks, enabling me to continue moving forward. Without their support, I would not have been able to complete this thesis.

I would also like to thank all the individuals who provided case study materials. Their valuable data and insights have added depth and breadth to the empirical research in my thesis. I am deeply grateful for their participation, which has been crucial to the success of my research.

Finally, I thank Silpakorn University for providing an excellent academic environment and resources, which have allowed me to delve deeply into my area of interest and grow both personally and professionally.

In the future, I will carry this sense of gratitude forward as I continue to explore and advance in my academic pursuits, hoping to achieve more significant results to repay those who have supported and cared for me. Once again, thank you to everyone who has helped and supported me on my academic journey. Your contributions have made my research path bright and hopeful.

Lei KUN

# TABLE OF CONTENTS

	<b>Page</b>
ABSTRACT.....	D
ACKNOWLEDGEMENTS.....	E
TABLE OF CONTENTS.....	F
List of tables.....	I
List of figures.....	K
CHAPTER 1 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Research Objectives.....	3
1.3 Research Contributions.....	3
1.4 Scopes and Limitations.....	4
1.5 Abbreviations.....	4
CHAPTER 2 LITERATURE REVIEW.....	5
2.1 Progress of construction project cost control.....	5
2.1.1 History of engineering cost management of construction project.....	5
2.1.2 International research on cost management of construction projects.....	6
2.1.3 Research on cost management of construction project in China.....	8
2.2 Progress of construction standardization.....	13
2.2.1 International research on construction standardization of project.....	13
2.2.2 Research on construction standardization of project in China.....	15
2.2.3 Realistic situation of construction standardization of project in China....	18
2.3 Related works.....	19
CHAPTER 3 RESEARCH METHODOLOGY.....	23

3.1 Entropy weight evaluation method .....	23
3.1.1 Formation of a decision matrix .....	24
3.1.2 Standardized decision matrixes .....	24
3.1.3 Characteristic weight of the evaluation program.....	25
3.1.4 Difference coefficient of evaluation indicators .....	25
3.1.5 Entropy weight of evaluation indicators .....	26
3.2 Entropy weight comprehensive evaluation method.....	26
3.2.1 Constructing a measure model with unascertained indicators .....	26
3.2.2 Data normalization .....	27
3.2.3 Calculation of indicator peaks.....	27
3.2.4 Comprehensive weights of evaluation program indicators .....	27
3.2.5 Determination of Confidence Level $\lambda$ .....	28
3.2.6 Calculation of Comprehensive Evaluation Value .....	28
3.3 Cloud model evaluation method.....	29
3.3.1 Fundamentals of cloud theory .....	29
3.3.2 Digital characteristics of clouds .....	29
3.3.3 Cloud model generator.....	30
3.3.4 The 3En rule for normal clouds.....	33
3.4 Research procedure and scheduling.....	34
<b>CHAPTER 4 ACONSTRUCTION PROJECT COST EVALUATION OF A</b>	
<b>HEALTH TOURISM CENTER.....</b>	<b>36</b>
4.1 Concept and characteristics of civil building projects.....	36
4.2 Analysis of construction cost composition and influencing factors .....	38
4.2.1 Concept of construction project cost .....	38
4.2.2 Composition of construction project costs .....	38

4.2.3 Construction project cost control .....	40
4.3 Establishment of project cost evaluation index system .....	41
4.4 Case calculation and analysis .....	50
4.4.1 Project overview .....	50
4.4.2 Evaluation index labels and measured value of project plans .....	51
4.4.3 Calculation of entropy weight values for evaluation indicators .....	54
4.4.4 Entropy-cloud comprehensive evaluation of project costs .....	56
4.4.5 Grade cloud diagrams of evaluation indicators .....	59
4.4.6 Membership Degree Matrix .....	61
4.4.7 Analysis of cloud model comprehensive evaluation results .....	63
<b>CHAPTER 5 EVALUATION OF STANDARDIZED CONSTRUCTION FOR A HEALTH TOURISM CENTERS .....</b>	<b>65</b>
5.1 Analysis of standardized construction and influencing factors .....	65
5.2 Establishment of Evaluation Index System for Construction Standardization ..	68
5.3 Case calculation and analysis .....	70
5.3.1 Evaluation index labels and measured value of construction proposal ...	70
5.3.2 Calculation of entropy weights for evaluation indicators .....	73
5.3.3 Multi-indicator comprehensive evaluation of construction proposal .....	75
<b>REFERENCES .....</b>	<b>79</b>
<b>VITA .....</b>	<b>82</b>

## List of tables

	<b>Page</b>
Table 3.1 Research schedule. ....	35
Table 4.1 Meaning and ranking of building engineering cost evaluation indicators...45	45
Table 4.2 Labels for the construction cost evaluation index system in the case analysis .....	51
Table 4.3 Measured values of indicators in the case .....	52
Table 4.4 Results of the standardization of indicator data in the case study .....	53
Table 4.5 Results of the characteristic weight of indicators in the case study.....	54
Table 4.6 Results of the parameters for 21 indicators in the case study .....	55
Table 4.7 Cloud Digital Characteristics of Hierarchical Evaluation Indicators .....	56
Table 4.8 Calculation results of the membership degree matrix for evaluation indicators.....	61
Table 4.9 Evaluation grades of each project proposal .....	64
Table 5.1 Evaluation index system for construction standardization .....	69
Table 5.2 Grading of construction standardization evaluation indicators .....	70
Table 5.3 Labels for construction standardization evaluation index system in the case analysis.....	70
Table 5.4 Measured values of indicators in the case .....	71
Table 5.5 Standardization results of indicators in the case study .....	72
Table 5.6 Calculation results of characteristic weights for construction standardization evaluation indicators in the case study.....	73
Table 5.7 Results of the parameters for 22 indicators in the case study .....	74
Table 5.8 Entropy weights of the 6 first-level indicators for construction standardization in the case study.....	74

Table 5.9 Calculation results of peak values for construction standardization evaluation indicators in the case study.....	76
Table 5.10 Comprehensive evaluation results for construction standardization in the case study.....	77



## List of figures

	<b>Page</b>
Figure 2.1 Annual publication trend of Chinese literature on construction cost management and its influencing factor.....	9
Figure 2.2 Annual publication trend of Chinese literature on construction standardization.....	16
Figure 3.1 Schematic diagram of forward cloud generator.....	31
Figure 3.2 Reverse Cloud Generator.....	32
Figure 3.3 The $3E_n$ rule for normal clouds.....	33
Figure 3.4 Research process flowchart .....	34
Figure 4.1 The composition of the total investment .....	40
Figure 4.2 Evaluation indicator system for project costs.....	43
Figure 4.3 Partial Bird's-Eye View of Dongfeng Yun International Health Tourism Resort.....	50
Figure 4.4 Distant Bird's-Eye View of the Health Tourism Center.....	51
Figure 4.5 Typical second-level indicator cloud diagrams for health tourism center project cost evaluation based on entropy-cloud model.....	60
Figure 4.6 Cloud model diagrams for 4 project proposal .....	64
Figure 5.1 Evaluation index system for construction standardization.....	68

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Background**

First of all, from the perspective of investors, the construction cost of a construction project refers to the expected expenditure or actual expenditure of all fixed asset investment costs for the construction of a project. Investors choose an investment project in order to obtain the expected benefits, and need to achieve this purpose through a series of activities such as evaluation, decision-making, design, bidding, construction, and completion acceptance. All the expenses paid in investment activities form fixed assets, and these expenses form the project cost. Therefore, the project cost is equal to the investment in fixed assets of the construction project. Construction project cost is not only an important basis for project decision-making, but also an effective means to specify investment plans and control investment, and an important index to evaluate investment effects. The effective control of engineering cost is based on the optimization of construction scheme, design scheme and construction scheme, using certain scientific and effective methods and measures at each stage of the construction procedure, to control the cost of construction project cost within a reasonable range and within the approved cost limit, and to correct its deviation at any time, so as to ensure the realization of the project cost management objectives. In other words, project cost control ensures the rational use of project funds and the maximization of investment benefits. It runs through the entire process of the construction project and is valued by investors and construction parties.

The standardization of construction project is an integral part of the standardization of engineering construction. Components, fittings, spare parts, general buildings, structures, public facilities, etc. of various engineering

construction should implement standardized design and construction as long as conditions permit. Making standardization of construction projects mainly includes standards or indicators in terms of construction scale, floor area, process equipment, construction standards, supporting projects, and labor quotas. Widely adopting construction standardization is conducive to speeding up the construction progress and reducing the project cost. The standardization level is an important basis for compiling, evaluating, and approving project feasibility study reports, and it is also an objective criterion for measuring whether the project cost is reasonable and supervising and inspecting project construction. Whether the standardization of construction project can play a role in controlling project cost and guiding construction investment depends on the rationality of the standardization level.

Currently, research on comprehensive engineering cost control and standardized construction management for construction projects in China is largely confined to conceptual discussions, theoretical explorations, and experience summaries. There is a lack of quantitative research that originates from mathematical principles, and the development of this field is still in its infancy. This study takes the current research status as its foundation and aims to innovate. By combining entropy weight and normal cloud models, which propose a comprehensive evaluation index system and model that can be applied to cost control and standardized construction for construction projects. Furthermore, a case study will be conducted on the construction of a health tourism center, testing the effectiveness of the evaluation system and model, and exploring their practical value in actual engineering management.

## 1.2 Research Objectives

1 . To construct a coupled evaluation model of entropy weight and normal cloud, and carry out the comprehensive transformation, processing and calculation of qualitative and quantitative data by considering the technical-economic-environmental impact characteristics of the evaluation object.

2. Taking the construction project of Maitreya Health Center in China as an example, to make a comprehensive evaluation and comparative analysis of the project construction schemes and standardized construction schemes in the bidding stage, and further verifies the effectiveness of the comprehensive evaluation model and evaluation method established in this research.

## 1.3 Research Contributions

1 . The multi-level indexes that affect the construction project cost are constructed, and the evaluation index system of construction project cost is established from the technical and economic point of view, which is in line with the actual engineering design needs.

2 . The multi-level indicators affecting the standardized construction of construction projects are explored. From the perspectives of construction cost, construction schedule, construction safety, construction quality, energy saving and environment, an evaluation index system for standardized construction of construction projects in line with the actual engineering design needs is established.

3. This study shows how to apply the mathematical theory of entropy weight and normal cloud coupling evaluation model to the actual project cost and standardized construction management, which is also helpful to solve the engineering problems of other construction projects.

#### 1.4 Scopes and Limitations

i. This study adopts literature research method, entropy weight method, evaluation method based on cloud theory, comprehensive evaluation method and empirical research method; however, the most important is the quantitative research based on entropy weight-cloud model, which tries to propose a practical tool, while the empirical research is to collect data from cases.

ii. The survey research has a specific manner. Thus, the result from the case study cannot guarantee other cases in general.

iii. The data of the empirical study was collected from the case of Health Tourism Center in Mile City, Yunnan Province, China.

iv. This study neglects uncertainty of variables.

#### 1.5 Abbreviations

**CNKI** China National Knowledge Infrastructure

**ISO** International Organization for Standardization

**OSHA** United States Occupational Safety and Health Administration

**TCM** Total Cost Management

**VM** Value Management

**WPCM** Whole Process Cost Management

## **CHAPTER 2**

### **LITERATURE REVIEW**

This chapter reviews the development history of construction project cost management in section 2.1 and provides an overview of the research on cost control and influencing factors from both international and Chinese perspectives. In section 2.2, the research on construction project standardization is summarized from international and Chinese viewpoints. The current status of construction project standardization in China is analyzed at the national, enterprise, and project levels, highlighting the existing problems. To conduct more effective quantitative evaluation research on construction project cost control and standardization, section 2.3 of this chapter focuses on the entropy weight-cloud model evaluation method and introduces its typical applications in related fields, laying the foundation for the feasibility of this study.

#### **2.1 Progress of construction project cost control**

##### **2.1.1 History of engineering cost management of construction project**

- Britain began to refine the division of labor in project management in 16<sup>th</sup> century, and the specialized occupation of project cost determination and control was born in Britain. The Royal Institute of Chartered Surveyors was established in Britain, which marked the formal birth of the modern engineering cost management specialty in 19<sup>th</sup> century.

- The principles of economics began to be applied to the field of engineering cost in the 1930s.

- There was a period of great development in the research of engineering cost management from theory to method, to the cultivation of professionals and the promotion of management practice in the 1950s. The

developed countries have established their own engineering cost management associations.

- The International Federation of Cost Engineering was founded in the 1970s, which marked the comprehensive development of the theory and method of project cost management.

- China put forward Whole Process Cost Management (WPCM), requiring that the calculation and control of construction project cost must start from the establishment of the whole process of management activities, from the preliminary work to the completion of the project in the 1980s and 1990s. During the similar period, American engineering cost management scholars put forward Total Cost Management (TCM), which involves the concept and theory of strategic asset management and engineering cost management of engineering projects.

- Since the 21st century, developed countries have formed a relatively perfect market system of project cost control, which is usually determined by both sides of the project construction, in which the government plays an indirect regulatory role to ensure the fairness of both sides in the transaction stage of the project construction. Developed countries have formed a unique project cost management model. Although the whole process control of project cost started late in China, it has gradually formed an innovative research model on the basis of the concept of whole process cost control.

### **2.1.2 International research on cost management of construction projects**

With the development of advanced management theories and methods, project cost management has gradually absorbed many theories and methods from other fields, and scholars from all over the world have made more in-depth research on project cost management and made rich research progress. In the progress of

long-term project cost management research in developed countries, the research on the influencing factors of project cost is endless.

Yehiel Rosenfeld (2014) used the expand-focus principle and event analysis method to summarize and analyze 15 causes of project cost overruns, and collected the opinions of 200 local construction practitioners through cross-sectional surveys, and ranked the 15 causes. The top three causes of project cost overruns are found out, namely, the hasty decision of bidding documents, the frequent changes of owners' requirements or regulations, and the low-price bidding.

Peter Smith (2014) reviewed the literature related to global construction project cost management and explored the global issues and challenges faced by the cost management profession. The article is based on research into global project cost management issues and, through collaborative research with multiple professional cost management associations, established standards for the global cost management profession. It clarified the necessity for the development of certified project cost management and proposed a series of recommendations and strategies.

Peter Smith (2016) further investigated the professional standards established by countries around the world and professional associations for quantity surveying, cost engineering, and project control. He pointed out that compared to other professional disciplines such as engineers and architects, professions like quantity surveying, cost engineering, and project control are not highly recognized in society, which poses many challenges in enhancing project value. He then discussed the benefits of developing an overall strategy to produce global standards/solutions regarding the lack of global standards for these professions and finally provided recommendations for formulating these specific global standards.

In order to solve the problem of cost overruns in the construction of residential projects, Laila M. Khodeir et al. (2019) proposed to use the Value Management (VM) method to control cost overruns, and applied it to residential

projects in Egypt. The findings highlight the added value of applying the VM methodology and observe that the approach can achieve savings of 15-40% of the total project cost. This shows that the VM method is effective in controlling the cost overruns of residential construction projects.

Akintola Akintoye (2000) conducted a comparative study on 84 UK contractors, categorized into very small, small, medium, and large firms, using a postal questionnaire survey to understand the factors influencing contractors' cost estimation practices. The research analysis indicated that the main factors affecting cost estimation practices include the complexity of the project, the scale and scope of construction, market conditions, construction methods, site constraints, the client's financial status, the feasibility of the project, and project location. The study emphasized that in cost estimation practice, construction companies consider factors that are not merely technical processes but also those related to the successful execution of the project.

### **2.1.3 Research on cost management of construction project in China**

Compared with developed countries, the research in the field of project cost control in China started relatively late. The economic system in China's social development belongs to the planned economy. As for the cost management of construction projects, it also focuses on the planned cost control in the construction stage. For the detailed cost control in the implementation stage of the specific project, the degree of attention is not high. With the open development of the domestic economy, the whole process of cost control has been paid more and more attention.

Enter the title including construction cost management or construction cost influencing factors in CNKI (China National Knowledge Infrastructure) for literature search, and a total of 5311 results are retrieved, and the trend chart is shown in Figure 2.1. According to the number of published papers, the research

history of project cost management and influencing factors in China can be divided into three stages, namely, the initial stage, the development stage and the mature stage. In the initial and development stages, the research focus is mainly on the influencing factors of project cost in each stage of project construction, but also on the decision-making stage, design stage and construction stage. In the mature stage, some scholars use quantitative analysis to study the influencing factors of project cost.

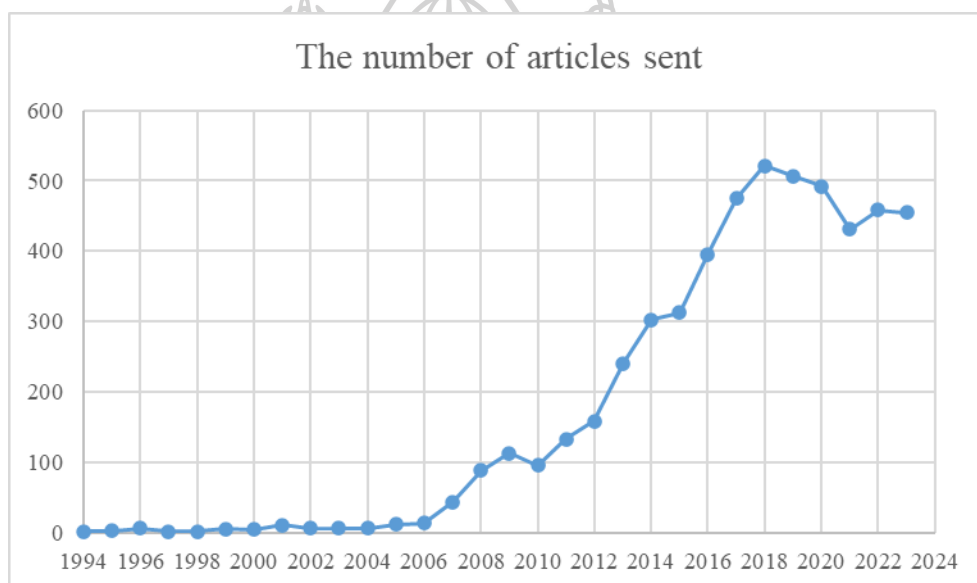


Figure 2.1 Annual publication trend of Chinese literature on construction cost management and its influencing factor.

The above data show that in 1994, the number of documents published in the whole year was 2, in 2009, the number of documents published in the year exceeded 100, and reached its peak in 2018, with 521 documents published annually. From the above information, we can see that in recent years, more and more Chinese scholars have begun to study the construction cost management,

explore its influencing factors, and constantly enrich and develop the theory and methods of the influencing factors of construction cost.

Zhang Shilian et al. (2010) believe that the design stage is the key stage of project construction, and the selection of design scheme directly affects building energy conservation and project cost. The author divides the factors affecting the project cost in the design stage into six first-level factors, namely, the factors of designers, the maturity of building energy-saving technology, the implementation of building energy-saving policies, the requirements of project for building energy-saving, and the external factors of consumers and markets. The six primary factors include different secondary factors, among which the factor of designers includes three secondary factors, the maturity of building energy-saving technology includes three secondary factors, the implementation of building energy-saving policies includes three secondary factors, and the requirements of engineering projects for building energy-saving includes five secondary factors. Consumer and market external factors contain three and two secondary factors respectively.

Li Wei (2010) believed that construction project cost control runs through all stages of the project construction. People often pay more attention to the project investment decision-making phase and the design phase, thereby neglecting the cost management during the construction phase. The construction phase is characterized by strong operability, complex situations, and potential vulnerabilities. As a result, it is more likely to encounter lax cost control management, higher costs, and budget overruns in construction projects. Based on this, the author argues that cost management during the construction phase is a crucial stage for reducing project costs, improving quality, and increasing benefits. The author also believes that the formulation of construction contracts, the compilation of construction organization and design, the selection of materials and equipment, as well as design

changes and on-site approvals are important factors that influence cost management during the construction phase.

Kong Fanwen et al. (2018) believed that the cost control in the construction stage is easy to be neglected, which will lead to the project funds cannot be rationally utilized, resulting in unnecessary economic losses. The cost management in the construction stage focuses on three aspects: the control of the cost of manpower, materials and machinery; the control of the construction contract management; the control of signing on the construction site of the construction project. The article also introduces the problems of cost control in the construction stage and puts forward the countermeasures to these problems.

With the progress of science and technology, the research on the influencing factors of project cost is becoming more and more mature, and the problems in the development of construction industry are becoming more and more complex, so the qualitative analysis of the influencing factors of project cost cannot meet the needs of practice. It has become a new research direction for scholars to use mathematical models to quantitatively analyze the influencing factors of project cost and properly combine qualitative analysis with quantitative analysis.

According to Ying-Mei Cheng (2014), project cost overruns are a common problem in the construction industry. The Delphi method and Takaujiro Kawakita method are used to consolidate the experts' opinions, identify and rank the key factors affecting the project cost. The analysis shows that there are 16 main factors affecting the project cost, among which the clear definition of the project scope in the contract and cost control are the main determinants of cost overruns.

Zhang Shengquan (2020) integrated modern information technology into the cost estimation, engineering design, construction site scheduling and operation management of prefabricated buildings, and controls and optimizes the project cost of prefabricated buildings through the information management of the

whole life cycle. Based on the application characteristics of BP neural network in project cost prediction, combined with the characteristics of prefabricated buildings, a BP neural network investment estimation model based on longicorn search algorithm was proposed, and 15 groups of case data were collected for comparative experimental analysis by using the model. The results showed that the cost prediction accuracy of BAS-BP investment estimation model is better than that of the traditional investment estimation method, and the prediction results are more stable, which is more suitable for the investment estimation of prefabricated buildings and helpful for the early control of project cost.

Yuan Zheng (2023) identified the key factors affecting engineering cost through literature analysis and Delphi method, and established a cost estimation indicator system based on the cost-influencing factors at the conceptual stage. Then, the principles and calculation methods of BP neural network were analyzed, and a calculation topology structure and prediction model were established, with the input of determined influencing factors, to establish a functional relationship between the influencing factors and single-item cost. Finally, the accuracy of the calculation results was improved through sample training, and the optimal cost management engineering cost estimation model was verified through case studies. The model can shorten the analysis time and scheme adjustment time in the early stages of a project, obtain the best solution, and ensure project cost control and profit realization.

In recent years, many scholars have gradually come to realize that, in studying the factors influencing engineering cost, it is necessary to combine qualitative analysis with quantitative analysis. Although scholars have already attempted to conduct integrated qualitative and quantitative analysis, and have achieved certain results, the current research findings still tend to focus on qualitative research. Given the diversity and complexity of engineering cost-

influencing factors, relying solely on qualitative research cannot meet the needs of project management. Therefore, it is imperative to strengthen research on engineering cost-influencing factors by integrating qualitative and quantitative analysis.

## **2.2 Progress of construction standardization**

### **2.2.1 International research on construction standardization of project**

International research on construction standardization has been conducted early on, with most studies focusing on single-dimensional research in areas such as safety standardization, quality standardization, management standardization, and product standardization for building materials, among others.

In the 1960s and 1970s, scholars had already recognized the crucial importance of construction safety production and began to conduct in-depth research on construction standardization theory. Early research emphasized the significance of safety systems and technical standards in preventing safety accidents, and systematically explored the role of laws and technologies in formulating safety systems. As early as 1971, the United States issued safety standards for construction machinery and equipment, marking a shift from theoretical research to practical application of construction standardization.

Matthew R. Hallowell et.al (2009) conducted an in-depth and detailed study, innovatively using the Delphi method to quantitatively analyze the prioritization of safety process control elements. He pointed out that the encouragement and support from senior management are crucial for the implementation of safety standardization.

Joe M. Wilson Jr. et.al (2000) examined how to implement safety management models in construction companies, covering internal control of safety policies, programs, and practices, as well as the challenges and strategies

encountered during implementation. First, the author emphasized that safety is a dynamic process that requires continuous monitoring and adjustment to achieve safety goals, i.e., implementing standardized safety processes. Second, the article presented a case study on how to effectively handle issues that arise during construction by leveraging accumulated experience. Specifically, it introduced a method of having different trade personnel rotate performing safety checks to share safety responsibilities, reflecting a strategy that utilizes experience and adaptability to solve problems. Additionally, the article mentioned the specific requirements of the United States Occupational Safety and Health Administration (OSHA) for workplace safety and the importance of considering safety in the design phase, highlighting that these are essential standardized processes in construction management.

T. Michael Toole et.al (2002) summarized the essential content of OSHA and safety standards relevant to professional engineers. The article provides a general description of OSHA construction standards, an overview of OSHA's multi-employer policy, and a summary of safety standards related to professional engineers. Based on incident analysis, the author improved work standard operating procedures to achieve the goal of reducing fatalities on construction sites.

The origin of quality standardization abroad dates back to the early years. In 1941, the US federal government issued the first quality standard document, "Statistical Methods for Quality Management". Subsequently, in 1947, the International Organization for Standardization (ISO) was established, and quality standardization work flourished in developed countries. Countries such as France, the UK, and Japan actively developed their own national quality standardization guidelines and implementation work, and academic research on quality standardization was also thriving.

Summarizing the key research findings include:

- Quality standards are the core elements of enterprise products, involving personnel, products, and users in a system engineering approach.

- The implementation of quality standardization emphasizes the establishment of a well-organized quality standardization management system and quality standardization management manual.

- Quality judgment is a behavior approach that relies on facts and data as the basis, with the quality standards established as a premise.

- The concept of lean management is also a vital part of quality standardization management.

### **2.2.2 Research on construction standardization of project in China**

China's research and implementation of quality and safety standardization management began relatively early. However, the model primarily relies on government initiatives with supplementary academic research. Typically, relevant government departments initiate projects, research institutions conduct studies, and implementation occurs through administrative legislation. In 1956, China promulgated the "Building Construction Safety Technical Regulations," which was an important milestone in the development of construction standardization management in China. After the reform and opening up, China creatively proposed the concept of Chinese-style construction standardization management and successively promulgated a series of administrative laws to regulate the implementation of construction standardization through legislation.

In CNKI, searching for literature with the title containing "Construction Standardization" yields 1,125 results, as shown in Figure 2.2. Based on the number of published articles, the research history of construction standardization in China can be divided into three stages: the beginning stage, the development stage, and the mature stage. The data shows that 5 articles were published in 1981, and the number

of published articles exceeded 100 in 2017. In 2018, the number of published articles reached its peak, with 115 articles published in that year.

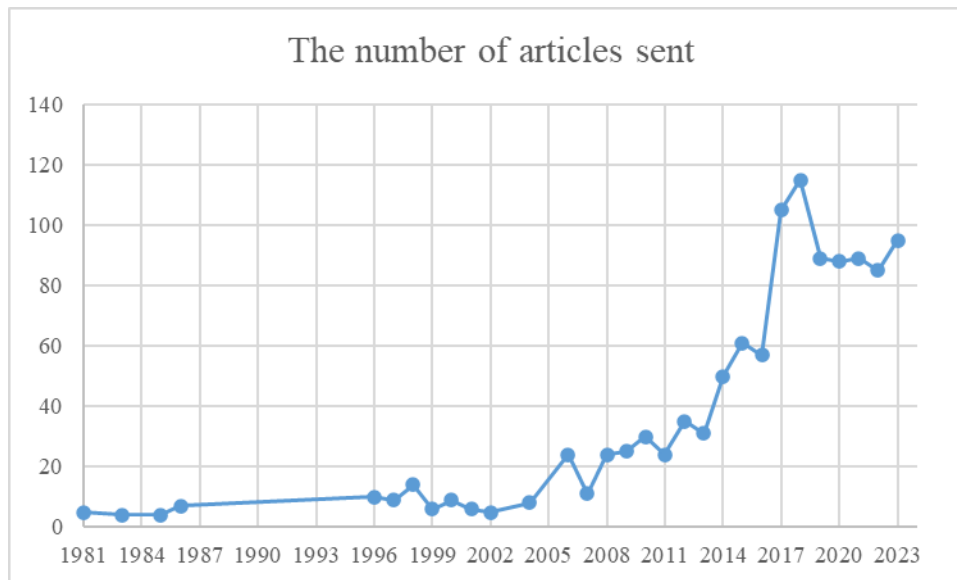


Figure 2.2 Annual publication trend of Chinese literature on construction standardization.

Chinese scholars mainly focus their research on construction quality and safety standardization management, with an emphasis on standardization inputs and outputs, quality and safety standardization technology, construction standardization organization and management, safety risk research and countermeasures, etc. Researchers tend to use or borrow advanced standardization management concepts from abroad to address quality, safety, or cost issues in engineering construction and propose their thoughts or ideas, creatively seeking solutions or summarizing empirical experiences.

Qu Lixiang (2008) proposes that by relying on regulatory norms, project standardization can be achieved. During project management, whether it's operational procedures, construction plans, or important regulations, they should be gradually formed and standardized, and widely applied in engineering projects.

This effective management method can be widely applied in practical scenarios, continuously expanding its scope of application. Yang Xiaolin et al. (2011) argued that engineering project management is a gradual process rather than a one-time effort. Effective project management requires ensuring seamless integration of all phases, minimizing potential defects to achieve the desired outcomes. Standardization of project management is not only a legal requirement but also an inherent need for building a professional implementation system. Chen Yongqiang et al. (2010) highlighted that the concept of standardization was first introduced by foreign scholars in the early 20th century and has gradually evolved into standardized procedures and operation methods, gaining widespread attention. During the implementation phase of engineering construction projects, standardization management can effectively control project quality, improve construction efficiency, and manage costs. With economic development and the increasing number of construction projects, enhancing project management quality requires a foundation of strengthened standardization management in engineering projects. Chen Wei (2018) pointed out that under the context of rapid development in the construction industry, strengthening management is a prerequisite for ensuring project quality. Implementing standardized management for engineering projects is the key to achieving healthy and orderly development for construction enterprises. Yu Tianbo (2020) briefly explains the concept of standardized management and then elaborates on how to implement standardized management in construction project management. Utilizing the advantages of standardized management can achieve quality improvement and efficiency enhancement in construction project management.

### **2.2.3 Realistic situation of construction standardization of project in China**

#### **(1) National level**

The Chinese government actively promotes the standardization of construction processes. Early efforts focused on standardizing construction products, such as the widespread adoption of prefabricated components. With industry development, the focus shifted to construction technology standardization. Unified construction codes were abolished and replaced by construction technical specifications, acceptance standards, and standard atlases, which are continuously updated. To regulate project management for construction enterprises, the government issued the "Technical Standardization Management Specification for Engineering Construction of Construction Enterprises", providing enterprises with clear goals, work approaches, and guiding principles, thus promoting the high-quality development of the construction industry.

#### **(2) Enterprise level**

Some construction companies still adopt extensive management methods, hindering the progress of construction standardization. Effective standardization requires expertise in both management and technology, necessitating skilled professionals who are currently lacking in the industry. High market competition and workforce mobility discourage companies from investing in standardization training. Consequently, the construction industry has yet to fully establish standardized concepts and work methods, demanding urgent improvement.

#### **(3) Project department level**

Construction enterprises manage project departments in two modes: direct and indirect management. In direct management, the enterprise has direct power over project department personnel, material procurement, engineering settlement, and project construction must follow enterprise instructions. In indirect

management, also known as "contracting", the enterprise only charges a management fee, conducts periodic safety and quality inspections, and does not interfere with project department operations. The contracting mode results in project departments lacking standardized management motivation. Project managers often pursue short-term benefits, ignoring the quality, safety, and reputation benefits of standardized construction, prioritizing construction progress and cost, neglecting construction quality, technical innovation, and safety management. This mode results in stagnating construction quality and safety management levels, frequent safety accidents, and damaged project reputation.

### **2.3 Related works**

Currently, research that integrates the mathematical methods of entropy weight and normal cloud model to construct a comprehensive evaluation index system and evaluation model for construction project cost control and standardized construction management remains scarce. To explore the application potential of this method in the present study, this section focuses on introducing typical application cases of the entropy weight-cloud model evaluation method in related fields.

Li Jiaoli (2018) conducted an evaluation study on the sustainability of green buildings based on the AHP-entropy weight method and cloud model. This paper presents a new hybrid sustainable evaluation method based on AHP-entropy weight method and cloud model. This method combines AHP method and entropy weight method to determine the index weight, and makes full use of their respective advantages. At the same time, it exerts the advantages of cloud model in the transformation between qualitative evaluation and quantitative expression, and in reflecting fuzziness and randomness. In order to verify the feasibility of this method,

an empirical study is carried out with the "Man Ting Chun" green building project in Nanchang.

Zhang Mengqi (2020) carried out research on the evaluation of Qingdao's healthy city construction level based on the entropy weight-cloud model. Firstly, 24 initial indicators are selected according to the actual development and construction of healthy cities in Qingdao, and 20 evaluation indicators that have a greater impact on healthy cities are determined by distributing questionnaires and analyzing the results, so as to construct a healthy city construction level evaluation index system including five dimensions of healthy environment, healthy population, healthy society, healthy service, and healthy industry. The evaluation model of healthy city construction based on entropy weight-cloud model is constructed, and the algorithm simulation is given to describe the average value of each index evaluation and the digital characteristics of the cloud model. Then, empirical research is carried out on the construction of healthy cities in Qingdao, including: dynamic evaluation of the development and construction level of healthy cities in Qingdao from 2008 to 2017, and comparative evaluation of 7 healthy city demonstration cities in Qingdao and sub-provincial cities.

Fang Chengkuan et al. (2021) carried out a safety risk assessment of prefabricated building construction based on the cloud model-entropy weight method. In order to reduce the incidence of prefabricated building construction accidents, the risk assessment index and model of prefabricated building construction safety are studied. According to the construction characteristics of prefabricated building, accident inducements, relevant specifications and research papers, a model of prefabricated building construction safety risk assessment based on cloud model-entropy weight method is constructed. Using cloud model, the fuzziness and randomness of risk assessment data are effectively considered, and then using entropy weight method, the weight coefficients of evaluation indicators

are given, which effectively avoids the subjectivity of expert weighting. The model is applied to an engineering example and has achieved good results. The research results show that the risk level assessment results of the model are consistent with those of the site risk level, which proves that the model can objectively and accurately assess the risk level of prefabricated building construction.

Lin Guichao (2022) carried out research on building construction safety evaluation based on the AHP-entropy weight-cloud model. On the basis of practical cases, the evaluation index system of influencing factors of construction safety is established. On this basis, the cloud model of construction safety evaluation is constructed, and the construction safety of K project in a city is evaluated as an example. The results show that the comprehensive evaluation of the project is medium risk, system factors are low risk, human factors are high risk, material and equipment factors are medium risk, organization and management factors are high risk, and environmental factors are low risk.

Fu Qingming (2023) conducted research on the performance evaluation of green behavior of papermaking enterprises based on the anti-entropy weight-cloud model. Aiming at the green behavior performance of papermaking enterprises, a comprehensive multi-level green behavior performance evaluation index system is established, and the anti-entropy weight theory is used to calculate the weight of the evaluation index. Rough number theory is used to preprocess evaluation information to improve the uncertainty and fuzziness of evaluation information in the process of evaluation and decision-making. The green behavior performance evaluation model of papermaking enterprises is constructed by cloud model. The quantitative and qualitative indicators are transformed by positive cloud model and reverse cloud model to reduce the uncertainty and fuzziness in the evaluation process, improve the accuracy of evaluation, and make the evaluation results more intuitive and closer to the actual situation. The final green behavior performance evaluation of

papermaking enterprises is obtained by drawing standard cloud images and comparing the final evaluation cloud images. The application of the performance evaluation index system is analyzed by an example, which verifies the scientific, rationality and effectiveness of the proposed method, and puts forward pertinent suggestions for the green behavior performance optimization of papermaking enterprises.

Kong Haixia (2023) studied the quality evaluation of building engineering survey based on the AHP-entropy weight-cloud model. Based on the AHP-entropy weight-cloud model, the survey quality evaluation of K construction project is carried out. It is concluded that the overall evaluation result of the survey quality risk of this project is medium risk, the personnel factor is evaluated as high risk, the measurement equipment factor, measurement method factor, and measurement environment factor are evaluated as medium risk, and the personnel factor is the focus of K project. It can provide a new method for the survey quality evaluation of construction project.



## **CHAPTER 3**

### **RESEARCH METHODOLOGY**

This chapter aims to construct a comprehensive evaluation method based on the entropy weight-cloud model to assess the influencing factors of construction project cost control and standardized construction management. The evaluation method consists of two main steps: first, the entropy weight method is employed to calculate the impact of each indicator on cost control or standardized construction, quantifying the importance of the indicators; second, through the membership degree model, the comprehensive evaluation value of each indicator is gradually calculated, serving as a basis for judging and evaluating the influencing factors of the cost control and standardized construction process.

This chapter only provides the methodology framework of the evaluation method. The specific analysis of construction cost influencing factors, the construction of the evaluation index system, the analysis of standardized construction influencing factors, and the construction of the evaluation index system will be elaborated and applied in subsequent chapters in conjunction with the case study of a health tourism center construction project.

#### **3.1 Entropy weight evaluation method**

To facilitate theoretical research, a mathematical model is established, comprising  $m$  schemes to be evaluated and  $n$  evaluation indicators. This forms the original index data matrix  $X=(x_{ij})\ m\times n$ , which serves as the foundation for subsequent entropy weight calculation. The entropy weight method determines the objective weight of each indicator based on its degree of variation. In this process, the information entropy tool can be utilized to calculate the weight of indicators at

all levels, providing a basis for the multi-indicator comprehensive evaluation system data.

### 3.1.1 Formation of a decision matrix

Assuming that there are  $m$  engineering plans for a construction project, the set of construction plans is  $M=(M_1, M_2, \dots, M_m)$ , and the determined indicators of the health tourism center construction project cost evaluation system are  $n$ . The set of indicators is  $D=(D_1, D_2, \dots, D_n)$ , and the specific data of different impact factors of the plan  $M_i$  are recorded as  $x_{ij}$  ( $i=1, 2, \dots, m; j=1, 2, \dots, n$ ), then the decision matrix obtained by evaluating  $n$  impact factors for  $m$  schemes is:

$$X_{ij} = \begin{bmatrix} & D_1 & D_2 & \cdots & D_n \\ M_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ M_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ M_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (3-1)$$

### 3.1.2 Standardized decision matrixes

Prior to calculation, standardized calculations are necessary to ensure unity of measurement units among indicators. This involves transforming the original data into a decision-making format. Each data item in the matrix is standardized, converting the absolute value of each indicator into a relative value. The resulting standardized matrix is denoted as  $V=(v_{ij})_{m \times n}$ .

The initial step involves determining the attribute of each indicator, namely, whether it is a positive or negative indicator. This is followed by standardizing the measured data for each indicator using a standardized formula, essentially rendering heterogeneous indicators homogeneous.

Formula for processing positive indicators ("larger is better" type indicators):

$$v_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (3-2)$$

Formula for processing negative indicators ("smaller is better" type indicators):

$$v_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (3-3)$$

In the formula,  $v_{ij}$ ,  $x_{ij}$  is the value obtained after the normalization of the instance data.  $\max(x_j)$ ,  $\min(x_j)$  is the maximum value of the  $j$ -th indicator and the minimum value of the  $j$ -th indicator.

### 3.1.3 Characteristic weight of the evaluation program

For a certain impact factor  $j$ , the greater the difference between the values of  $v_{ij}$ , the greater the impact factor on the final selection result of the scheme, and the more useful information the factor can provide for the selection of construction schemes. Under the  $j$ -th indicator, the proportion of the  $i$ -th option in this indicator is  $p_{ij}$ , as follows.

$$p_{ij} = \frac{v_{ij}}{\sum_{i=1}^m v_{ij}} \quad (3-4)$$

### 3.1.4 Difference coefficient of evaluation indicators

According to the concept of entropy, an increase in information corresponds to a decrease in entropy. Therefore, entropy can be used to measure the size of information. Based on the weights calculated previously, the entropy value of the  $j$ -th evaluation indicator can be calculated.

$$e_j = - \frac{1}{\ln(m)} \sum_{i=1}^m p_{ij} \ln(p_{ij}) \quad (3-5)$$

When  $p_{ij}=0$  or  $p_{ij}=1$ ,  $p_{ij} \ln(p_{ij})=0$ .

The larger the difference in evaluation index values, the more crucial it is to prioritize this index in the comparison process, and the greater the weight that should be assigned to it.

Next, the difference coefficient is calculated based on the entropy value calculated in the previous step, using the following formula.

$$d_j = 1 - e_j \quad (3-6)$$

### 3.1.5 Entropy weight of evaluation indicators

The entropy weight  $\omega_j$  of each influencing factor  $j$  is determined as follows.

$$\omega_j = \frac{d_j}{\sum_{k=1}^n d_k} \quad (j=1, 2, \dots, n) \quad (3-7)$$

A smaller entropy weight value  $\omega_j$  indicates that influence factor  $j$  has weaker distinguishing ability and a lesser impact on the selection result. Conversely, a larger value indicates stronger distinguishing ability and a greater impact.

## 3.2 Entropy weight comprehensive evaluation method

### 3.2.1 Constructing a measure model with unascertained indicators

In  $X_{ij}$ , if the evaluation value of each impact index has  $n$  grades, the classification of evaluation index can be expressed as  $Y=(Y_1, Y_2, \dots, Y_n)$ , and if there is a magnitude relationship between the graded  $k$  grades, it can be expressed as  $C=(C_1, C_2, \dots, C_k)$ . In this paper, if the evaluation value of each impact index has  $k$  grades, the classification of evaluation index can be expressed as  $C_1 < C_2 < \dots < C_k$ . If in this evaluation system, all the classification criteria for each impact indicator  $j$  are ascertained, then the classification criteria matrix can be expressed as:

$$A_k = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & a_{2k} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nk} \end{bmatrix} \quad (3-8)$$

In a matrix, for any one  $1 \leq j \leq n$ , it should be satisfied  $a_{j1} < a_{j2} < \cdots < a_{jk}$ . For the index decision matrix  $X_{ij}$  formed by  $m$  heating schemes, combined with the matrix  $A_k$  of the newly established classification standard, using the unknown measure model, we can obtain the unascertained single index measure  $u_{ij}$  of the  $c_l$  classification type of each index  $x_{ij}$ , and then determine the weight of each evaluation index.

### 3.2.2 Data normalization

In order to eliminate the adverse effects on the results caused by the different dimensions of different index data, the data should be processed by a normalized processing method. The processing method is as follows:

$$d_{ij} = \frac{x_{ij}}{\sum_{j=1}^n x_{ij}} \quad (3-9)$$

### 3.2.3 Calculation of indicator peaks

Applying the idea of the concept of information entropy, the peak value of the indicator can be defined:

$$V_{ij} = 1 + \frac{1}{\log_2^k} \sum_{j=1}^k \mu_{ij} \log_2^{\mu_{ij}} \quad (3-10)$$

### 3.2.4 Comprehensive weights of evaluation program indicators

The size of the peak value of the indicator can objectively reflect the importance of the impact indicator in the evaluation plan. Based on this, the weight of the impact indicator has a clear definition:

$$\omega_{ij} = \frac{V_{ij}}{\sum_{j=1}^n V_{ij}} \quad (3-11)$$

Apparently, the multi-index comprehensive measure of scheme  $i$  is obtained from the weights of the influencing indexes:

$$u_{ij} = \sum_{j=1}^n \omega_{ij} \mu_{ij} \quad (3-12)$$

And then can carry on the identification and the comparative analysis.

### 3.2.5 Determination of Confidence Level $\lambda$

The identification standard of confidence level can be used to evaluate the order of index categories according to their grades. That is, the ordered evaluation category  $C=(C_1, C_2, \dots, C_k)$  mentioned earlier, for a certain degree of confidence  $\lambda(0.5 < \lambda < 1)$ , if one of the evaluation grades  $h(1 \leq h \leq k)$  satisfies.

$$\left. \begin{array}{l} \sum_{l=h}^k \mu_{il} \geq \lambda \\ \sum_{l=h+1}^k \mu_{il} < \lambda \end{array} \right\} \quad (3-13)$$

Then, it is considered that the index data  $x_i$  belongs to the evaluation grade category  $C_h$ .

### 3.2.6 Calculation of Comprehensive Evaluation Value

In order to further rank the values  $x_i$ , the comprehensive evaluation value of each evaluation scheme can be calculated separately:

$$P_i = \sum_{l=1}^k u_{il} \frac{l}{k} \quad (3-14)$$

The results are compared and sorted.

### **3.3 Cloud model evaluation method**

#### **3.3.1 Fundamentals of cloud theory**

Let  $X$  be a set of exact numeric quantities, denoted as  $X = \{x\}$ , which constitutes a universe of discourse. In this context, a qualitative concept corresponds to a stable tendency of random numbers associated with each numeric quantity, represented by a membership degree. The distribution of these membership degrees within the universe of discourse is referred to as a membership cloud, whose overall shape, including thickness and dispersion, reflects the characteristics of the qualitative concept (Zhang Jiechao, 2011).

Throughout the research results of scholars for many years, the evaluation method based on cloud theory can be applied to different fields for research, such as intelligent simulation, decision-making evaluation, mine safety analysis and transportation. Combining with the construction cost system of the type of health tourism center.

Reviewing the research outcomes of scholars over the years, cloud theory-based evaluation methods have been applied to various fields, including intelligent simulation, decision-making assessment, mine safety analysis, and transportation. However, there is still a lack of research that integrates cloud evaluation methods with construction cost or standardized construction evaluation of health tourism center-type building projects.

#### **3.3.2 Digital characteristics of clouds**

The digital features of clouds can reflect the overall characteristics of uncertain concepts, which is the quantitative feature of qualitative concepts. This is crucial for understanding the connotations and extensions of qualitative concepts (Shen Mengting, 2018 & Wu Xianguo et.al, 2014).

- The expected value  $E_x$  of a cloud, which is the expected distribution of cloud droplets in the domain space, is the most representative point of a qualitative concept and the most typical sample of quantifying the concept.

- Entropy  $E_n$ , a fundamental concept in thermodynamics, measures the disorder or randomness of systems in nature. In the context of cloud models, entropy is determined by the randomness and fuzziness of concepts, and can be used to measure the uncertainty of a concept. On one hand,  $E_n$  can measure the randomness of qualitative concepts, reflecting the dispersion degree of cloud droplets that represent the concept. On the other hand, it can measure the fuzziness of concepts, reflecting the range of values that can be accepted by the concept in the domain space.

- Super entropy  $H_e$ , or the entropy of entropy, measures the uncertainty of entropy, which is determined by the randomness and fuzziness of entropy. It reflects the cohesion degree of each numerical value representing the linguistic value and the aggregation degree of cloud droplets.

The cloud parameter calculation formula is as follows:

$$E_x = \bar{X} \quad (3-15)$$

$$E_n = \sqrt{\frac{\pi}{2}} \times \frac{1}{n} \sum_{i=1}^n |X_i - E_x| \quad (3-16)$$

$$H_e = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2 - E_n^2} \quad (3-17)$$

### 3.3.3 Cloud model generator

The cloud model generator is an algorithm for generating cloud models based on the central limit theorem. It establishes a mutual connection between qualitative and quantitative aspects, forming a one-to-many mapping relationship. This includes forward cloud generators (which represent the process of converting qualitative concepts to quantitative representations) and reverse cloud generators

(which represent the process of converting quantitative representations to qualitative concepts) (Li Min, 2014, Li Qing et.al, 2013 & Wang Guoyin et.al, 2012). The cloud generator is the foundation for constructing uncertain reasoning, and the cloud model uncertain reasoning system consists of multiple cloud generators aggregated according to certain rules.

The forward cloud generator can directly extract quantitative data ranges and distribution patterns from linguistic values expressing qualitative information. This process takes three digital features of the cloud ( $E_x$ ,  $E_n$ ,  $H_e$ ) and the desired number of cloud droplets  $N$  as input, and outputs  $N$  cloud droplet values and a cloud chart composed of these droplets. The schematic diagram of the forward cloud generator is shown in Figure 3.1.

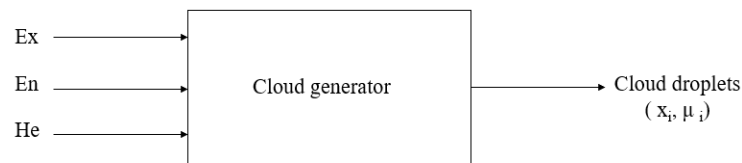


Figure 3.1 Schematic diagram of forward cloud generator

The specific algorithm involves generating the required number of cloud droplets  $n$  and membership degrees  $u$  based on the known cloud model parameters ( $E_x$ ,  $E_n$ ,  $H_e$ ). By leveraging the obtained cloud feature values, the algorithm converts the object's indices into effective parameters in the cloud model using a membership function, and then calculates the membership degrees of each index corresponding to different levels using the cloud generator.

The specific calculation steps are as follows:

- Generate a normal random number with  $E_n$  as the expected value and  $H_e$  as the variance  $E'_n$ .

$$E'_n = \text{NORM}(E_x, E'_n) \quad (3-18)$$

- A normal random number  $X$  with expectation  $E_x$  and variance  $E'_n$ .

$$x = \text{NORM}(E_0, E'_n) \quad (3-19)$$

- Calculate the membership  $u$  of the cloud droplet.

$$u = \left[ \frac{(x - E_x)^2}{2(E'_n)^2} \right] \quad (3-20)$$

- The generated  $(x, u)$  is a cloud droplet in the universe of discourse.
- The above steps are repeated until the generation of  $n$  cloud droplets stops.

According to the above steps, the cloud model can be generated, the membership function of the normal cloud model is generated through MATLAB programming, and the measured value of the index is substituted into the membership function to obtain the membership degree  $d_{ij}$  at each grade, wherein  $d_{ij}$  is the membership degree of the  $i$ -th index at the corresponding  $j$  grade.

The reverse cloud generator is a mapping from quantitative to qualitative, inputting a certain number of values (cloud droplets) and outputting digital characteristics of clouds representing qualitative concepts. The accuracy of the reverse cloud generator is related to the number of cloud droplets  $n$ . The larger  $n$  is, the higher the accuracy is, and the smaller the corresponding digital characteristic error is. The schematic diagram of the reverse cloud generator is shown in Figure 3.2.

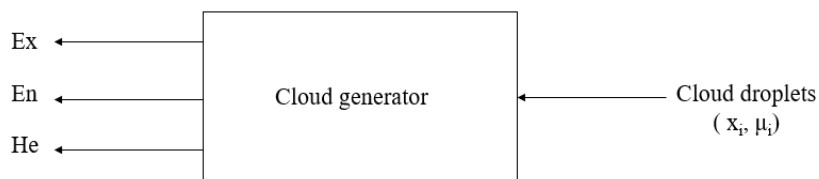


Figure 3.2 Reverse Cloud Generator

### 3.3.4 The $3E_n$ rule for normal clouds

In the normal cloud model, the influence of a certain cloud droplet on the cloud image is negligible, but a certain number of cloud droplets has a great impact on the concept of the whole and determines the thickness and dispersion of the cloud image. Analyzing a large number of cloud images shows that the  $[E_x - 3E_n, E_x + 3E_n]$  interval is the main range of quantitative values contributed by qualitative concepts, and the membership degree of cloud droplets in other intervals is almost zero. The above rule is called the  $3E_n$  rule of normal clouds, as shown in Figure 3.3.

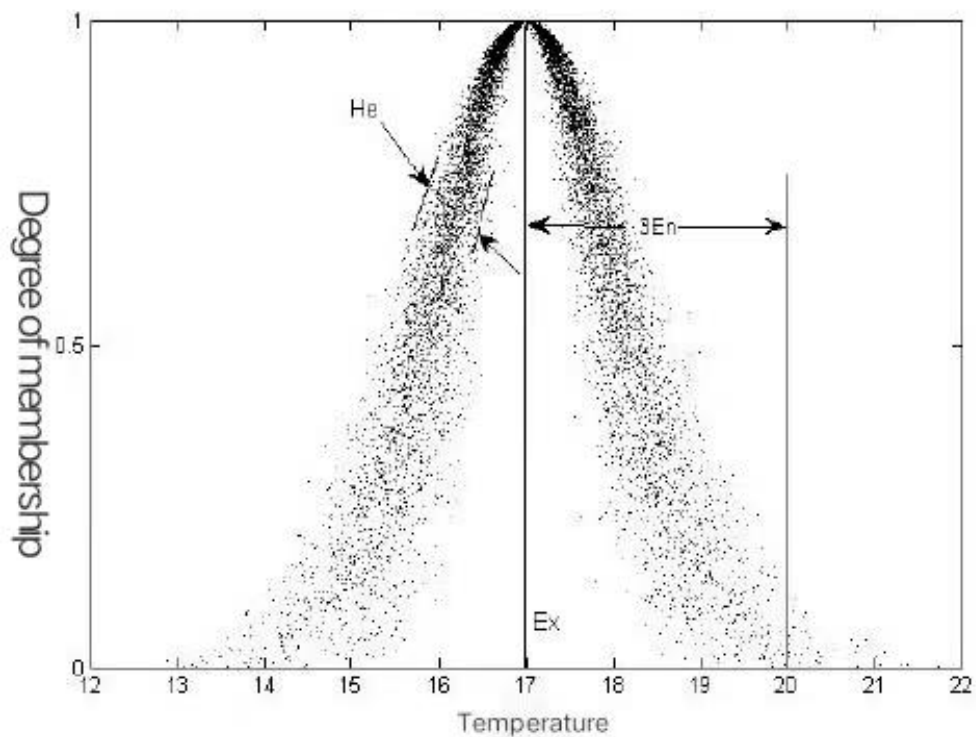


Figure 3.3 The  $3E_n$  rule for normal clouds

### 3.4 Research procedure and scheduling

The steps of this research project are shown in Figure 3.4. The research schedule of this study is shown in Table 3.1.

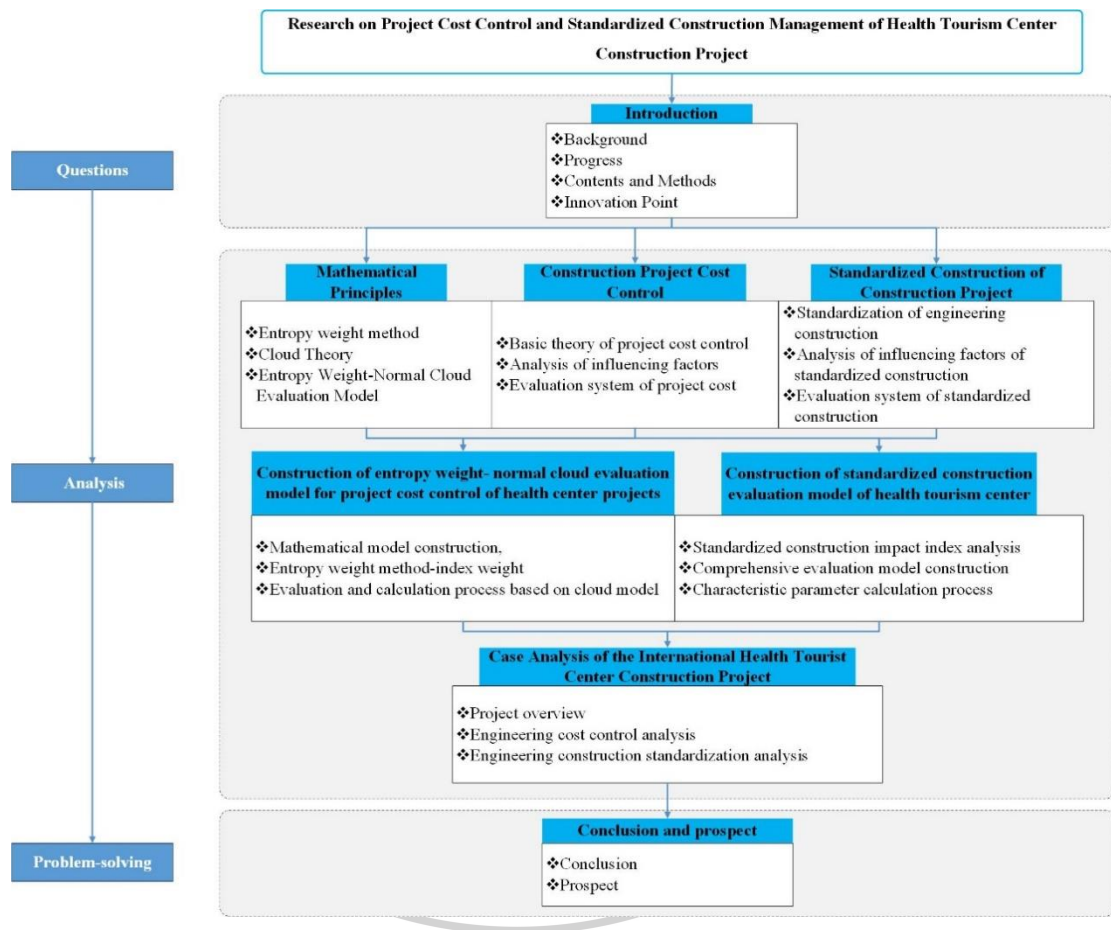
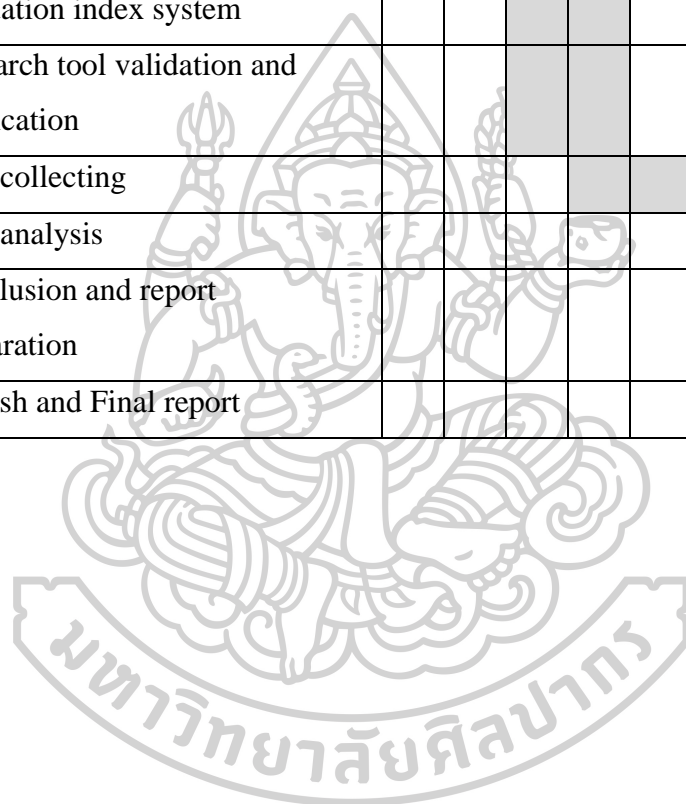


Figure 3.4 Research process flowchart

Table 3.1 Research schedule.

Step	Details	Month							
		1	2	3	4	5	6	7	8
1	Research objective design	■							
2	Literature review		■	■					
3	Research design			■					
4	Construction of multi-level evaluation index system			■	■				
5	Research tool validation and verification			■	■				
6	Data collecting				■	■			
7	Data analysis						■		
8	Conclusion and report preparation							■	
9	Publish and Final report								■



**CHAPTER 4**  
**ACONSTRUCTION PROJECT COST EVALUATION OF**  
**A HEALTH TOURISM CENTER**

The cost of construction projects not only serves as a crucial basis for project decision-making but also acts as an effective tool for specifying investment plans and controlling expenditures. Moreover, it is a key indicator for evaluating investment outcomes. The control of construction costs ensures the rational use of project funds and maximizes investment returns. This chapter focuses on the cost management and control of civil construction projects. Based on the entropy weight-cloud model, a comprehensive evaluation model for construction costs is presented. The model incorporates 21 evaluation indicators across four categories: installation, construction, decoration, and miscellaneous expenses. We have developed an evaluative indicator system for the cost of civil construction projects. Using a real case study of a health tourism center project, we demonstrate the feasibility and unique advantages of applying this model in the quantitative evaluation of civil construction project costs.

**4.1 Concept and characteristics of civil building projects**

Within the realm of engineering projects, residential construction projects are defined as one-time activities that require a substantial investment and involve a sequence of events including planning, design, and construction, all carried out under certain resource constraints with the goal of creating fixed residential assets. From the perspective of cost estimation and control, these projects can be understood as processes aimed at constructing residential buildings in the most cost-effective manner while meeting quality, functionality, and schedule requirements. They focus not only on the resulting fixed assets but also emphasize

effective planning, control, and management of costs throughout the project's entire lifecycle to maximize investment returns. These projects exhibit the following distinctive characteristics:

i. **Complex Cost Structure:** The cost makeup of residential construction projects is complex, involving multiple disciplines and sub-projects, including civil engineering, installation, and interior design. This necessitates detailed cost estimation and control for each phase.

ii. **Large Investment Scale:** Residential construction projects generally involve substantial investments with long capital expenditure cycles, demanding higher requirements for the sourcing and efficiency of fund usage. Accurate investment estimations and effective cost control are crucial for project success.

iii. **Multiple Influencing Factors:** The cost of residential construction projects is affected by a variety of factors, including design plans, fluctuations in material prices, construction techniques, and changes in policies and regulations. The uncertainty of these factors increases the difficulty of cost control.

iv. **Challenging Control:** Due to the long duration, multiple stakeholders, and complex site conditions characteristic of residential construction projects, cost control is particularly challenging. Establishing a comprehensive cost management system and employing scientific cost control methods are essential.

v. **Strong Controllability:** Despite the numerous influencing factors, the cost of residential construction projects remains highly controllable. Effective cost management can be achieved through scientific forecasting, rational planning, and effective control measures, maximizing the investment benefits of the project.

## **4.2 Analysis of construction cost composition and influencing factors**

### **4.2.1 Concept of construction project cost**

In October 1996, the Academic Committee of the China Construction Engineering Management Association published an article titled "Opinions on the Definition of Construction Cost," in which the concept of construction cost was analyzed from two perspectives:

#### **(1) Construction Cost as the Sum of Project Construction Expenses:**

This definition states that construction cost refers to the total cost of project construction, which includes expenses related to engineering, installation, equipment, personnel, and other related costs. From the viewpoint of investors, owners, or project legal entities, this cost is referred to as the construction cost or project investment. It represents the effort of investors, owners, or project entities to achieve higher economic benefits at lower costs while ensuring project quality and construction requirements.

#### **(2) Construction Cost as the Contracting Price of Construction**

**Projects:** In this context, the construction cost is understood from the perspective of the contractor and is referred to as the engineering price, which is the contracting price of the commissioned engineering project.

These definitions clarify the concept and connotations of construction cost, providing significant guidance for the study of related theories in construction cost management. The first interpretation views construction cost from the perspective of the investor, owner, or project legal entity, emphasizing cost-effectiveness and quality assurance. The second interpretation views it from the contractor's perspective, focusing on the agreed contractual price of the project.

### **4.2.2 Composition of construction project costs**

Construction costs include both capital investment and interest incurred during the construction period. Capital investment consists includes:

- **Engineering Costs:** These encompass expenses for equipment and tool purchases, as well as construction and installation costs.

- **Other Construction-Related Costs:** These include costs for land used for construction, other expenses related to the construction project, and additional costs relevant to future production and operations.

- **Contingencies:** Comprising basic reserve funds and price difference reserves.

Construction and installation expenses cover labor costs, material costs, usage fees for construction equipment, corporate management fees, profits, other costs, and taxes. Specifically:

- **Construction Costs:** Include direct costs, indirect costs, and taxes and levies.

- **Equipment Purchase Costs:** Cover the original price of equipment and transportation costs.

- **Other Costs:** Encompass land usage fees and additional expenses related to the construction project and future business operations.

- **Contingencies:** Include basic reserve funds and inflation reserve funds.

Cost components can be categorized into labor costs, material costs, engineering machinery costs, corporate management fees, profits, regulatory fees, and taxes. Based on how they accumulate, these can be divided into costs for specific sections or items, costs for project measures, other project costs, regulatory fees, and taxes.

The total investment in a construction project refers to the sum of all expenses (expected or actual) incurred during the construction period until the project is completed. Construction projects can be categorized into productive and

non-productive projects based on their intended use. The composition of the total investment in construction projects in China is illustrated in Figure 4.1.

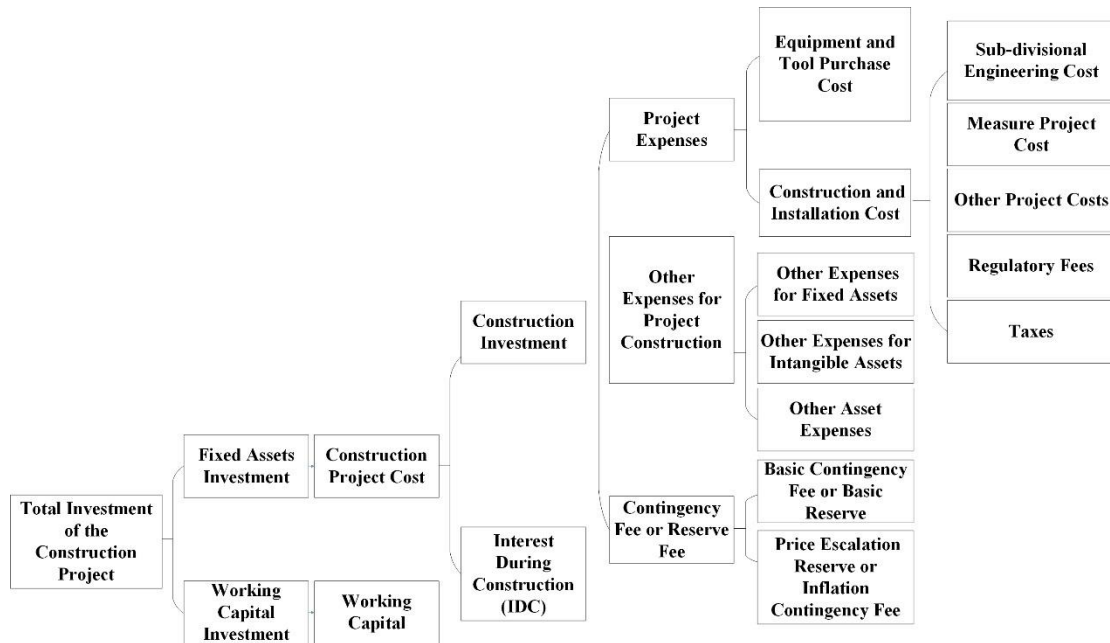


Figure 4.1 The composition of the total investment

### 4.2.3 Construction project cost control

The construction project cost, also known as the engineering cost, serves as a crucial basis for project decision-making, an effective means for setting investment plans and controlling investments, and a significant indicator for evaluating investment outcomes. Engineering cost management and control involve utilizing scientific management methods and techniques to efficiently plan, organize, coordinate, and control the costs of engineering projects. This process spans across various project stages, from project planning, design, and construction to final acceptance, encompassing the entire project life cycle. In other words, engineering cost control ensures the rational utilization of project funds and

maximizes investment returns, making it an essential aspect throughout the construction project process that both investors and contractors prioritize.

Reviewing the development of research on construction engineering cost management and control, scholars have conducted extensive studies and achieved fruitful results regarding cost management strategies and factors influencing the entire process. However, in recent years, with the increasing diversity and complexity of modern construction industries, the existing qualitative analysis of engineering cost influence and control can no longer meet the demands of contemporary project management. Therefore, it has become imperative to strengthen the quantitative evaluation of engineering cost management and control based on mathematical principles.

#### **4.3 Establishment of project cost evaluation index system**

Health tourism centers are a type of multi-functional comprehensive building project that typically involves the construction of various functional spaces such as medical, health, leisure, entertainment, and accommodation. This type of building combines multiple functional spaces such as medical, health, tourism, and leisure, providing one-stop services for tourists and residents, including health management, medical rehabilitation, and vacation.

According to the "Unified Standard for Quality Acceptance of Building Construction" (GB 50300) and the "General Rules for Civil Building Design" (GB 50352-2019), health tourism centers are classified as Class I civil building projects, which have the highest requirements for safety and hygiene, relatively low fire hazard, and significant impact in the event of an accident. This type of building has the most stringent standards and requirements in design, construction, and use to ensure a safe and healthy environment during use.

Health tourism center construction projects encompass building projects, decoration projects, installation projects, miscellaneous projects, fees, and taxes. The primary construction projects include:

1) Building projects: civil earthwork, piling and foundation projects, masonry projects, concrete and reinforced concrete projects, metal structure projects, etc.

2) Installation projects: electrical projects, plumbing projects, fire protection projects, building automation projects, HVAC projects.

3) Decoration projects: roof waterproofing projects, thermal insulation and moisture barrier projects, interior flooring projects, wall and column finishing projects, ceiling projects, painting, wallpaper, and window treatments.

Based on literature research, this paper adopts the analogy index estimation method, compares it with the cost indicators of existing health tourism projects in China, and adjusts it in combination with the characteristics of the project and local documents (such as the basis for pricing of construction projects, comprehensive budget quota for projects, budget quota for construction projects, budget quota for installation projects, and budget quota for decoration projects). Finally, a comprehensive evaluation index system of project cost is determined, including 4 first-level indicators and 21 second-level indicators. Based on the unit area cost, the evaluation indicators are graded, as shown in Figure 4.2, and the meanings and grades of each indicator for project costs are shown in Table 4.1.

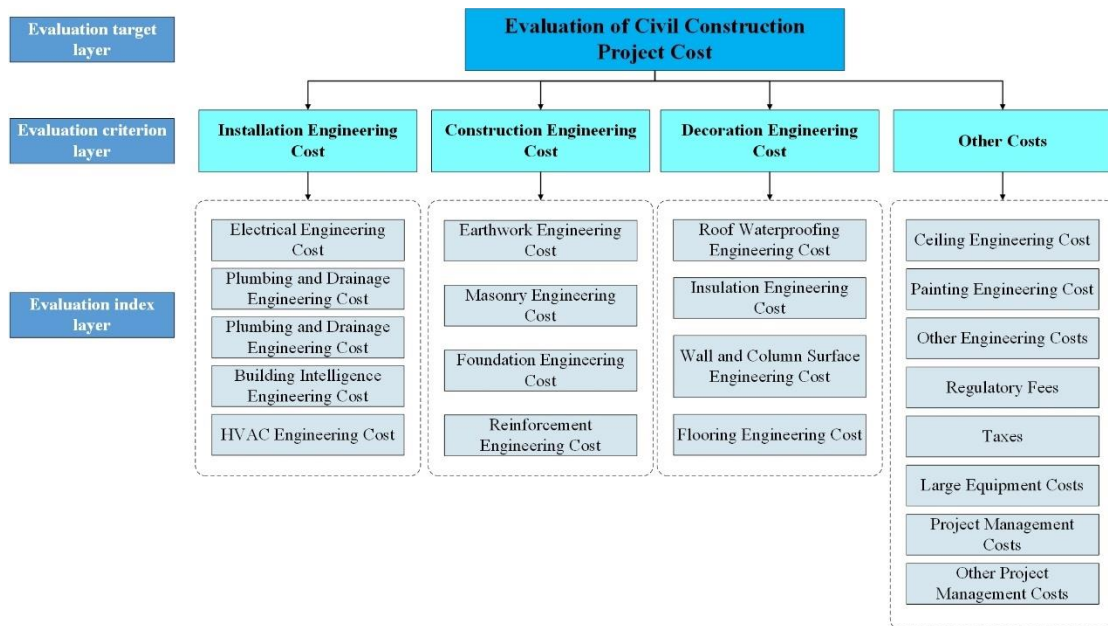


Figure 4.2 Evaluation indicator system for project costs

**Installation Engineering Costs:** Installation engineering is vital for ensuring the proper functioning of a building, encompassing systems like plumbing, electricity, HVAC, fire protection, and smart technology. These costs include equipment procurement, pipe installation, wiring, commissioning, and acceptance testing. Installation involves specialized equipment and systems, requiring skilled professionals and thus incurring higher labor costs. This category can be further detailed into expenses for electrical engineering, plumbing and drainage, fire protection, building intelligence systems, and air conditioning.

**Construction Engineering Costs:** Construction engineering forms the core of a project, providing the infrastructure and spatial framework. Construction costs typically constitute the largest portion of the overall project budget. This category encompasses all expenses related to the building structure, from excavation and foundation treatment to the construction of the main structure and roofing. The scale and complexity of these works directly influence the cost. It can be further broken

down into expenses for earthwork, masonry, foundation engineering, and reinforcement engineering.

**Decoration Engineering Costs:** Decoration engineering is a crucial component for enhancing the functionality and aesthetics of a building, directly impacting user experience and satisfaction. These costs cover interior and exterior decoration, finishing works, flooring, and ceiling installations. Decoration costs offer a degree of controllability, as material selection and construction techniques can influence expenses. However, high-end materials and complex processes can significantly escalate costs. This category can be further subdivided into expenses for roofing waterproofing, thermal insulation, wall and column finishes, and flooring.

**Other Costs:** Beyond direct construction costs, numerous other expenses arise during a project, crucial for its successful completion. These can be further categorized as follows:

**Project Measure Costs:** Expenses incurred for measures implemented to ensure smooth project execution, such as scaffolding, formwork, temporary facilities, and environmental protection.

**Statutory Fees:** Charges levied by government authorities, including sewage discharge fees, social security contributions, and housing provident fund contributions.

**Taxes:** Taxes payable as per national tax laws, such as business tax and surcharges, and value-added tax.

**Other Construction Project Costs:** Costs beyond those mentioned above, such as ceiling works, painting works, other miscellaneous construction costs, costs for heavy machinery, and other project measure expenses.

Table 4.1 Meaning and ranking of building engineering cost evaluation indicators

First-Level Indicators	Second-Level Indicators	Indicator Meaning	Ranking	
			Grade	Score Range
Installation Engineering Cost	Electrical Engineering Cost	Electrical and Lighting Systems, Power Systems, Transformation and Distribution Systems, etc.	Grade I	66-71
			Grade II	71-73
			Grade III	73-75
			Grade IV	75-80
	Plumbing and Drainage Engineering Cost	Water Supply and Drainage Pipes and Accessories	Grade I	55-57
			Grade II	57-57.8
			Grade III	57.8-60
			Grade IV	60-65
	Plumbing and Drainage Engineering Cost	Fire Alarm and Linkage Systems, Fire Water Supply and Indoor/Outdoor Fire Hydrant Systems, Automatic Sprinkler Systems, Gas Extinguishing Systems, etc.	Grade I	35-39.5
			Grade II	39.5-42
			Grade III	42-44
			Grade IV	44-47
	Building Intelligence Engineering Cost	Integrated Cabling Systems, Computer Network Systems, Telephone Systems, Security Monitoring Systems, Access Control Systems, Public Address Systems, Building Automation Systems, Intelligent Building Management Systems, and Data Center Construction, etc.	Grade I	23-24
			Grade II	24-24.6
			Grade III	24.6-25.5
			Grade IV	25.5-27.8

Table 4.1 Meaning and ranking of building engineering cost evaluation indicators

(continued)

First-Level Indicators	Second-Level Indicators	Indicator Meaning	Ranking	
			Grade	Range
	HVAC (Heating, Ventilation, and Air Conditioning) Engineering Cost	Air Handling Units, Air Conditioning System Pipes and Accessories	Grade I	375-385
			Grade II	385-390
			Grade III	390-398
			Grade IV	398-412
Construction Engineering Cost	Earthwork Engineering Cost	Includes all aspects of earthwork such as excavation, filling, transportation, drainage, and dewatering	Grade I	130-137
			Grade II	137-138
			Grade III	138-139
			Grade IV	139-147
	Masonry Engineering Cost	Construction involving the use of common clay bricks, load-bearing clay hollow bricks, and various small to medium-sized masonry blocks and stone materials in building projects	Grade I	80-82.5
			Grade II	82.5-83
			Grade III	83-84
			Grade IV	84-90
	Foundation Engineering Cost	Unsupported excavation, supported excavation, foundation treatment, and pile foundation	Grade I	25-31
			Grade II	31-34
			Grade III	34-36
			Grade IV	36-40

Table 4.1 Meaning and ranking of building engineering cost evaluation indicators  
continued

First-Level Indicators	Second-Level Indicators	Indicator Meaning	Ranking	
	Reinforcement Engineering Cost	Cold working of steel bars, welded connections for steel bars, and mechanical connections for steel bars, etc.	Grade I	205-215
			Grade II	215-222
			Grade III	222-230
			Grade IV	230-246
Decoration Engineering Cost	Roof Waterproofing Engineering Cost	Includes roofing membrane waterproofing, roof coating waterproofing, and rigid roof waterproofing	Grade I	50-55
			Grade II	55-60
			Grade III	60-62
			Grade IV	62-66
	Insulation Engineering Cost	Includes the use of insulation materials and maintenance	Grade I	2-2.4
			Grade II	2.4-2.7
			Grade III	2.7-2.9
			Grade IV	2.9-3.3
	Wall and Column Surface Engineering Cost	Decorative plastering, tiling, wall and column decoration, and curtain walls	Grade I	39.5-41
			Grade II	41-42.5
			Grade III	42.5-44
			Grade IV	44-49
Flooring Engineering Cost	Includes integral surface layers, tile surface layers, resilient flooring, other material surface layers, baseboards, stair decoration, handrails, railings, panel decoration, step decoration, and miscellaneous decorative items	Grade I	135-141	
		Grade II	141-143	
		Grade III	143-146	
		Grade IV	146-152	

Table 4.1 Meaning and ranking of building engineering cost evaluation indicators  
continued

First-Level Indicators	Second-Level Indicators	Indicator Meaning	Ranking	
Other Costs	Ceiling Engineering Cost	Ceiling Suspension and Decoration	Grade I	505-512
			Grade II	512-516
			Grade III	516-518
			Grade IV	518-524
	Painting Engineering Cost	Paint Materials and On-Site Application	Grade I	75-81
			Grade II	81-82.5
			Grade III	82.5-84
			Grade IV	84-94
	Other Engineering Costs	Other Construction Engineering Projects	Grade I	1.5-1.9
			Grade II	1.9-2.5
			Grade III	2.5-2.9
			Grade IV	2.9-3.4
	Regulatory Fees	Engineering Quota Determination Fees, Safety Production Supervision	Grade I	270-277
			Grade II	277-282
			Grade III	282-290
			Grade IV	290-320

Table 4.1 Meaning and ranking of building engineering cost evaluation indicators  
continued

First-Level Indicators	Second-Level Indicators	Indicator Meaning	Ranking	
			Grade	Value Range
	Taxes	Refers to the taxes that should be included in the construction and installation engineering costs according to national tax laws, including business tax, urban maintenance and construction tax, and education surcharge	Grade I	210-220
			Grade II	220-233
			Grade III	233-235
			Grade IV	235-250
	Large Equipment Costs	Expenses incurred for the purchase of large-scale specialized mechanical equipment necessary for construction engineering	Grade I	26-28
			Grade II	28-29
			Grade III	29-30
			Grade IV	30-34
	Project Management Costs	Expenses incurred for technical, living, safety, and environmental protection aspects before and during the construction of the engineering project	Grade I	12-13
			Grade II	13-14
			Grade III	14-14.5
			Grade IV	14.5-18
	Other Project Management Costs	Part of the project measures fee excluding the project measures fee	Grade I	45-48
			Grade II	48-49
			Grade III	49-49.2
			Grade IV	49.2-52.3

## 4.4 Case calculation and analysis

### 4.4.1 Project overview

Taking a health tourism center construction project in Mile City, Yunnan Province, China as an example. The construction project is located within the Dongfengyun International Health and Tourism Resort. The building design is divided into six major zones: healthy dining, sports and fitness, traditional Chinese medicine therapy, service exhibition, cultural center, and ecological center. It features a reinforced concrete frame structure and includes various sub-projects such as electrical, fire protection, gas, water supply and drainage, HVAC, and intelligent building systems. Figure 4.3 shows a partial aerial view of the Dongfengyun International Health and Tourism Resort, and Figure 4.4 presents an aerial perspective of the health tourism center building. Based on the data from this project, this chapter employs the entropy-weighted cloud model to conduct a comprehensive index evaluation of the cost control for the construction plans proposed by four engineering companies.



Figure 4.3 Partial Bird's-Eye View of Dongfeng Yun International Health Tourism Resort



Figure 4.4 Distant Bird's-Eye View of the Health Tourism Center

#### 4.4.2 Evaluation index labels and measured value of project plans

In the construction of the health tourism center used as a case study, four engineering companies from Yunnan proposed construction plans, project details, and relevant data that meet the project requirements. The four construction plans are labeled as M1, M2, M3, and M4, while the 21 evaluation indices are labeled as D1 to D21 (see Table 4.2 for details). The measured unit cost values for the evaluation indices across the four construction plans are summarized in Table 4.3.

Table 4.2 Labels for the construction cost evaluation index system in the case analysis

First-Level Indicators	Second-Level Indicators	Labels
Installation Engineering Cost	Electrical Engineering Cost	D1
	Plumbing and Drainage Engineering Cost	D2
	Plumbing and Drainage Engineering Cost	D3
	Building Intelligence Engineering Cost	D4
	HVAC (Heating, Ventilation, and Air Conditioning) Engineering Cost	D5

Table 4.2 Labels for the construction cost evaluation index system in the case analysis (continued)

First-Level Indicators	Second-Level Indicators	Labels
Construction Engineering Cost	Earthwork Engineering Cost	D6
	Masonry Engineering Cost	D7
	Foundation Engineering Cost	D8
	Reinforcement Engineering Cost	D9
Decoration Engineering Cost	Roof Waterproofing Engineering Cost	D10
	Insulation Engineering Cost	D11
	Wall and Column Surface Engineering Cost	D12
	Flooring Engineering Cost	D13
Other Costs	Ceiling Engineering Cost	D14
	Painting Engineering Cost	D15
	Other Engineering Costs	D16
	Regulatory Fees	D17
	Taxes	D18
	Large Equipment Costs	D19
	Project Management Costs	D20
	Other Project Management Costs	D21

Table 4.3 Measured values of indicators in the case

Project Proposal	D1	D2	D3	D4	D5	D6	D7
M1	72.1	56.5	43.9	25.0	397.0	136.6	83.4
M2	75.7	59.3	44.3	25.5	388.5	138.6	84.2
M3	73.3	57.4	40.8	24.0	400.0	140.6	82.9
M4	70.8	56.6	39.2	24.1	396.5	137.2	82.2
Project Proposal	D8	D9	D10	D11	D12	D13	D14
M1	35.9	242.1	58.0	2.6	43.1	142.5	510.0
M2	36.3	230.1	58.2	3.2	44.8	145.7	514.8
M3	33.4	220.0	60.2	3.0	42.2	147.7	515.3
M4	32.0	234.9	56.6	3.1	43.9	145.5	519.3

Table 4.3 Measured values of indicators in the case (continued)

Project Proposal	D1	D2	D3	D4	D5	D6	D7
Project Proposal	D15	D16	D17	D18	D19	D20	D21
M1	81.3	2.1	285.7	219.3	29.1	13.8	49.2
M2	83.6	3.0	276.4	233.7	29.8	14.4	47.6
M3	85.9	2.4	296.7	236.4	31.6	15.0	49.3
M4	84.7	2.9	289.3	232.5	30.7	15.0	49.1

Based on the calculation methods and steps outlined in Chapter 3, the measured values of the evaluation indices are processed and calculated. In this chapter's construction cost evaluation, all 21 evaluation indices are negative indicators, meaning that the smaller the value, the better the indicator. Therefore, the measured values are standardized using Equation (3-10), with the results presented in Table 4.4.

Table 4.4 Results of the standardization of indicator data in the case study

Project Proposal	D1	D2	D3	D4	D5	D6	D7
M1	0.73	1.00	0.08	0.33	0.26	1.00	0.40
M2	0.00	0.00	0.00	0.00	1.00	0.50	0.00
M3	0.49	0.68	0.69	1.00	0.00	0.00	0.65
M4	1.00	0.96	1.00	0.93	0.30	0.85	1.00
Project Proposal	D8	D9	D10	D11	D12	D13	D14
M1	0.09	0.00	0.61	1.00	0.65	1.00	1.00
M2	0.00	0.54	0.56	0.00	0.00	0.38	0.48
M3	0.67	1.00	0.00	0.33	1.00	0.00	0.43
M4	1.00	0.33	1.00	0.17	0.35	0.42	0.00
Project Proposal	D15	D16	D17	D18	D19	D20	D21
M1	1.00	1.00	0.54	1.00	1.00	1.00	0.06
M2	0.50	0.00	1.00	0.16	0.72	0.50	1.00
M3	0.00	0.67	0.00	0.00	0.00	0.00	0.00
M4	0.26	0.11	0.36	0.23	0.36	0.00	0.12

#### 4.4.3 Calculation of entropy weight values for evaluation indicators

According to the calculation methods and steps outlined in Chapter 3, the entropy weight parameters for the 21 evaluation indicators are calculated using formulas (3-4) to (3-7). The smaller the entropy weight, the lower the distinguishing ability of the corresponding influencing factor, and the lesser its impact on the selection of the engineering plan. The characteristic weight calculation results for the 21 evaluation indicators across the four schemes are listed in Table 4.5. The difference coefficients and entropy weight calculation results for each evaluation indicator are presented in Table 4.6.

Table 4.5 Results of the characteristic weight of indicators in the case study

Project Proposal	D1	D2	D3	D4	D5	D6	D7
M1	0.33	0.38	0.04	0.15	0.17	0.43	0.20
M2	0.00	0.00	0.00	0.00	0.64	0.21	0.00
M3	0.22	0.26	0.39	0.44	0.00	0.00	0.32
M4	0.45	0.36	0.57	0.41	0.19	0.36	0.49
Project Proposal	D8	D9	D10	D11	D12	D13	D14
M1	0.05	0.00	0.28	0.67	0.33	0.55	0.52
M2	0.00	0.29	0.26	0.00	0.00	0.21	0.25
M3	0.38	0.54	0.00	0.22	0.50	0.00	0.22
M4	0.57	0.17	0.46	0.11	0.17	0.23	0.00
Project Proposal	D15	D16	D17	D18	D19	D20	D21
M1	0.57	0.56	0.28	0.72	0.48	0.67	0.05
M2	0.28	0.00	0.52	0.11	0.35	0.33	0.85
M3	0.00	0.38	0.00	0.00	0.00	0.00	0.00
M4	0.15	0.06	0.19	0.16	0.17	0.00	0.10

Table 4.6 Results of the parameters for 21 indicators in the case study

Parameters	D1	D2	D3	D4	D5	D6	D7
$e_j$	0.76	0.78	0.6	0.73	0.65	0.77	0.75
$d_j$	0.24	0.22	0.4	0.27	0.35	0.23	0.25
$\omega_j$	0.03	0.03	0.06	0.04	0.05	0.03	0.04
Parameters	D8	D9	D10	D11	D12	D13	D14
$e_j$	0.61	0.72	0.77	0.61	0.73	0.72	0.74
$d_j$	0.39	0.28	0.23	0.39	0.27	0.28	0.26
$\omega_j$	0.06	0.04	0.03	0.06	0.04	0.04	0.04
Parameters	D15	D16	D17	D18	D19	D20	D21
$e_j$	0.69	0.62	0.73	0.56	0.74	0.46	0.37
$d_j$	0.31	0.38	0.27	0.44	0.26	0.54	0.63
$\omega_j$	0.04	0.05	0.04	0.06	0.04	0.08	0.09

According to the entropy weight method calculation results from Table 4-6, the entropy weight values of indicators D20 and D21 are the largest, reaching 0.08 and 0.09 respectively. This indicates that the proportion of project measure costs accounts for 17% of the total project cost, and thus, the greatest effort should be made to control costs during project implementation to achieve the cost control target. Among the four first-level indicators, the second-level indicators with an entropy weight value of 0.06 are D3, D8, D11, and D18, which correspond to fire protection engineering costs, low-level engineering costs, insulation engineering costs, and taxes, respectively. These four indicators also have a significant impact on the total project cost, and their contribution to project cost control is second only to the project measure costs. The entropy weight values of the remaining second-level indicators are relatively small and do not differ significantly, indicating that the differentiation among these indicators is not large, and their contribution to the overall project cost control is comparable.

#### 4.4.4 Entropy-cloud comprehensive evaluation of project costs

(1) Cloud model digital characteristics of hierarchical evaluation indicators Assume that the upper and lower boundary values corresponding to factor  $j$  are  $x^{\max}$  and  $x^{\min}$ , respectively. The calculation formula for the cloud parameters is as follows:

$$Ex = \frac{x^{\max} + x^{\min}}{2} \quad (4-1)$$

$$En = \frac{x^{\max} - x^{\min}}{2.355} \quad (4-2)$$

$$He = k \quad (4-3)$$

Where,  $x^{\max}$  and  $x^{\min}$  are the maximum and minimum values of the variable, respectively,  $k$  is a constant.

Since hyper-entropy reflects the uncertainty of entropy and is a variable related to entropy, it is assumed that hyper-entropy and entropy have a linear relationship. Therefore, formula (4-3) is modified to:

$$He = kEn \quad (4-4)$$

Based on engineering experience, this paper sets  $k$  to 0.1.

Using the above method, the interval values of each evaluation indicator (Table 4.1) are converted into cloud model digital characteristic values. That is, each evaluation indicator corresponds to the digital characteristics (expected value  $Ex$ , entropy  $En$ , and hyper-entropy  $He$ ) of different levels, as listed in Table 4.7.

Table 4.7 Cloud Digital Characteristics of Hierarchical Evaluation Indicators

Cloud parameters	D1	D2	D3	D4	D5	D6	D7	
Grade I	$Ex$	68.50	56.00	37.25	23.50	380.00	133.50	81.25
	$En$	2.12	0.85	1.91	0.42	4.25	2.97	1.06
	$He$	0.21	0.08	0.19	0.04	0.42	0.30	0.11

Table 4.7 Cloud Digital Characteristics of Hierarchical Evaluation Indicators

(continued)

Cloud parameters		D1	D2	D3	D4	D5	D6	D7
Grade II	<i>Ex</i>	72.00	57.40	40.75	24.30	387.50	137.50	82.75
	<i>En</i>	0.85	0.34	1.06	0.25	2.12	0.42	0.21
	<i>He</i>	0.08	0.03	0.11	0.03	0.21	0.04	0.02
Grade III	<i>Ex</i>	74.00	58.90	43.00	25.05	394.00	138.50	83.50
	<i>En</i>	0.85	0.93	0.85	0.38	3.40	0.42	0.42
	<i>He</i>	0.08	0.09	0.08	0.04	0.34	0.04	0.04
Grade IV	<i>Ex</i>	77.50	62.50	45.50	26.65	405.00	143.00	87.00
	<i>En</i>	2.12	2.12	1.27	0.98	5.94	3.40	2.55
	<i>He</i>	0.21	0.21	0.13	0.10	0.59	0.34	0.25
Cloud parameters		D8	D9	D10	D11	D12	D13	D14
Grade I	<i>Ex</i>	28.00	210.00	52.50	2.20	40.25	138.00	508.50
	<i>En</i>	2.55	4.25	2.12	0.17	0.64	2.55	2.97
	<i>He</i>	0.25	0.42	0.21	0.02	0.06	0.25	0.30
Grade II	<i>Ex</i>	32.50	218.50	57.50	2.55	41.75	142.00	514.00
	<i>En</i>	1.27	2.97	2.12	0.13	0.64	0.85	1.70
	<i>He</i>	0.13	0.30	0.21	0.01	0.06	0.08	0.17
Grade III	<i>Ex</i>	35.00	226.00	61.00	2.80	43.25	144.50	517.00
	<i>En</i>	0.85	3.40	0.85	0.08	0.64	1.27	0.85
	<i>He</i>	0.08	0.34	0.08	0.01	0.06	0.13	0.08
Grade IV	<i>Ex</i>	38.00	238.00	64.00	3.10	46.50	149.00	521.00
	<i>En</i>	1.70	6.79	1.70	0.17	2.12	2.55	2.55
	<i>He</i>	0.17	0.68	0.17	0.02	0.21	0.25	0.25
Cloud parameters		D15	D16	D17	D18	D19	D20	D21
Grade I	<i>Ex</i>	78.00	1.70	273.50	215.00	27.00	12.50	46.50
	<i>En</i>	2.55	0.17	2.97	4.25	0.85	0.42	1.27
	<i>He</i>	0.25	0.02	0.30	0.42	0.08	0.04	0.13

Table 4.7 Cloud Digital Characteristics of Hierarchical Evaluation Indicators  
(continued)

Cloud parameters		D1	D2	D3	D4	D5	D6	D7
Grade II	<i>Ex</i>	81.75	2.20	279.50	226.50	28.50	13.50	48.50
	<i>En</i>	0.64	0.25	2.12	5.52	0.42	0.42	0.42
	<i>He</i>	0.06	0.03	0.21	0.55	0.04	0.04	0.04
Grade III	<i>Ex</i>	83.25	2.70	286.00	234.00	29.50	14.25	49.10
	<i>En</i>	0.64	0.17	3.40	0.85	0.42	0.21	0.08
	<i>He</i>	0.06	0.02	0.34	0.08	0.04	0.02	0.01
Grade IV	<i>Ex</i>	89.00	3.15	305.00	242.50	32.00	16.25	50.75
	<i>En</i>	4.25	0.21	12.74	6.37	1.70	1.49	1.32
	<i>He</i>	0.42	0.02	1.27	0.64	0.17	0.15	0.13

The expectation value represents the central tendency of an evaluation indicator in the cloud model, reflecting the typical performance level of the indicator in cost evaluation. A higher expectation value indicates a more prominent impact of the indicator on engineering costs. The expectation value is often used to evaluate the relative impact of a specific indicator, but for different descriptive objects, there is no intrinsic connection among the expectation values of different indicators.

Entropy represents the uncertainty or randomness of the cloud model, reflecting the degree of dispersion or fuzziness of the model. Higher entropy values indicate more dispersed evaluation indicator values, less effective information, and a weaker influence on the determinacy of the evaluation results. Hyper-entropy represents the uncertainty or randomness of the entropy values, reflecting the degree of dispersion in the distribution of entropy values. Larger hyper-entropy values indicate greater uncertainty in the entropy values.

It is evident that in engineering cost evaluation, the entropy value of an indicator is the primary data for examining its impact on the overall cost. The smaller the entropy value of an evaluation indicator and the smaller the hyper-entropy, the greater the impact of the indicator on the overall cost and the more definite its influence. Based on the calculation results in Table 4.7, the impact of each indicator varies across different levels. For example, considering the optimal level (Level I), a comprehensive examination of the cloud digital characteristics of each indicator shows that D2, D4, D11, and D16 are high-impact indicators, while D5, D6, D9, D14, D17, and D18 are low-impact indicators. The remaining indicators have a medium impact. This provides a core focus for practical engineering cost management and control.

#### **4.4.5 Grade cloud diagrams of evaluation indicators**

The core algorithm of the forward cloud generator is based on the central limit theorem in probability theory. By generating normal random numbers, it constructs a cloud diagram composed of a large and finite number of cloud drops, displaying the quantitative characteristics of directed concepts on the cloud diagram. Based on the cloud parameter calculation results of the 21 second-level indicators under the 4 first-level indicators, 2000 cloud drops were randomly generated using the forward cloud generator to draw the cloud diagrams. The typical cloud diagrams of the second-level indicators with the greatest impact in each first-level indicator are shown in Figure 4.5.

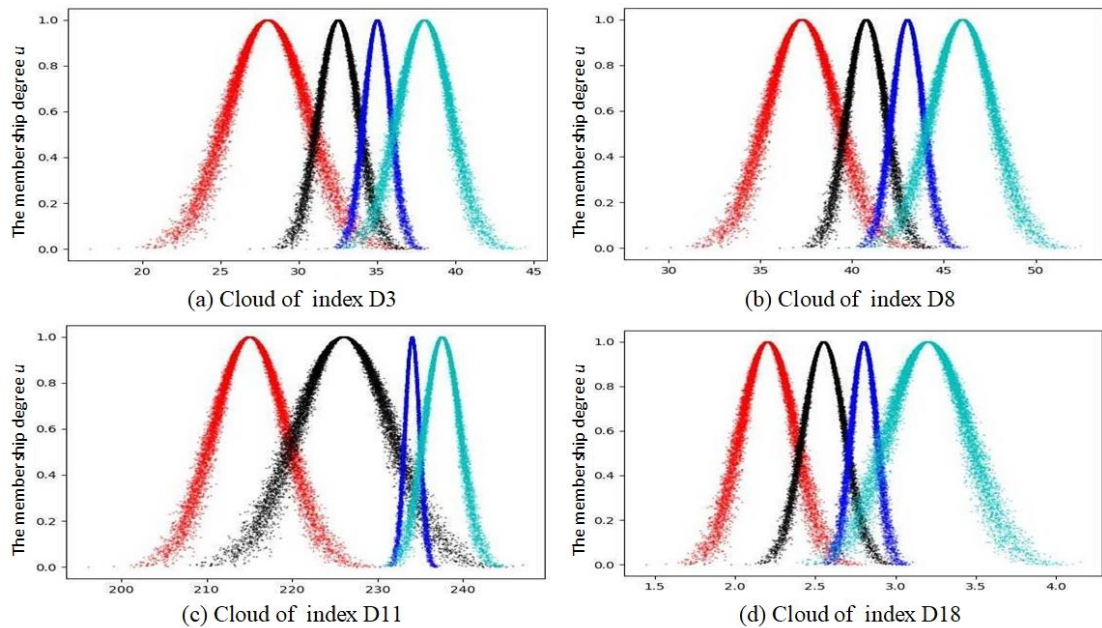


Figure 4.5 Typical second-level indicator cloud diagrams for health tourism center project cost evaluation based on entropy-cloud model

In the above 4 evaluation indicator cloud diagrams, the horizontal coordinate represents the quantitative range of the indicator, and the vertical coordinate represents the membership degree of the cloud drops. In the diagrams, red represents Level I cloud, black represents Level II cloud, blue represents Level III cloud, and cyan represents Level IV cloud. The levels improve from right to left along the x-axis. A thick cloud layer and wide tail indicate a high degree of dispersion in the numeric values. For example, in Figure 4-5(a), the cloud diagram for the fire protection engineering indicator, the maximum boundary value of the indicator is 45, and the minimum boundary value is 20. The cloud drops are mainly concentrated around the median value of 27, demonstrating the optimal characteristics of this indicator. In the central region of the cloud diagram, the membership degree of the cloud drops is relatively high, indicating strong representativeness and reliability of the indicator. However, the cloud drops on both

sides show greater dispersion and uncertainty. Comparing the four clouds, the probability of cloud drops falling into the optimal cloud is the highest.

#### 4.4.6 Membership Degree Matrix

Using the characteristic parameters and membership degree function of the cloud model, the membership degree ( $U$ ) of each indicator's measured value ( $x_i$ ) belonging to a certain grade cloud is calculated. The calculation results of the membership degree matrix for the evaluation indicators of the 4 engineering schemes are listed in Table 4.8.

Table 4.8 Calculation results of the membership degree matrix for evaluation indicators

Project Proposal	Grade	D1	D2	D3	D4	D5	D6	D7
M1	Grade I	0	0.68	0.26	0.03	0	0.09	0.24
	Grade II	0	0.19	0.03	0.08	0	0.98	1
	Grade III	0.76	0.06	0.98	0.67	0	0.01	0.13
	Grade IV	0.51	0.06	0.49	0.58	0.98	0.14	0.14
	Grade	D8	D9	D10	D11	D12	D13	D14
	Grade I	0	0.31	0.91	0.54	0.24	0	0.69
	Grade II	0.22	0.88	0.14	0.8	0.95	0.05	0.54
	Grade III	0.97	0.42	0	0.03	0.01	1	0
	Grade IV	0.16	0.02	0	0.17	0	0.36	0
	Grade	D15	D16	D17	D18	D19	D20	D21
	Grade I	0.09	0.02	0.21	0	0.68	0.26	0.03
	Grade II	0.48	0.83	0.37	0	0.19	0.03	0.08
	Grade III	0.72	0.19	0.6	0.76	0.06	0.98	0.67
	Grade IV	0.28	0.38	0.61	0.51	0.06	0.49	0.58

Table 4.8 Calculation results of the membership degree matrix for evaluation indicators (continued)

Project Proposal	Grade	D1	D2	D3	D4	D5	D6	D7	
M2	Grade I	0.01	0	0	0	0.16	0.27	0.04	
	Grade II	0	0	0.01	0	0.9	0.04	0	
	Grade III	0.16	0.92	0.35	0.53	0.31	0.9	0.28	
	Grade IV	0.72	0.36	0.64	0.53	0.02	0.22	0.58	
	Grade	D8	D9	D10	D11	D12	D13	D14	
	Grade I	0.01	0	0.04	0	0	0.01	0.14	
	Grade II	0.02	0	0.95	0	0	0	0.91	
	Grade III	0.35	0.52	0.01	0	0.08	0.67	0.13	
	Grade IV	0.64	0.54	0.09	1	0.98	0.44	0.03	
	Grade	D15	D16	D17	D18	D19	D20	D21	
	Grade I	0.1	0	0.66	0	0	0	0.72	
	Grade II	0.03	0.01	0.38	0.46	0.01	0.13	0.13	
	Grade III	0.91	0.25	0.03	0.95	0.79	0.79	0	
	Grade IV	0.45	0.75	0.03	0.24	0.45	0.5	0.22	
	Project Proposal	Grade	D1	D2	D3	D4	D5	D6	D7
	M3	Grade I	0.15	0.34	0.3	0.57	0	0.14	0.45
Grade II		0.43	1	1	0.62	0	0	0.83	
Grade III		0.78	0.39	0.09	0.07	0.33	0.28	0.48	
Grade IV		0.25	0.13	0.04	0	0.8	0.75	0.4	
Grade		D8	D9	D10	D11	D12	D13	D14	
Grade I		0.19	0.13	0.01	0	0.03	0	0.16	
Grade II		0.84	0.91	0.56	0.03	0.87	0	0.81	
Grade III		0.28	0.33	0.72	0.13	0.34	0.11	0.35	
Grade IV		0.07	0.14	0.35	0.81	0.02	0.99	0.08	
Grade		D15	D16	D17	D18	D19	D20	D21	
Grade I		0.03	0.01	0	0	0	0	0.19	

Table 4.8 Calculation results of the membership degree matrix for evaluation indicators (continued)

Project Proposal	Grade	D1	D2	D3	D4	D5	D6	D7
	Grade II	0	0.81	0	0.32	0	0.01	0.27
	Grade III	0	0.35	0.03	0.06	0	0.01	0.13
	Grade IV	0.94	0.03	0.95	0.91	1	0.78	0.63
Project Proposal	Grade	D1	D2	D3	D4	D5	D6	D7
M4	Grade I	0.37	0.63	0.43	0.15	0	0.28	0.54
	Grade II	0.2	0.01	0.14	0.55	0	0.66	0
	Grade III	0	0.01	0	0	0.64	0.03	0
	Grade IV	0	0	0	0	0.16	0.01	0.05
	Grade	D8	D9	D10	D11	D12	D13	D14
	Grade I	0.12	0	0.04	0	0	0	0
	Grade II	0.88	0	0.86	0	0	0	0
	Grade III	0	0	0	0	0.49	0.59	0.18
	Grade IV	0	0.74	0	0.86	0.26	0.16	0.4
	Grade	D15	D16	D17	D18	D19	D20	D21
	Grade I	0	0	0	0	0	0	0.04
	Grade II	0	0	0	0.37	0	0	0.19
	Grade III	0.02	0.28	0.46	0.08	0	0	1
	Grade IV	0.51	0.26	0.27	0.01	0.71	0.55	0.29

#### 4.4.7 Analysis of cloud model comprehensive evaluation results

The dimensionless values are located in the indicator cloud diagrams to find the corresponding certainty degree. These certainty degrees are then multiplied by the entropy weight values of the evaluation indicators to obtain the final certainty degree, which determines the comprehensive evaluation level of each engineering scheme, as shown in Table 4.9. The cloud model diagram is shown in Figure 4.6.

Table 4.9 Evaluation grades of each project proposal

Project Proposal	Grade I	Grade II	Grade III	Grade IV	Evaluation Ranking
M1	0.2225	0.3351	0.4819	0.3425	Grade III
M2	0.1210	0.1799	0.4075	0.4524	Grade IV
M3	0.1210	0.4183	0.2136	0.4956	Grade IV
M4	0.1038	0.1744	0.2116	0.2676	Grade IV

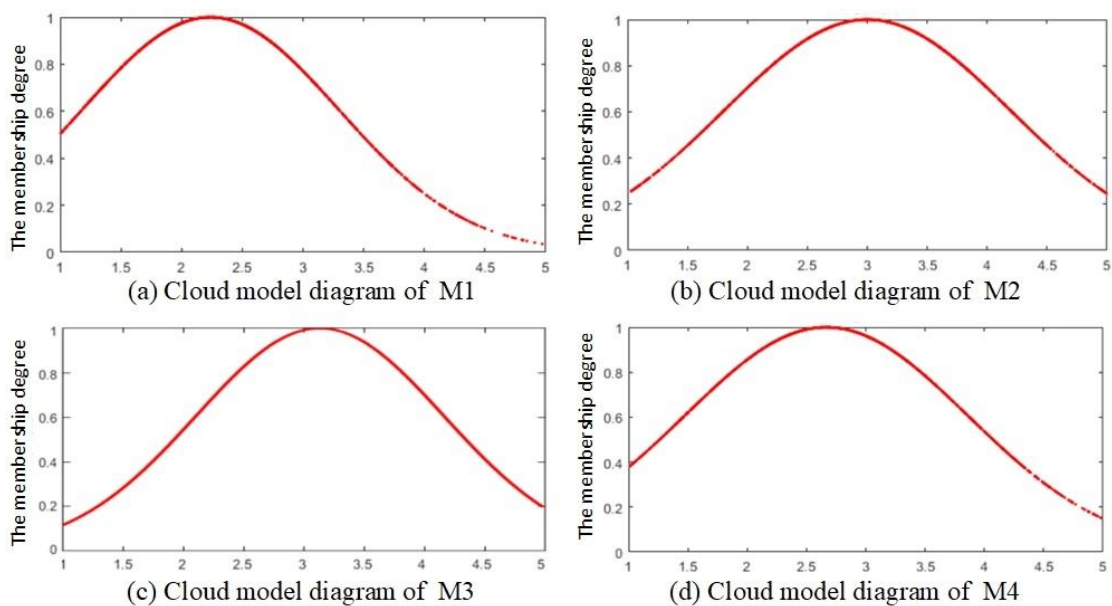


Figure 4.6 Cloud model diagrams for 4 project proposal

From Table 4.9 and Figure 4.6, applying the principle of maximum certainty, it can be determined that engineering scheme M1 is at Level III (Good), while schemes M2, M3, and M4 are all at Level IV (Passable). Analyzing the data, the final certainty degree of scheme M2 at Level III (Good) is 0.4075, and the final certainty degree of scheme M3 at Level II (Suboptimal) is 0.4183. Comparatively, scheme M3 is superior to M2. The final ranking of the 4 engineering proposal is approximately:  $M1 > M3 > M2 \approx M4$ .

## **CHAPTER 5**

### **EVALUATION OF STANDARDIZED CONSTRUCTION FOR A HEALTH TOURISM CENTERS**

Standardized construction in the building industry refers to the strict adherence to national or industry standards, regulations, and operational procedures during the design, construction, and management phases of building projects. Its core objective is to ensure the quality, safety, and efficiency of the project through standardized and systematic construction methods. Standardized construction for civil buildings aims to improve project quality and construction safety, optimize resource allocation, reduce costs, promote technological innovation and industry development, and safeguard user rights and environmental sustainability, thereby achieving high-efficiency, high-quality, and green development in building projects. This chapter focuses on the standardized construction and management of civil buildings. Based on the entropy-weight comprehensive evaluation method, 22 evaluation indicators covering construction costs, construction progress, construction safety, construction quality, energy efficiency, and environmental impact have been selected to construct a standardized construction evaluation indicator system for civil buildings. This system is exemplified by a real health tourism center construction project to demonstrate the feasibility and unique advantages of the model in the quantitative evaluation of standardized construction for civil building projects.

#### **5.1 Analysis of standardized construction and influencing factors**

The importance of standardization in construction lies in enhancing the quality and safety of engineering projects, reducing construction costs and delays, minimizing material waste and energy consumption, and effectively controlling environmental impacts, thereby promoting sustainable development in the construction industry. Based on the standardization experience of existing civil engineering construction projects, the main factors influencing the standardization of construction processes include: construction costs, construction schedules, construction safety, construction quality, energy efficiency in construction, and environmental impact control. Specifically, these factors are as follows:

(1) Construction costs refer to all production expenses incurred during the construction process, mainly including labor costs (wages for workers and management personnel, accounting for approximately 30-35% of the total construction cost), material costs (costs of various building and auxiliary materials, accounting for approximately 55-60% of the total construction cost), and mechanical costs (equipment rental, operation, and maintenance costs, accounting for approximately 5% of the total construction cost).

(2) Construction schedule control refers to the management of the content and duration of each phase of work through planning, implementation, and inspection of the actual schedule against the planned schedule, and analysis and adjustment of any deviations. The construction period is the time from the start to the completion and acceptance of the project. This is ensured through the approval of the schedule plan, supervision of the schedule, adjustment of the plan, and reasonable arrangement of technical personnel. Mechanized operation shifts and labor efficiency significantly affect the construction period. Effective schedule control ensures that the construction is completed on time and with the required quality.

(3) Construction safety management involves the use of reasonable measures to constrain special situations involving people, objects, and the environment during the construction process, ensuring that the entire process operates safely. This includes the completeness of safe and civilized construction, the qualification rate of materials, and the proficiency in key technical operations. Construction safety is a crucial indicator of standardized construction management, representing the highest level of protection for workers' personal safety, and is the fundamental guarantee for increased production and rapid development.

(4) Construction quality refers to the degree to which the construction activities and products of an engineering project meet the owner's requirements and comply with national laws, regulations, and technical documents. It encompasses functionality and durability. Quality control in construction is ensured through a full range of quality management measures. The main indicators for evaluating construction quality include: the first-time pass rate of engineering quality inspections, which is assessed through technical measurements and inspections of materials and construction techniques; the industrial integration degree of the external

protective structure, which evaluates the structure's ability to withstand climatic factors; and construction accuracy, which ensures that construction errors are within the permissible range of standards. These indicators collectively ensure that the construction quality meets the expected standards and achieves investment benefits.

(5) Construction energy efficiency management aims to maximize energy utilization rates and reduce costs while meeting the project's needs. Energy efficiency is calculated by comparing actual construction energy consumption with reference energy consumption and is a key indicator of standardization and energy efficiency in construction. The utilization rate of new energy sources evaluates the effectiveness of new energy applications in construction, reducing the consumption of traditional energy sources. The application degree of new technologies assesses the quantity and maturity of energy-saving technologies, as well as their effectiveness in improving construction efficiency and energy conservation. The evaluation of indoor thermal environment quality ensures that buildings remain comfortable under various climatic conditions, which can be achieved through optimizing construction techniques and building structures to meet energy efficiency goals.

(6) Environmental impact control in construction involves the use of reasonable measures to minimize environmental pollution during the construction process, ensuring minimal ecological impact. This mainly includes controlling noise pollution, light pollution, construction waste, dust emissions, and the quality of drinking water sources. Noise pollution control is based on the "Construction Site Noise Limit Standard," light pollution requires reasonable control of strong light radiation, construction waste should be collected and disposed of regularly, dust emissions should be controlled according to the "Construction Site Dust Emission Standard," and drinking water source quality should ensure that industrial and domestic wastewater treatment meets standards. These measures collectively ensure the sustainability of the environment and the standardization of construction quality during the construction process.

## 5.2 Establishment of Evaluation Index System for Construction Standardization

Based on literature research, this paper employs a comparative indicator estimation method. By comparing with the standardization indicators of established health tourism engineering projects in China, and adjusting according to project characteristics and local documents (such as Construction Design Specifications, Construction Quality Management Specifications, Construction Safety Management Specifications, Construction Technical Specifications, and Construction Environmental Management Specifications), a comprehensive evaluation index system for construction standardization has been finalized. This system includes 6 primary indicators and 22 secondary indicators. The evaluation indicators are graded based on normalized data, as shown in Figure 5.1, Table 5.1, and Table 5.2.

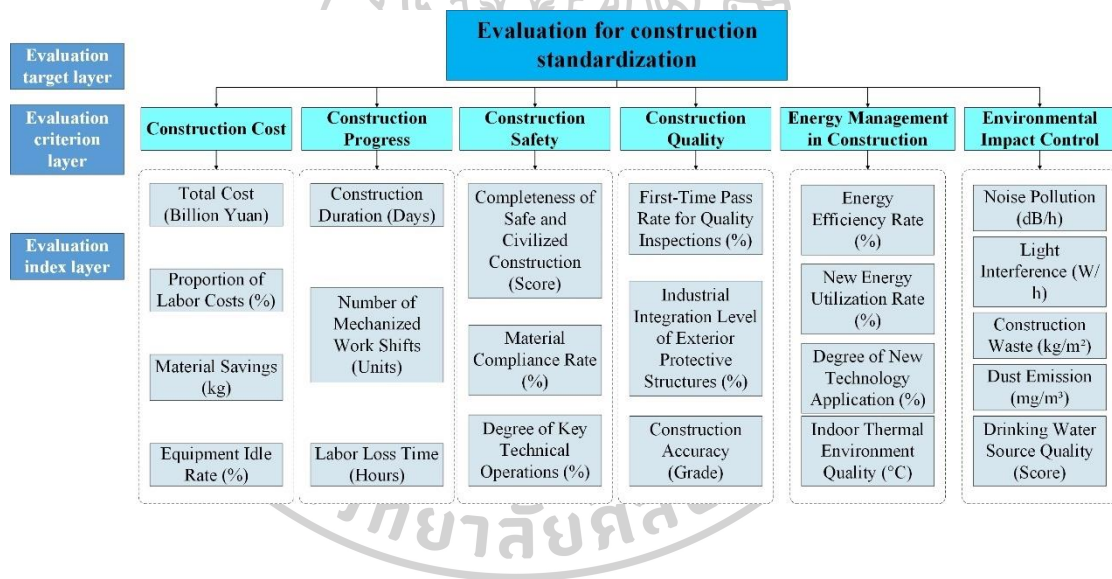


Figure 5.1 Evaluation index system for construction standardization

Table 5.1 Evaluation index system for construction standardization

First-Level Indicators	Second-Level Indicators	Index property
Construction Cost	Total Cost (Billion Yuan)	Negative
	Proportion of Labor Costs (%)	Negative
	Material Savings (kg)	Positive
	Equipment Idle Rate (%)	Negative
Construction Progress	Construction Duration (Days)	Negative
	Number of Mechanized Work Shifts (Units)	Positive
	Labor Loss Time (Hours)	Negative
Construction Safety	Completeness of Safe and Civilized Construction (Score)	Positive
	Material Compliance Rate (%)	Positive
	Degree of Key Technical Operations (%)	Positive
Construction Quality	First-Time Pass Rate for Quality Inspections (%)	Positive
	Industrial Integration Level of Exterior Protective Structures (%)	Positive
	Construction Accuracy (Grade)	Positive
Energy Management in Construction	Energy Efficiency Rate (%)	Positive
	New Energy Utilization Rate (%)	Positive
	Degree of New Technology Application (%)	Positive
	Indoor Thermal Environment Quality (°C)	Positive
Environmental Impact Control	Noise Pollution (dB/h)	Negative
	Light Interference (W/h)	Negative
	Construction Waste (kg/m <sup>2</sup> )	Negative
	Dust Emission (mg/m <sup>3</sup> )	Negative
	Drinking Water Source Quality (Score)	Positive

Table 5.2 Grading of construction standardization evaluation indicators

Index property	Grading					
	Grade I	Grade II	Grade III	Grade IV	Grade V	Grade IV
Positive	>0.5	0.4-0.5	0.3-0.4	0.2-0.3	0.1-0.2	<0.1
Negative	<0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	>0.5

### 5.3 Case calculation and analysis

#### 5.3.1 Evaluation index labels and measured value of construction proposal

This section continues to rely on the data from Chapter 4 regarding the construction project of the health tourism center. The Entropy Weight Comprehensive Evaluation Method is used to conduct a comprehensive evaluation of the standardization control of the construction plans submitted by four bidding construction companies. The four construction plans are labeled as N1, N2, N3, and N4, while the 22 evaluation indicators are labeled as E1 to E22 (see Table 5.3 for details). The measured values of the standardized control for each evaluation indicator of the four construction plans are summarized in Table 5.4.

Table 5.3 Labels for construction standardization evaluation index system in the case analysis

First-Level Indicators	Second-Level Indicators	Labels
Construction Cost	Total Cost (Billion Yuan)	E1
	Proportion of Labor Costs (%)	E2
	Material Savings (kg)	E3
	Equipment Idle Rate (%)	E4
Construction Progress	Construction Duration (Days)	E5
	Number of Mechanized Work Shifts (Units)	E6
	Labor Loss Time (Hours)	E7
Construction Safety	Completeness of Safe and Civilized Construction (Score)	E8
	Material Compliance Rate (%)	E9
	Degree of Key Technical Operations (%)	E10

Table 5.3 Labels for construction standardization evaluation index system in the case analysis (continued)

First-Level Indicators	Second-Level Indicators	Labels
Construction Quality	First-Time Pass Rate for Quality Inspections (%)	E11
	Industrial Integration Level of Exterior Protective Structures (%)	E12
	Construction Accuracy (Grade)	E13
Energy Management in Construction	Energy Efficiency Rate (%)	E14
	New Energy Utilization Rate (%)	E15
	Degree of New Technology Application (%)	E16
	Indoor Thermal Environment Quality (°C)	E17
Environmental Impact Control	Noise Pollution (dB/h)	E18
	Light Interference (W/h)	E19
	Construction Waste (kg/m <sup>2</sup> )	E20
	Dust Emission (mg/m <sup>3</sup> )	E21
	Drinking Water Source Quality (Score)	E22

Table 5.4 Measured values of indicators in the case

Construction proposal	E1	E2	E3	E4	E5	E6	E7	E8
N1	9	34	10	0.35	18	9	37	8
N2	8.7	32.7	12	0.47	20	7	31	7
N3	8.8	30.6	12	0.41	22	8	42	7
N4	8.6	31.5	15	0.32	17	10	35	9
Construction proposal	E9	E10	E11	E12	E13	E14	E15	E16
N1	95.5	97.7	90	90	72	93.7	57.1	55.1
N2	96.6	96.2	82	86	96	92.1	55.2	45.7
N3	97.7	94.4	80	89	87	94	64.5	49.3
N4	98.4	97.3	87	92	94	95.8	62.7	52.6

Table 5.4 Measured values of indicators in the case

Construction proposal	E1	E2	E3	E4	E5	E6	E7	E8
Construction proposal	E17	E18	E19	E20	E21	E22	-	-
N1	23	57	90	58.3	0.23	95	-	-
N2	26	61	90	54	0.27	80	-	-
N3	27	60	85	60	0.3	90	-	-
N4	24	54	95	56.2	0.25	90	-	-

Based on the calculation methods and steps outlined in Chapter 3, the measured values of the evaluation indicators will be processed and calculated. In this chapter's evaluation of construction standardization, among the 22 evaluation indicators, 9 are negative indicators, meaning that smaller values are preferable, while 13 are positive indicators, meaning that larger values are preferable. Therefore, the measured values are standardized using formulas (3-2) and (3-3), as listed in Table 5.5.

Table 5.5 Standardization results of indicators in the case study

Construction proposal	E1	E2	E3	E4	E5	E6	E7	E8
N1	0.91	0.65	0.1	1	0.81	0.09	0.61	0.08
N2	0.91	0.66	0.12	1	0.8	0.07	0.68	0.07
N3	0.91	0.69	0.12	1	0.78	0.08	0.57	0.07
N4	0.92	0.68	0.15	0	0.17	0.1	0.35	0.09
Construction proposal	E9	E10	E11	E12	E13	E14	E15	E16
N1	1	1.02	0.94	0.94	0.75	0.98	0.6	0.58
N2	1	1	0.85	0.89	0.99	0.95	0.57	0.47
N3	1	0.97	0.82	0.91	0.89	0.96	0.66	0.5
N4	1	0.99	0.88	0.94	0.96	0.97	0.64	0.53
Construction proposal	E17	E18	E19	E20	E21	E22	-	-
N1	0.24	0.4	0.06	0.39	1	1	-	-
N2	0.27	0.37	0.07	0.44	1	0.83	-	-
N3	0.27	0.39	0.13	0.39	1	0.92	-	-
N4	0.24	0.45	0.04	0.43	1	0.09	-	-

### 5.3.2 Calculation of entropy weights for evaluation indicators

According to the calculation methods and steps outlined in Chapter 3, the entropy weights for the 22 evaluation indicators are calculated using formulas (3-4) to (3-7). The results of the characteristic weights for the 22 evaluation indicators of the four construction plans are listed in Table 5.6. The coefficients of variation for each evaluation indicator and the results of the entropy weight calculations are presented in Tables 5.7 and 5.8.

Table 5.6 Calculation results of characteristic weights for construction standardization evaluation indicators in the case study

Construction proposal	E1	E2	E3	E4	E5	E6	E7	E8
N1	0.064	0.046	0.007	0.071	0.057	0.007	0.043	0.006
N2	0.065	0.047	0.009	0.071	0.057	0.005	0.049	0.005
N3	0.065	0.049	0.009	0.071	0.055	0.006	0.041	0.005
N4	0.079	0.059	0.013	0	0.015	0.009	0.03	0.008
Construction proposal	E9	E10	E11	E12	E13	E14	E15	E16
N1	0.071	0.072	0.067	0.067	0.053	0.069	0.042	0.041
N2	0.071	0.071	0.061	0.064	0.071	0.068	0.041	0.034
N3	0.071	0.069	0.058	0.065	0.063	0.069	0.047	0.036
N4	0.086	0.085	0.076	0.081	0.082	0.084	0.055	0.046
Construction proposal	E17	E18	E19	E20	E21	E22	-	-
N1	0.017	0.029	0.004	0.028	0.071	0.07	-	-
N2	0.019	0.026	0.005	0.032	0.071	0.059	-	-
N3	0.02	0.028	0.009	0.028	0.071	0.066	-	-
N4	0.021	0.039	0.003	0.037	0.086	0.007	-	-

Table 5.7 Results of the parameters for 22 indicators in the case study

Parameters	E1	E2	E3	E4	E5	E6	E7	E8
$e_j$	-0.399	-0.323	-0.095	-0.271	-0.282	-0.073	-0.283	-0.068
$d_j$	1.399	1.323	1.095	1.271	1.282	1.073	1.283	1.068
$\omega_j$	0.05	0.047	0.039	0.045	0.045	0.038	0.045	0.038
Parameters	E9	E10	E11	E12	E13	E14	E15	E16
$e_j$	-0.423	-0.426	-0.4	-0.404	-0.389	-0.416	-0.302	-0.282
$d_j$	1.423	1.426	1.4	1.404	1.389	1.416	1.302	1.282
$\omega_j$	0.05	0.051	0.05	0.05	0.049	0.05	0.046	0.045
Parameters	E17	E18	E19	E20	E21	E22	-	-
$e_j$	-0.161	-0.234	-0.045	-0.238	-0.423	-0.285	-	-
$d_j$	1.161	1.234	1.045	1.238	1.423	1.285	-	-
$\omega_j$	0.041	0.044	0.037	0.044	0.05	0.046	-	-

Table 5.8 Entropy weights of the 6 first-level indicators for construction standardization in the case study

First-Level Indicators	$\omega_j$
Construction Cost	0.181
Construction Progress	0.128
Construction Safety	0.193
Construction Quality	0.149
Energy Management in Construction	0.182
Environmental Impact Control	0.221

From Table 5.7, it can be seen that the differences in the entropy weights of the secondary indicators are not significant. Among them, seven secondary indicators, including E10, E1, E9, E11, E12, E14, and E21, have relatively high entropy weights, reaching 0.05. This indicates that among the secondary indicators, total cost, material compliance rate, degree of key technical operations, first-time pass rate for quality inspections, industrial integration level of exterior protective

structures, energy-saving rate, and dust emission have a significant impact on the degree of construction standardization.

From Table 5.8, it can be observed that the entropy weights of the six primary indicators show significant differences. Based on the ranking of the indicators' influence according to their entropy weights, the order is as follows: Environmental Impact Control > Construction Safety > Energy Management in Construction > Construction Cost > Construction Quality > Construction Progress. Among these, the higher entropy weights of Environmental Impact Control, Construction Safety, and Energy Management reflect elements that represent the social benefits of construction projects, concerning environmental protection, pollution control, personnel safety, and resource and energy utilization during the construction process. These factors are directly related to the social responsibility and corporate image of construction enterprises, as well as to the long-term sustainable development of the companies. In contrast, the entropy weights for economic benefit factors (Construction Cost, Construction Quality, and Construction Progress) are lower. This does not imply that these factors are unimportant; rather, it suggests that, in selecting construction standardization schemes, social benefit factors should be prioritized. The social responsibilities undertaken by construction enterprises should take precedence over economic benefits, stemming from the social activity nature of construction projects.

### **5.3.3 Multi-indicator comprehensive evaluation of construction proposal**

Based on the standardized data of the 22 secondary indicators for the four construction plans in Table 5-5, the peak values for each indicator in the four plans are calculated according to Formula (3-10) from Chapter 3, as shown in Table 5.9.

Table 5.9 Calculation results of peak values for construction standardization evaluation indicators in the case study

Construction proposal	E1	E2	E3	E4	E5	E6	E7	E8
N1	0.873	0.774	0.615	0.692	0.755	0.764	0.889	0.844
N2	0.945	0.906	0.889	0.599	0.819	0.617	0.635	0.692
N3	0.969	0.795	0.889	0.764	0.635	0.764	0.624	0.692
N4	0.889	0.889	0.617	0.617	0.664	0.617	0.831	0.624
Construction proposal	E9	E10	E11	E12	E13	E14	E15	E16
N1	0.906	0.925	0.774	0.945	0.617	0.969	0.795	0.706
N2	0.969	0.969	0.844	0.831	0.686	0.889	0.857	0.686
N3	0.945	0.889	0.774	0.969	0.969	1	0.729	0.858
N4	0.925	0.945	0.858	0.844	0.729	0.889	0.795	0.831
Construction proposal	E17	E18	E19	E20	E21	E22	-	-
N1	0.721	0.906	1	0.889	0.889	0.737	-	-
N2	0.819	0.746	1	0.774	0.858	0.686	-	-
N3	0.721	0.831	0.774	0.906	0.635	0.906	-	-
N4	0.819	0.746	0.774	0.906	0.795	0.906	-	-

Using the indicator peak values and applying Formula (3-11), the comprehensive indicator weight vector for the four construction plans can be calculated as follows:

$$\omega_{1j} = (0.049, 0.043, 0.034, 0.038, 0.042, 0.042, 0.049, 0.047, 0.050, 0.051, 0.043)$$

$$\omega_{2j} = (0.053, 0.034, 0.054, 0.044, 0.039, 0.040, 0.050, 0.056, 0.049, 0.049, 0.041)$$

$$\omega_{3j} = (0.054, 0.044, 0.049, 0.042, 0.035, 0.042, 0.035, 0.038, 0.052, 0.049, 0.043)$$

$$\omega_{4j} = (0.051, 0.051, 0.035, 0.035, 0.038, 0.035, 0.047, 0.036, 0.053, 0.054, 0.049)$$

Next, the multi-indicator measurement matrix for each construction plan is calculated based on Formula (3-12):

$$u_{ij} = (\mu_{ij})_{4 \times 6} = \begin{pmatrix} 0 & 0.005 & 0.514 & 0.431 & 0.051 & 0 \\ 0 & 0.059 & 0.582 & 0.370 & 0.033 & 0 \\ 0 & 0.047 & 0.553 & 0.427 & 0.029 & 0 \\ 0 & 0.031 & 0.623 & 0.388 & 0.013 & 0 \end{pmatrix}$$

According to Formula (3-14), the comprehensive evaluation results for construction standardization of the four construction plans are listed in Table 5.10.

Table 5.10 Comprehensive evaluation results for construction standardization in the case study

Construction proposal	N1	N2	N3	N4
$P_i$	0.601	0.585	0.592	0.588

Based on the comprehensive evaluation results, the construction standardization management of the four construction plans can be ranked as follows:  $N1 > N3 > N4 > N2$ . It is evident that the construction plan provided by Company A is the most optimal in the standardization process. The comprehensive evaluation value of Company C is closest to that of Company A, and in the actual construction process, relevant indicator data from Company C can also be referenced as a basis for dynamic adjustments in standardization management.

Combining the indicator weight vectors of the four construction plans with the comprehensive evaluation results reveals the following:

Company A's construction proposal N1 has 5 secondary indicators with weights greater than 0.05, including 1 item for construction safety (material qualification rate), 1 item for construction quality (industrialized integration degree of peripheral protection structure), 1 item for construction energy-saving management (energy-saving rate), and 2 items for construction environmental impact control (noise pollution and light-electric influence). The weight distribution of the 22 indicators is relatively even, with only 3 indicators having weights less than 0.04, and 81% of the indicators having weights close to 0.05. This indicates that Company A's indicators are relatively standardized and comprehensive.

Company C's construction proposal N3 has 7 secondary indicators with weights greater than 0.05, similar to Company A, with the only difference being that Company C focuses on construction precision instead of industrialized integration degree of peripheral protection structure. However, the weight distribution of Company C's secondary indicators is uneven, with approximately 30% of the indicators having weights less than 0.04.

Company D's construction proposal N4 has 7 secondary indicators with weights greater than 0.05, including 2 items for construction cost (total construction cost and labor cost proportion), 2 items for construction safety (material qualification rate and key technical operation degree), 1 item for construction energy-saving management (energy-saving rate), and 2 items for construction environmental impact control (building waste and drinking water source detection quality). The weight distribution of the secondary indicators is uneven, with approximately 30% of the indicators having weights less than 0.04.

Company B's construction proposal N2 has 7 secondary indicators with weights greater than 0.05, similar to Company A, with the difference being that Company B focuses on 3 items for construction cost (total construction cost, labor cost proportion, and material saving), and only 1 item for construction environmental impact control (light-electric influence). The weight distribution of the secondary indicators is also uneven, with approximately 30% of the indicators having weights less than 0.04.

In conclusion, based on the entropy weight comprehensive evaluation method, the evaluation results of the construction standardization for the health tourism center project show that Company A's construction proposal N1 is the most optimal choice, meeting the basic requirements of project construction standardization and energy-saving construction. The proposal's indicator weight distribution is relatively even, comprehensive, and strong in environmental protection and energy-saving awareness. Therefore, Company A's construction proposal is the best choice for construction standardization evaluation.

## REFERENCES

- Akintoye, A. (2000). "Analysis of factors influencing project cost estimating practice." **Construction Management and Economics**, 18: 77–89.
- Cheng, Y.-M. (2014). "An exploration into cost-influencing factors on construction projects." **International Journal of Project Management**, 32: 850–860.
- Chengkuan, F., and Chun-ling, Z. (2021). "Risk assessment for construction safety of prefabricated building based on cloud model and entropy weight method." **Journal of Jilin Jianzhu University**, 38, 6: 67-74.
- Fanwen, K., Tianjiao, L., and Hongyan, Z. (2018). "Emphasis and measures of cost control in real estate development project during construction." **Journal of Shenyang Jianzhu University Social Science**, 20, 2: 148–153.
- Guichao, L. (2022). "Research on construction safety evaluation based on AHP-entropy-cloud model." **Construction Machinery & Maintenance**, 5: 243-247.
- Guoyin, W., Deyi, L., Yiyu, Y., Jiye, L., Duoqian, M., Yanping, Z., and Qinghua, Z. (2012). **Cloud Model and Granular Computing**. China Science Publishing & Media LTD.
- Haixia, K. (2023). "Research on quality evaluation of construction engineering surveying based on AHP entropy weight cloud model." **Project Management Technology**, 21, 8: 146-150.
- Hallowell, M. R., and Gambatese, J. A. (2009). "Construction safety risk mitigation." **Journal of Construction Engineering and Management**, 135, 12: 1316-1323.
- Jiaoli, L. (2018). "Study on sustainability evaluation of green building based on AHP-entropy weight method and cloud model." **Jiangxi University of Finance and Economics**.
- Jie-chao, Z. (2011). "A spatial load forecasting method based on cloud theory and analytic hierarchy process." North China Electric Power University.
- Joe M. Wilson Jr., Enno “Ed” Koehn, Fellow, and ASCE. (2000). "Safety management: problems encountered and recommended solutions." **Journal of Construction Engineering and Management**, 126: 77-79.

- Khodeir, L. M., and Ghandour, A. E. (2019). "Examining the role of value management in controlling cost overrun [application on residential construction projects in Egypt]." **Ain Shams Engineering Journal**, 10: 471–479.
- Lixiang, Q. (2008). "Discussion on standardized management of engineering project." **Project Management Technology**, 3: 57-60.
- Mengqi, Z. (2020). "Research on the evaluation of the healthy city construction level of Qingdao based on the entropy weight method cloud model." Qingdao University of Science & Technology.
- Mengting, S. (2018). "Research on route decision method based on cloud model." Hefei University of Technology.
- Min, L. (2014). "Research on controller algorithm based on cloud model." **Xian University of Architecture and Technology**.
- Qing, L., Qingkuan, D., and Lei, Z. (2013). "Modified forward cloud generator in the cloud model." **Journal of Xidian University**, 40, 5: 169-174, 180.
- Qingming, F. (2023). "A study on the evaluation of paper companies' green behaviour performance based on the anti-entropy-cloud model." Chongqing Technology and Business University.
- Rosenfeld, Y. (2014). "Root-Cause analysis of construction-cost overruns." **J. Constr. Eng. Manage**, 140, 1: 04013039.
- Shengquan, Z. (2020). "Study on control and Optimization of prefabricated construction cost." Anhui University of Technology.
- Shi-lian, Z., and Jiao-jiao, X. (2010). "Analysis of the influence of building energy efficiency on engineering cost at the design stage based on grey system theory." **Journal of Xihua University Natural Science**, 28, 5: 60–62, 74.
- Smith, P. (2014). "Project cost management—global issues and challenges." **Procedia-Social and Behavioral Sciences** 119: 485–494.
- . (2016). "Global professional standards for project cost management." **Procedia-Social and Behavioral Sciences**, 226: 124–131.
- T. Michael Toole, P.E., M.ASCE, John A. Gambatese, P.E., and M.ASCE. (2002). "Safety management: problems encountered and recommended solutions." **Practice Periodical on Structural Design and Construction**, 7: 56-60.

- Tianbo, Y. (2020). "Discussion on standardized management strategy of construction engineering project." **China Construction**, 3: 36-37.
- Wei, C. (2018). "Discussion on standardized management of engineering project in construction enterprise." **Sichuan Cement**, 4: 203.
- Wei, L. (2010). "Discussion on the cost control management in the construction stage of construction project." **Journal of ShanXi Finance and Economics University**, 32, 1: 154.
- Xian-guo, W., Hai-zhou, Z., Li-mao, Z., Ya-wei, Q., and Yan-hong, W. (2014). "Improved R=P×C risk assessment method based on cloud model." **Journal of Civil Engineering and Management**, 31, 1: 37-42.
- Xiaolin, Y., Shoujian, Z., and Liang, M. (2011). "A study of the maturity model for enterprise implementation of construction standards." **China Civil Engineering Journal**, 44, 3: 136-142.
- Yong-qiang, C., Ning, Z., and Qiu-bo, Y. (2010). "Literature review on project delivery systems." **Journal of Engineering Management**, 24, 5: 473-478.
- Zheng, Y. (2023). "Research on residential engineering cost estimation based on BPNN-taking H company as an example." Zhe Jiang University.



## VITA

**NAME**

Mr. Lei Kun

**INSTITUTIONS**

1. Hohai University, Bachelor's degree in  
Water Conservancy Engineering

**ATTENDED**

2. Silpakom University, Master of Engineering,  
Program in Engineering Management

