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Life Cycle Assessment of Wood as a Sustainable Material: Greenhouse Gas Emissions and Life Cycle Costs

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Abstract: With the increasingly serious environmental problems, the use of sustainable materials is particularly important. This study focuses on the greenhouse gas emissions and economic costs of wood over its life cycle as a sustainable resource. We use a systematic life cycle assessment (LCA) approach to assess the entire process from raw material collection, processing, use to disposal. The study found that using wood can significantly reduce greenhouse gas emissions compared to traditional building materials such as steel and concrete. In addition, although the initial procurement costs of wood may be higher, its maintenance costs are lower in the long run, making the life cycle costs generally more economical. The results of this study highlight the environmental and economic advantages of wood in the selection of sustainable building materials, and provide a scientific basis for promoting the use of wood.

Keywords: Wood; Sustainable materials; Life cycle assessment; Greenhouse gas emissions; Life cycle cost

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1. Introduction

With the prominence of global environmental problems, human beings pay increasing attention to ecological protection and climate change. Therefore, the development and use of sustainable materials, especially in the construction industry, has become urgent. The subject of this study is wood, a renewable resource, to explore its environmental and economic performance as a building material. Compared with traditional non-renewable resources such as steel and concrete, wood has environmental advantages such as efficient absorption of carbon dioxide and trace greenhouse gases released during the life cycle. However, in terms of economic costs, the use of wood is not universally accepted, often due to its high initial procurement costs. Therefore, this study adopts a systematic life cycle assessment method to comprehensively analyze the whole process of wood collection, processing, use to waste, in order to measure its actual effect as a sustainable material and reveal its potential economic value. This will not only promote and enhance the use of wood in the field of construction, but also provide scientific theoretical basis and practical guidance for achieving double benefits of environmental protection and economy.

2. Sustainable development and sustainable materials

2.1. Importance of sustainable development

Sustainable development has gradually become the core issue of global social concern, and its importance is reflected in the comprehensive needs of environmental protection, economic development and social progress^[1]. With the intensification of resource consumption and environmental pollution, mankind is faced with major challenges such as resource depletion and climate change. Sustainable development aims at meeting the needs of the present and preserving adequate resources and environmental conditions for future generations. This concept emphasizes that economic growth must go hand in hand with environmental protection to ensure the long-term health of ecosystems and sustainable human development.

Environmentally, sustainable development requires reducing dependence on fossil fuels and reducing greenhouse gas emissions in order to slow the rate of climate warming. Economically, shifting to renewable resources and sustainable solutions not only creates new jobs, but also drives technological innovation and makes resource use more efficient. On the social side, it is committed to achieving broader social equity and improving the quality of human life. In summary, the importance of sustainable development is not only related to the carrying capacity of the earth, but also to the future prosperity of human civilization^[1-3]. The choice of sustainable materials, such as wood, is important to achieve this goal.

2.2. Definition and classification of sustainable materials

Sustainable materials are those that have the least impact on the environment during the production, use and waste stages and are economical. These materials focus on reducing resource consumption and pollution emissions throughout their life cycle to achieve long-term ecological balance. According to their source and characteristics, sustainable materials can be divided into natural renewable materials, recycled materials and low-energy materials. Natural renewable materials such as wood, bamboo, etc. are renewable and biodegradable. Recycled materials include materials processed from waste recycling, such as recycled paper and recycled plastics. Low-energy materials are materials that consume less energy during manufacturing and use, such as high-efficiency insulation. Through proper selection and use, sustainable materials can help mitigate environmental degradation and resource scarcity.

2.3. Advantages of wood as a sustainable material

Wood has multiple advantages as a sustainable material. Its biodegradability allows it to break down naturally at the end of its life cycle, reducing environmental pollution. Wood absorbs a large amount of carbon dioxide through photosynthesis during the growth process, thus exhibiting carbon-negative emission characteristics during the use stage. Compared with traditional materials, the processing of wood consumes less energy and the production process is more environmentally friendly. The good insulation properties of wood can also improve the energy efficiency of buildings and reduce energy consumption. These properties make wood an ideal material choice for sustainable construction.

3. Greenhouse gas emissions and life cycle assessment

3.1. Relationship between greenhouse gas emissions and environmental problems

Greenhouse gas emissions are one of the main drivers of global climate change, with significant negative impacts on the environment. These gases are mainly produced by human activities, including fossil fuel use, industrial processes, and land use changes. Carbon dioxide, methane, and nitrous oxide are the main greenhouse gases, and their long-term existence in the atmosphere causes the Earth's surface temperature to rise, which in turn causes

a series of environmental problems, such as frequent extreme weather events, sea level rise, and ecosystem imbalance ^[4-6]. As one of the world's important economic sectors, the construction industry is one of the main sources of greenhouse gas emissions. Careful evaluation of the selection and use of building materials, especially the assessment of greenhouse gas emissions, has become particularly important. Life Cycle Assessment (LCA) is a systematic approach that can be used to quantify the environmental impact of building materials over their entire life cycle. LCA enables the identification and quantification of greenhouse gas emissions from raw material extraction to final disposal, thereby providing a basis for the selection of low-emission materials and helping to drive the construction industry towards a lower environmental impact.

3.2. Concepts and methods of life cycle assessment

Life Cycle Assessment (LCA) is a systematic method for assessing the environmental impact of a product throughout its life cycle. Its main steps include definition of objectives and scope, inventory analysis, impact assessment and interpretation of results. This approach provides a comprehensive understanding of a product's environmental footprint by analyzing the stages from raw material acquisition to production, use and final disposal. In the field of environmental science, LCA is widely used to quantify greenhouse gas emissions and other environmental impacts. It helps decision makers identify the most environmentally responsible parts of the product life cycle and provides scientific support for sustainable production and consumption. LCA assessments of sustainable materials, particularly wood, reveal their potential to reduce carbon emissions and resource consumption.

3.3. Assessment of greenhouse gas emissions from wood

Greenhouse gas emissions from wood as a building material are assessed using a life cycle assessment approach. The assessment covers all stages from raw material collection, processing, and manufacturing to use and disposal. Wood sequesters carbon through photosynthesis as it grows, reducing overall greenhouse gas emissions. The relatively low energy consumption and emissions at the processing stage further enhance its environmental advantages. Compared to traditional building materials, the use of wood significantly reduces carbon dioxide emissions, which is attributed to wood's natural carbon sequestration capacity and lower manufacturing energy consumption, providing a strong environmental case for its use as a sustainable building material.

4. The life cycle cost of wood

4.1. Cost of wood collection and processing

The cost of collecting and processing wood plays an important role in its life cycle cost. During the collection process, the main costs come from forest management, harvesting operations, and raw material transportation ^[7]. Efficient forest management helps to reduce the cost of harvesting and ensure the sustainability of resources. In logging operations, the use of machinery, fuel consumption, and labor costs are the main components of the cost. During the transportation phase, the logistics costs of transporting wood from the harvesting site to the processing plant significantly affect the overall cost, with distance and traffic conditions being key factors.

The processing cost mainly involves two stages of wood primary processing and deep processing. In the initial processing stage, common processes such as sawing and drying require a lot of energy, and equipment depreciation and labor costs constitute the main expenses at this stage. The deep processing stage involves fine processing and finished product production, which also requires high-tech equipment and skilled labor, resulting in higher costs. Thanks to technological advances and scale effects, processing efficiency has been improved, and unit costs have been reduced. Costs in these processes can also be affected by regional energy prices and labor

market fluctuations.

4.2. The cost of using wood

The cost of using wood plays an important role in the life cycle of a building, including maintenance, repair, and maintenance. Compared to other building materials, wood has good durability and natural thermal insulation, reducing the need for additional energy and thus reducing long-term operating costs ^[8]. The lightweight nature of this material not only simplifies structural design but also reduces equipment and labor costs during construction. In daily maintenance, wood needs to be regularly treated against insects and moisture, but these costs are relatively low due to the reparability and ease of processing of the material itself. The natural aging process of wood gives the building a unique aesthetic value, increasing the attractiveness of long-term investments and market competitiveness. These factors make wood significantly cost-effective at the use stage.

4.3. Waste disposal cost of wood

The cost of wood disposal plays an important role in life cycle cost assessment. The abandonment stage includes demolition, transportation, and final disposal, and the main factors affecting the cost of disposal are local waste management policies and infrastructure. Compared with other materials, due to the renewable and biodegradable properties of wood, the processing cost can be reduced through recycling and biological treatment. The recycling of waste wood not only reduces its treatment costs but also provides raw material support for subsequent industries. The cost of wood disposal is economically advantageous and meets the requirements of sustainable development, which helps to reduce the environmental burden ^[9].

5. Comparison of wood and other building materials

5.1. Comparison of wood and steel

When comparing the performance of wood versus steel as a building material, the focus is on greenhouse gas emissions and life-cycle costs. The production process of steel involves high temperature heating and REDOX reactions, resulting in significant carbon dioxide emissions, and is one of the major sources of greenhouse gas emissions. In contrast, wood absorbs carbon dioxide through photosynthesis during its natural growth and is sequestered during its use stage, which results in lower net emissions over its life cycle. Maintenance and corrosion protection of steel often require additional energy inputs and chemical treatment, increasing the environmental load during its use phase. In terms of economic costs, although the initial purchase of wood may be costly, the low maintenance and processing costs show long-term economic advantages over its life cycle. The superior performance of wood in environmental benefits and economy provides an effective material choice for the transformation of the construction industry to the direction of low-carbon and sustainable development ^[10, 11].

5.2. Comparison between wood and concrete

There are significant differences between wood and concrete in terms of greenhouse gas emissions and life cycle costs. In the process of concrete production, due to the need for high-temperature calcination of limestone, it will release a lot of carbon dioxide, making its greenhouse gas emissions significantly higher than those of wood. Concrete production involves several resource-intensive steps, including mining, transportation, and processing, which have a much higher energy consumption and environmental impact than wood. Wood, as a natural material, its collection and processing process has a low impact on the environment, and it can also sequester carbon during the use stage, which helps to mitigate climate change. In terms of life cycle costs, although the initial procurement cost of wood may be higher than that of concrete, due to the lower maintenance and restoration costs of wood,

considering its full life cycle costs, wood is more economical. The above comparison shows that wood has advantages in terms of both environmental friendliness and economy, providing a sustainable alternative for the construction industry ^[12].

5.3. Demand and utilization of wood in the construction industry

The demand for and use of wood in the construction industry has shown a growing trend in recent years, mainly due to its widely recognized ecological advantages as a sustainable material. Compared to steel and concrete, wood attracts more construction companies because of its low carbon emissions and lower life cycle costs. In the promotion of green building and environmental protection regulations, wood is gradually used for structure, decoration, furniture, and other purposes. Its renewable and aesthetic characteristics have further increased the market demand, and an increasing number of construction projects have begun to prioritize wood, creating opportunities for innovation and transformation in the industry ^[13, 14].

6. Conclusion and future outlook

6.1. Environmental and economic significance of the results of this study

A detailed analysis of the life cycle of wood as a sustainable material reveals its environmental and economic significance. In terms of the environment, the use of wood can significantly reduce greenhouse gas emissions and has a positive effect on climate change mitigation compared to traditional building materials such as steel and concrete. This will not only help meet global greenhouse gas reduction targets, but also provide a green, low-carbon solution for the construction industry.

At the economic level, although wood may lead to higher inputs when initially purchased, low maintenance costs throughout its life cycle make the total cost more economical. This cost-effectiveness continues to stand out over the long term, providing sustainable economic support for construction projects. Especially in the context of sustainable development and green economic transformation, the economic competitiveness of wood has been further reflected ^[15].

This study not only validates the dual advantages of wood as a sustainable material, but also provides a scientific and forward-looking reference basis for policymakers and industry practitioners in the selection of materials, helping to promote the widespread use of sustainable materials in the construction industry.

6.2. The application prospect of wood as a sustainable material

Wood holds great promise as a sustainable material, and its use in the construction industry helps to reduce environmental impact and reduce long-term economic costs. Due to its low carbon footprint and renewable properties, wood will play an important role in the future of green buildings. Wood's unique structure and ability to regenerate make it an ideal alternative material, especially in the context of rapid urbanization. With the advancement of technology and the improvement of design standards, the durability and safety of wood are gradually enhanced, opening up more application possibilities. The increase in policy support and market demand will also drive the expansion of sustainable wood applications, contributing to the low-carbon transition in the construction industry.

6.3. Suggestions for future research directions

Future research should focus on the sustainability performance of wood in different geographical and climatic settings to more fully understand its potential benefits. In-depth analysis of wood's synergies with other emerging sustainable materials can reveal its potential for use in innovative architectural design. Research into technological

innovations in wood production and processing can help further reduce costs and environmental impact. Considering the changing policy and market trends, it is also important to study how to promote the use of wood by optimizing supply chain management and sustainable building policies. These directions will help promote the wider application and development of wood on a global scale.

7. Conclusion

Using life cycle assessment (LCA) methods, this study examines wood from raw material collection, processing, use to waste, and reveals the environmental and economic benefits of wood as a sustainable resource compared to traditional building materials such as steel and concrete. The results of the study show that although the initial procurement cost of wood may be higher, in the long term, its overall life cycle cost is economically beneficial due to its lower maintenance costs. At the same time, wood can effectively reduce greenhouse gas emissions, showing superior environmental performance. Therefore, the promotion and application of wood in the field of construction has great potential and significant environmental and economic benefits. However, this study only evaluated wood as a sustainable material from the perspectives of greenhouse gas emissions and life cycle costs, and it did not take into account other environmental factors such as forestry management and wood sources. Therefore, further evaluation and discussion are needed in future studies. Future studies will also need to consider the source of wood, such as whether it comes from sustainable forest management, and whether it has an impact on biodiversity. It is hoped that these studies will provide a more comprehensive and in-depth assessment to support decision makers in making informed choices by choosing sustainable building materials. This study provides a strong scientific basis for promoting the use of wood and provides a new research direction for future studies of wood as a sustainable material.

Disclosure statement

The author declares no conflict of interest.

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Research on Project Quality Management Mechanism of IT SMEs

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Abstract: IT SMEs as an important force can promote scientific and technological innovation and economic development, the effectiveness of project quality management mechanism is directly related to the survival and development of IT SMEs. This paper take IT SMEs as the research object, which deeply discusses the situation, existing problems and improvement strategies of the project quality management mechanism, and combines agile management and total quality management (TQM) theories to build a dynamic and adaptive project quality management mechanism. Through deeply analysis, the effectiveness of the mechanism is proposed, and the optimization path is proposed, aiming at providing theoretical support and practical guidance for enterprises to improve project delivery quality and enhance market competitiveness.

Keywords: IT SMEs; Project quality management; Mechanism study; Agile management; TQM theories

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1. Introduction

With the acceleration of digital transformation and the rapid development of information technologies, such as artificial intelligence, cloud computing, and Internet of Things, IT SMEs are playing an increasingly important role in promoting global economic development ^[1]. According to the data of China's Ministry of Industry and Information Technology, the income scale of China's information technology service industry exceeded 12 trillion yuan in 2023, with an annual growth rate of 15%, and SMEs will account for more than 70%, becoming an important force for technological innovation. However, the speed of technology iteration, such as the rapid update of software development frameworks, has led to a surge in project complexity and higher requirements for quality management ^[2]. As the core carrier of enterprise development, the quality management level of the project directly affects the market competitiveness and sustainable development ability of the enterprise. The information technology industry has the characteristics of rapid technology iteration and high demand uncertainty, and SMEs often face the risk of quality loss due to resource constraints ^[3]. Traditional quality management model, like the waterfall model, is difficult to meet the needs of agile development, and it is urgent to explore a lightweight and flexible management mechanism ^[4]. Therefore, it is of great practical significance to deeply study the project quality management mechanism of IT SMEs.

2. Literature review

Total Quality Management (TQM) is a management concept proposed by American quality management experts in the late 1950s, aiming to improve product quality and enterprise efficiency through full participation and whole-process control. After decades of development, total quality management has become an important part of modern enterprise management, which has a profound impact on the competitiveness of enterprises and sustainable development^[5]. Edwards is one of the founders of total quality management and is known as the “pioneer of quality management”^[6]. He developed the famous “Deming Cycle” (PDCA cycle) and the “Fourteen points”. The PDCA cycle includes four stages: Plan, Conduction, Check and Act. It is a management method that continuously cycles and gradually improves. Juran, an important promoter of total quality management, proposed the “Juran three steps”, namely quality planning, quality control, and quality improvement^[7]. Quality planning refers to the determination of quality objectives and the formulation of plans to achieve the objectives; Quality control refers to the monitoring of the production process to ensure that the product quality meets the standards; Quality improvement refers to increasing the level of quality through continuous improvement of products and processes. Juran also put forward the “20 to 80 rule”, that is, 80% of quality problems are caused by 20% of the key reasons, emphasizing the identification and solution of key problems^[7].

Crosby who is the author of the “Zero defect” quality management philosophy, emphasizes “doing things right the first time” and he believes that quality is compliance, prevention is better than inspection, and the standard must be “zero defects” and measured in terms of “the cost of substandard products^[8].” Crosby also proposed the four basic principles of quality management: the definition of quality, the system of quality, the standard of work, and the measurement of quality. Feigenbaum propose the total quality control, advocated a systematic approach to quality management that involved all functional departments, not just production^[9]. He emphasizes establishing quality early in the formation of a product, rather than inspecting and controlling it after it is finished. Juran’s quality management concept has been widely disseminated and applied in China. Many Chinese quality management experts and scholars have put forward quality management methods and tools suitable for China’s national conditions combined with the actual situation of Chinese enterprises^[10].

Agile quality management is an important management concept to adapt to rapidly changing market demands and enhance enterprise competitiveness^[11]. It takes iterative delivery and continuous feedback as the core to adapt to rapidly changing demands. The development of agile quality management can be traced back to the early 1990s, with the rise of agile methods in the field of software development and gradually attracted attention^[12]. In 1991, Jeff Sutherland and Ken Schwaber developed the Scrum framework, an iterative and incremental software development process that emphasizes team collaboration and rapid delivery^[13]. Then, the Agile Software Development Manifesto marked the formal formation of the Agile approach, which set forth the values of individuality and interaction, software that works, customer collaboration, and responsiveness to change. Since then, the concept of agile quality management has gradually expanded from the field of software development to other industries, such as manufacturing and service industries^[14].

Poppendieck focuses on Lean Agile and quality management, proposing Value stream-driven quality optimization, identifying waste in the development process (e.g., repeated testing, waiting for approval), and shortening the quality feedback loop through Value Stream Mapping^[15]. Farley, who has studied continuous delivery and quality engineering for a long time, proposed that automated testing should cover functional, performance, and safety dimensions, and be linked to monitoring systems to achieve a “production-as-test environment^[16].” The modular design and low coupling architecture support continuous quality optimization and avoid large-scale refactoring costs. Shi *et al.* proposed agile quality management methods and tools tailored to China’s national context, aligning closely with the practical conditions of Chinese enterprises^[17]. She emphasized

that in agile project management, it is necessary to pay attention to team collaboration, customer demand orientation and continuous delivery, and improve the quality and efficiency of projects by establishing efficient communication and feedback mechanisms^[17]. In the research and practice of agile quality management, Xing *et al.* put forward the agile quality management system based on value stream^[18]. The system is customer-oriented and optimizes processes through value stream analysis to reduce waste and improve value creation efficiency. At the same time, he emphasized building a quality culture in Agile teams, cultivating employees' quality awareness and responsibility, and promoting the participation of all employees in quality management. The difference between Agile project management and traditional quality management is shown in **Table 1**.

Table 1. The difference between Agile project management and traditional quality management

Field	Traditional quality management (e.g. TQM)	Agile quality management
Process focus	Phased control (e.g. demand freezing)	Dynamic adjustment (embrace change)
Document dependencies	Highly documented (e.g. test case library)	Light documentation (code is documentation)
Defect treatment	Centralized repair (late test phase)	Instant repair (daily build)

3. The current situation of the project quality management mechanism of IT SMEs

3.1. The establishment of the quality management system

Some IT SMEs have initially established quality management systems, such as ISO 9001 and other standards; however, there are issues in practical implementation, including a disconnect between documented procedures and actual operations. Although some enterprises have developed quality manuals and procedural documents, in actual project implementation, time, cost, and other constraints often lead to the simplification or omission of key quality control processes, resulting in a superficial or ineffective quality management system.

3.2. Application of quality management methods

Common quality management methods such as total quality management (TQM), Six Sigma, etc. are not widely and deeply applied in IT SMEs. Some enterprises still mainly rely on traditional quality inspection and testing means, and lack of quality control and preventive measures for the whole process of the project. This allows quality problems to be discovered late in the project, increasing rework costs and the risk of project delays.

3.3. Quality awareness and cultural construction

The quality awareness of employees in IT SMEs is uneven; some employees do not know enough about the importance of quality management, and lack the enthusiasm to actively participate in quality management. At the same time, the quality culture within the enterprise has not yet formed, causing the lack of quality environment to encourage innovation and pursue excellence, which has a negative impact on the continuous improvement of project quality management.

4. Problems existing in the project quality management mechanism of IT SMEs

4.1. Weak quality awareness

The management and employees of some IT SMEs do not know enough about the importance of quality management, and focus on the progress and cost control of the project, while ignoring the improvement of quality. This short-sighted behavior leads to the continuous reduction of quality requirements in the process of project

execution, which ultimately affects the overall quality of the project.

4.2. Lack of quality management personnel

IT SMEs often face the problem of talent shortage, especially the lack of professional quality management talents. This makes the enterprise lack of professional guidance and supervision in project quality management, difficult to effectively implement quality control measures, resulting in frequent quality problems.

4.3. The quality management system is not perfect

There are many defects in the quality management system of some IT SMEs, such as unclear quality objectives, unclear division of quality responsibilities, and incomplete quality records. These problems cause the quality management system to not operate effectively, and affects the ability to effectively monitor and improve the quality of the project.

4.4. Backward means of quality control

IT SMEs often adopt more traditional and backward means in project quality control, and lack of advanced quality detection tools and technologies. This makes it difficult to find and solve potential quality problems in time during the implementation of the project, which increases the risk of the project.

4.5. The quality improvement mechanism is not sound

Some IT SMEs lack effective quality improvement mechanisms and fail to conduct in-depth analyses and summaries of quality problems during project implementation. This causes similar problems to recur in subsequent projects and prevents the achievement of continuous improvement in project quality.

5. IT SMEs project quality management dynamic mechanism model

The effective operation of the project quality management mechanism is very important for the survival and development of IT SMEs. Through in-depth analysis of the current situation and existing problems, and adopting corresponding improvement strategies, the project quality management level of enterprises can be effectively improved, and the market competitiveness and sustainable development ability of enterprises can be enhanced. Enterprises should attach great importance to quality management, constantly optimize the quality management mechanism, and lay a solid foundation for the long-term development of enterprises. The project quality management mechanism model is shown in **Figure 1**.

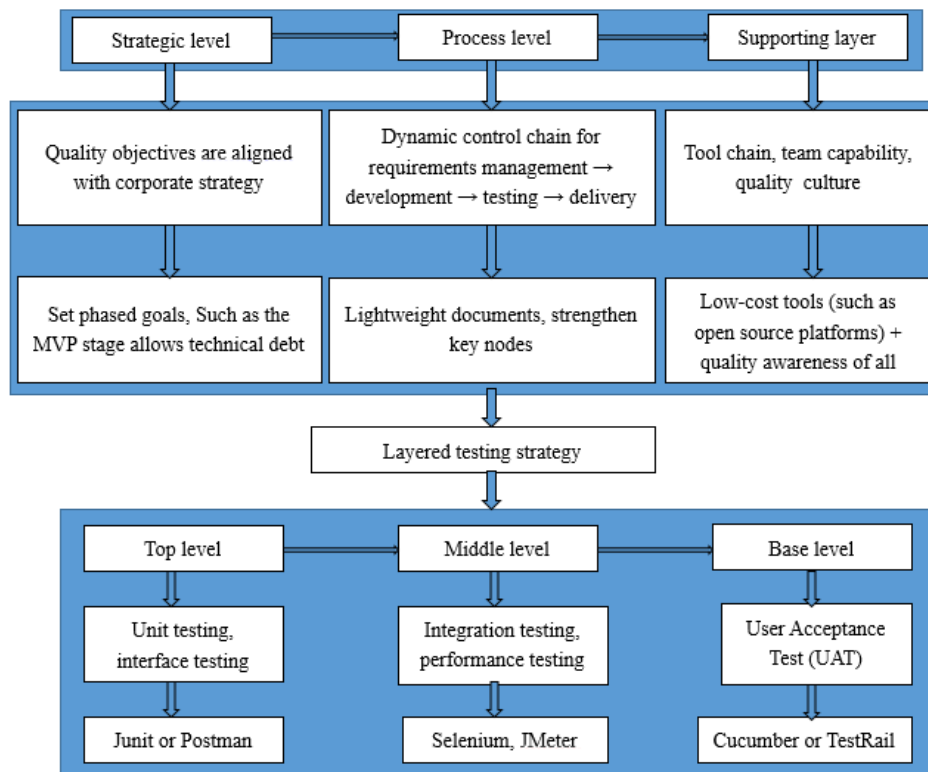


Figure 1. The project quality management mechanism model.

6. Conclusion

To better promote the long-term and stable development of enterprises, project quality management mechanism improvement strategy of IT SMEs is proposed.

6.1. Strengthen quality awareness training

Enterprises should strengthen the quality awareness education of all employees through quality training and publicity activities, so that they realize the importance of quality management for enterprise development. At the same time, the quality performance is included in the staff assessment system to encourage employees to actively participate in quality management and form a good atmosphere for all staff to pay attention to quality.

6.2. Strengthen the construction of quality management personnel

Enterprises should increase the introduction and training of quality management talents, and improve the overall quality of enterprise quality management team through recruitment of professional talents and internal training. In addition, employees can also be encouraged to participate in quality management related certification examinations to enhance their professional level and ability.

6.3. Improve the quality management system

Enterprises should establish a set of scientific, perfect and in line with the characteristics of information technology project quality management system based on their own actual conditions. Define quality objectives, quality responsibilities and quality processes to ensure the effective operation and continuous improvement of the quality management system. At the same time, strengthen the internal audit and management review of the quality management system to find and correct the existing problems in a timely manner.

6.4. Introduce advanced quality management methods and tools

Enterprises can learn from and apply advanced quality management methods such as Total Quality Management (TQM) and Six Sigma, as well as advanced quality control tools such as project management software and automated testing tools. Through the application of these methods and tools, the whole process of project quality control can be realized, and the level and efficiency of project quality management can be improved.

6.5. Establish a quality improvement mechanism

Enterprises should establish a set of perfect quality improvement mechanisms to systematically analyze and summarize the quality problems in the process of project implementation. Corrective and preventive measures should be developed to continuously improve project quality and prevent similar problems from happening again. At the same time, employees should be encouraged to put forward quality improvement suggestions to form a quality culture of continuous improvement.

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Development and Evolution of Digital Construction Management Adoption in China's Construction Industry

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Abstract: The development of digital construction management is an important initiative to promote the digital transformation of the construction industry. But the attention to the regional differences in the development level of digital construction management in China from the industrial level is still relatively scarce. In this paper, the combination assignment method, Dagum's Gini coefficient and Kernel density estimation method, are used to explore the regional differences and their dynamic evolution trends of China's digital construction management development level. The study finds that the overall development level in China's construction industry is on the rise, but it is still at a relatively low level. The overall Gini coefficient has increased, which is mainly due to uneven development between regions. There are large development differences between the eastern region and the other three regions. The interregional Gini coefficients for the Central-Northeastern and Central-Western regions are all growing at a higher rate.

Keywords: Digital; Construction management; Regional differences; Dagum's Gini coefficient; Kernel density estimation

Online publication: May 30, 2025

1. Introduction

Industrial digitization, as an important part of the digital economy, has a profound impact on the digital transformation and upgrading of traditional industries. It has become a new engine for building a modernized industrial system with high added value^[1]. The construction industry is one of the important implementation areas of industrial digitization. But its pace of transformation is still relatively backward, with problems like high energy consumption and pollution, sloppy management methods, and a low level of informatization^[2, 3]. Deep-rooted conflicts between the above problems and the increasing projects volume, technical difficulties and society's requirements for the environment, urgently require the promotion of industrial digitization, which empowers the transformation and upgrading of the construction industry^[4]. Scholars at home and abroad have focused on the research of digital construction management in the fields of building information modeling (BIM) and digital twin, Internet of Things (IoT), blockchain, and artificial intelligence (AI). There are strong advantages of BIM technology in the management of engineering project entity data and information^[5]. At the same time, real-time

prediction, optimization, control, and improved decision-making are accomplished through data and simulators by digital twin technology, which has received much attention^[6, 7]. Blockchain and IoT, increasingly applied to solve the problems of lack of collaboration, poor supervision, and information occlusion in construction management, are also the focus of research in related fields^[8]. Automatic identification of worker behavior, construction prediction using neural network models, and effective management of construction resources of AI technology have also become research hotspots^[9–11].

For the problem of inadequate integration and uneven development between digital technology and construction management, scholars mostly focus on the project level, with technology development and improvement as the breakthrough to promote the digital transformation of construction management. However, the problems are difficult to be solved only by technological innovation at the project level. It is urgent to think about the solution from the perspective of the whole industry. However, there is a large gap in the research launched from the industrial level. Whether digital construction management has landed at the industrial level and whether there are differences in the industrial development level, attention to these issues is lacking in the existing research. Therefore, the regional difference and its evolution trend of the development level of digital construction management in China's construction industry are studied from the industrial level in this paper, to promote the integrated and balanced development of digital construction management.

2. Methodology and indicator system

2.1. Research methods

2.1.1. Dagum Gini coefficient decomposition

The Gini coefficient decomposition method proposed by Dagum is an important method to measure the regional development differences^[12]. The relative difference of China's digital construction management development in different regions are reflected by decomposing the Gini coefficient into three parts: intra-regional difference contribution, inter-regional difference contribution, and hyper-variable density contribution.

2.1.2. Kernel density estimation

Kernel density estimation relies solely on sample data to assess the characteristics of spatial distribution and trends, avoiding discrepancies between actual and measured values that may arise from assuming a predefined functional form. So this method is weakly dependent on the model and has strong stability, and often used to explore the spatial non-equilibrium of the data^[13].

2.2. Composite indicator system and data sources

Based on existing research experience, this paper constructs a digital construction management evaluation index system with four first-level indicators^[14, 15]. The index system takes digital infrastructure as the foundation, digital effect as the core objective, digital input as the driving force, and digital application as the engine. The system includes nine second-level indicators, their weights are shown in **Table 1** below.

This paper selects data from 31 provinces (administrative regions) in China other than Hong Kong, Macao, and Taiwan as the research sample, spanning the period from 2014 to 2022. The data for the research are all obtained from *China Statistical Yearbook*, *China Statistical Yearbook on Construction*, *China Statistical Yearbook on Science and Technology*, statistical yearbooks of various provinces in China, and the National Bureau of Statistics (NBS).

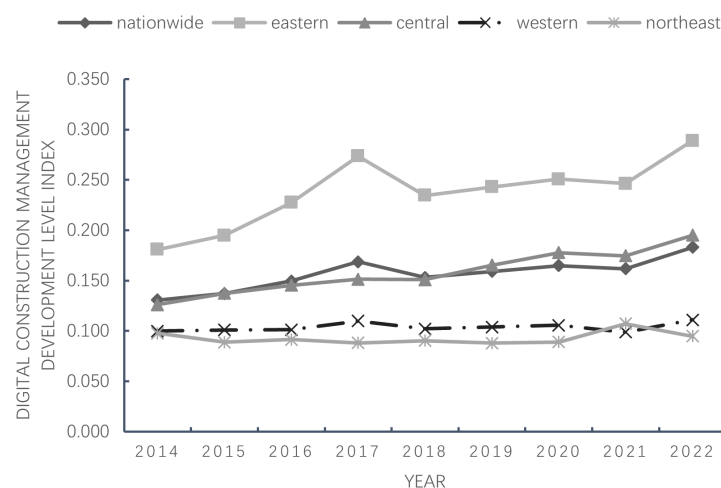
Table 1. Digital construction management evaluation index system

First-level indicators	Second-level indicators	Weight	Indicator attribute
Digital input	Enterprise digital R&D expenses	0.12	+
	Total internal expenditure of R&D funds	0.18	+
	R&D personnel in full-time equivalents	0.16	+
Digital application	Enterprise innovation rate	0.17	+
	Number of patent applications	0.20	+
Digital infrastructure	Total number of digital construction machinery and equipment	0.09	+
	Digital technical equipment rate	0.05	+
Digital effect	Total energy consumption	0.01	-
	Labor productivity	0.02	+

3. Empirical results

3.1. Measuring the development level of digital construction management in China

Figure 1 shows the trend of the development level in the regions. From a general perspective, the development level in the whole country as well as in each region showed an overall upward fluctuating trend. However, the digitalization development index of each province is in the lower-middle level and has a large gap between different provinces. By region, the average development level in the eastern region is the highest and the overall increase is the largest, which indicates that the digital construction management in the eastern region is not only better developed, but also ranks first in the country in terms of the speed of development. The development level in the northeastern region and the western region are both lower than the national average.

**Figure 1.** Trend of the composite index of the development level of digital construction management

3.2. Regional differences in the development level of digital construction management in China

Dagum Gini coefficient decomposition method was used to further analyze the regional differences, and the results of which are shown below.

3.2.1. Overall and intra-regional differences

As shown in **Figure 2**, the overall Gini coefficient of the development level showed a fluctuating upward trend. Sub-regionally, the Gini coefficient of the Eastern region is the largest and fluctuates the most. The Gini coefficient of the Central and Western regions is relatively close to each other. The Gini coefficient for the Central region has a growth rate of 5.17%, while the growth rate of the Western region is 75.51%. In addition, the Gini coefficient of the Northeast region is at the lowest level except for 2021, and the decline rate is 40.68%. The above results show that the regional differences in the eastern region is always in the first place in the country, and the northeast region has the smallest development differences among the four regions.

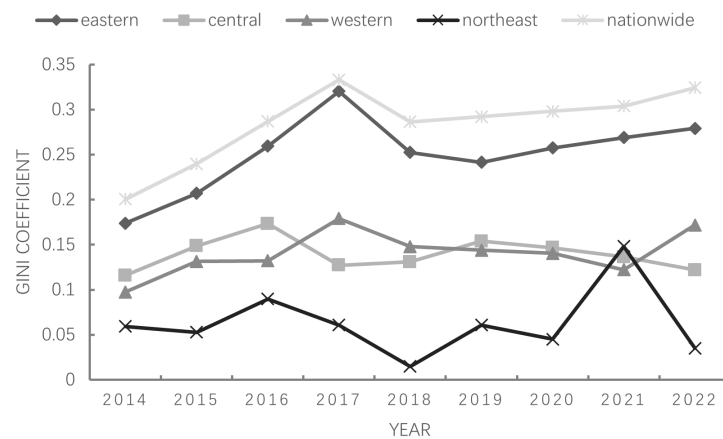


Figure 2. Overall and regional Gini coefficient and its evolution trend

3.2.2. Inter-regional differences

The inter-regional differences and their development trends between the four regions are shown in **Figure 3**, from which it can be seen that the Gini coefficient between the regions generally shows a fluctuating upward trend. The East-Northeast region has the largest inter-regional Gini coefficient and a larger fluctuation and the Gini coefficient growth rate of the central-northeast region is the largest. The Gini coefficient of the West-Northeast region is the lowest and fluctuates more gently. The above analysis indicates that the inter-regional differences in the development level of China's digital construction management have been expanding. The inter-regional differences between the Eastern region and the Western region, the Northeastern region are the largest.

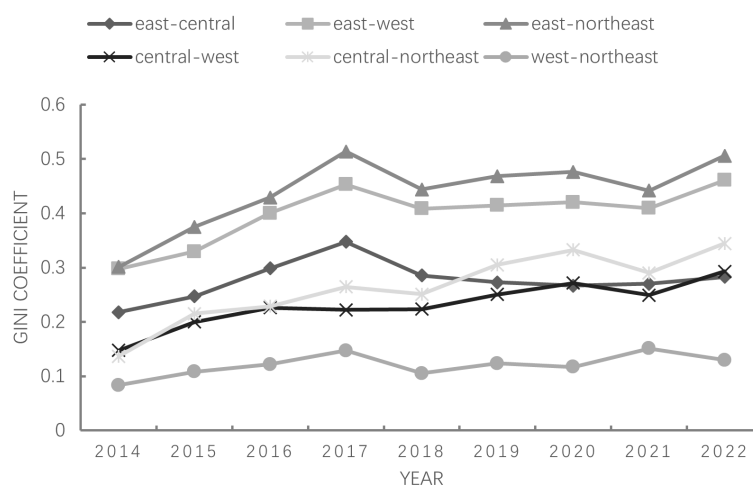


Figure 3. Inter-regional Gini coefficients and evolution trend

3.2.3. Sources and contributions of differences

Figure 4 shows the sources and the contribution rate of regional differences in the development level of digital construction management in China during the research period. The contribution rate of inter-regional difference is 70.89% on average, indicating that inter-regional difference is the main source of the overall development difference. The intra-regional difference and hyper-variable densities did not have a significant impact on the difference. Therefore, to solve the problem of the difference in development, it is crucial to reduce the development difference between regions.

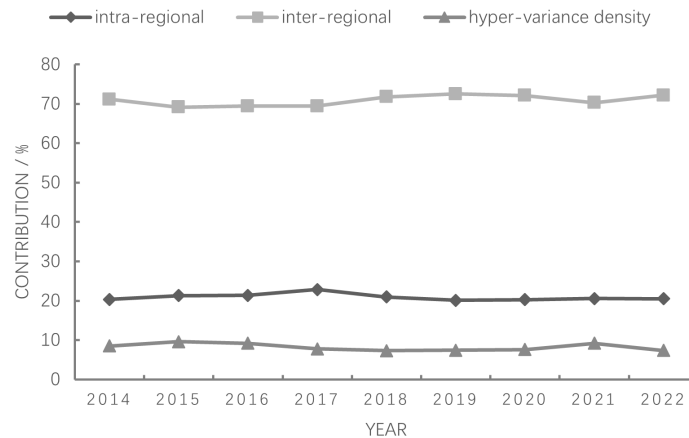


Figure 4. Sources and contributions of regional differences

3.3. Dynamic evolution of the differential development levels of digital construction management in China

This paper analyzes the location, shape, and ductility of the distribution of the development level index by means of the Kernel density estimation, as shown in **Figure 5**. From the position of the wave peak, the overall position of the main peak shifted to the right, which indicates that the development level has improved nationwide. However, the height of the main peak declined and the width increased, indicating that the regional development imbalance has increased. In addition, there are side peaks and the gap between the main side peaks widens between 2014 and 2019, indicating that there is bipolar or even multipolar polarization, and the gap is gradually increasing.

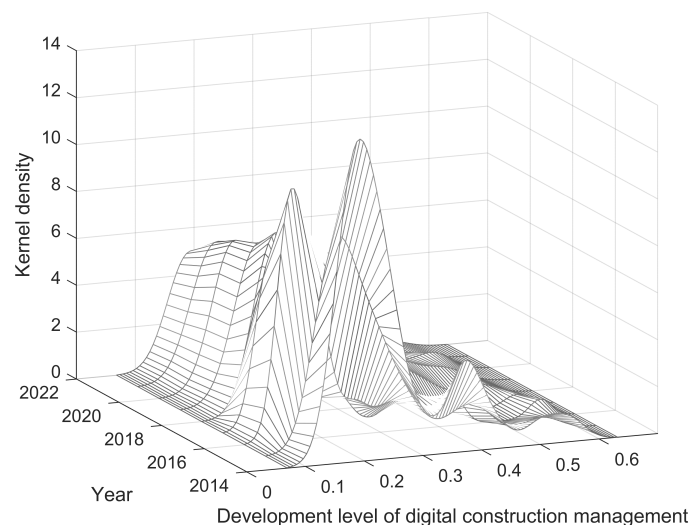


Figure 5. Dynamics of distribution of digital construction management development index in China

As shown in **Figure 6** is the distribution dynamics of the development level in the four regions. As seen in **Figure 6(a)**, the development level in the Eastern region shows an upward trend and the unevenness has increased. From the analysis of **Figure 6(b)**, it can be seen that the regional development differences in the Central region have been increasing. Side peaks exist until 2019, indicating that the polarization phenomenon is obvious. As can be seen in **Figure 6(c)**, the development level in the Western region has increased, but the degree of imbalance has worsened and the phenomenon of polarization is serious. As can be seen in **Figure 6(d)**, the development level in the Northeast has polarized and intensified as the number of years has increased.

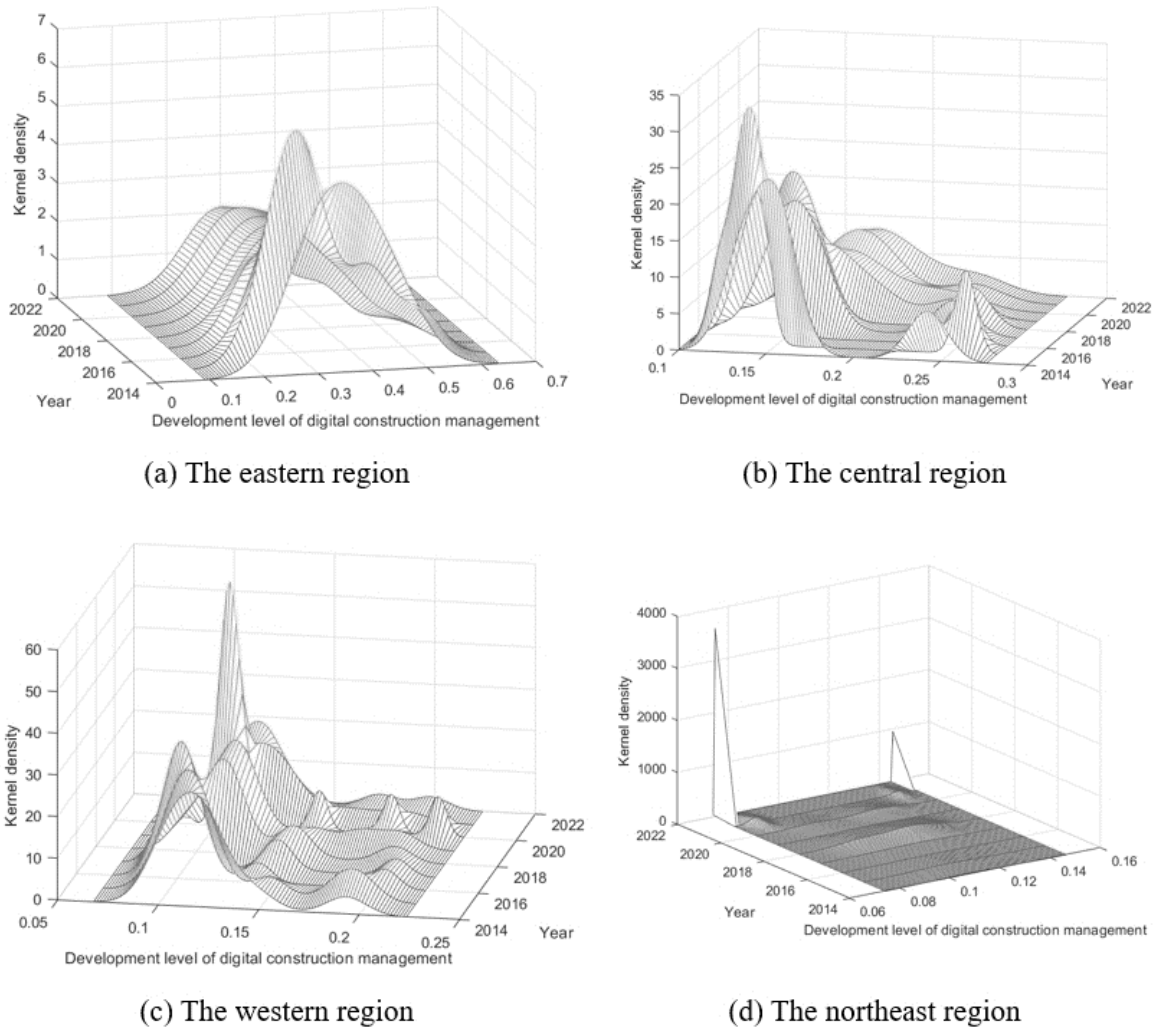


Figure 6. Distribution of digital construction management development index in four regions

4. Conclusions

This paper measures the development level of digital construction management in China's construction industry from the industrial level. The Dagum Gini coefficient decomposition method is used to decompose the development differences across the country and the four regions. And finally, the Kernel density estimation is used to analyze the spatio-temporal dynamic distribution and evolution trend of the development level. The empirical results show that:

- (1) The development level has risen in waves. However, most provinces are still at a low level and pace of

development, and there are large differences between regions. Motivating industrial transformation and promoting quality and efficiency in digital development remain key points.

- (2) The development level of regional differences show a trend of expanding. Excessive differences may pose risks and obstacles in terms of resource allocation and development dynamics. The Northeast region has the smallest intra-regional development difference. However, this is not necessarily a good thing, implying a lack of development drivers and regional “bellwether”.
- (3) The development differences mainly come from inter-regional development differences. The inter-regional differences between the Eastern region and the Western, Northeast regions are the largest. Therefore, narrowing the inter-regional differences is the key to solving China’s development imbalance problem.
- (4) The emergence of the phenomenon of polarization indicates that the unevenness of development has been serious. The government should give full play to the means of macro-control, for the digital transformation of construction management escort.

Disclosure statement

The author declares no conflict of interest.

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Analysis of Path Planning and Navigation for Smart Plastering Robots Based on Indoor Construction

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Abstract: Taking modern indoor building construction as an example, this study analyzes the path planning and navigation of a smart plastering robot. It includes a basic introduction to smart plastering robots, an analysis of multi-sensor fusion localization algorithms for smart plastering robots, and an analysis of path planning and navigation functions for smart plastering robots. It is hoped that through this analysis, a reference is provided for the path planning and navigation design of such robots to meet their practical application needs.

Keywords: Construction engineering; Indoor construction; Smart plastering robot; Path planning; Navigation function

Online publication: May 30, 2025

1. Introduction

In modern indoor construction projects, the smart plastering robot is a high-tech equipment. Through precise path planning and intelligent navigation, this robot can complete indoor plastering operations with high quality and efficiency, improving the plastering effect and reducing labor costs^[1]. To achieve the rational application of such robots, researchers need to analyze their path planning and intelligent navigation based on their basic conditions and multi-sensor fusion localization algorithms, ensuring the effectiveness of their applied functions.

The smart plastering robot is an advanced intelligent robotic device used in wall plastering construction in the modern architectural engineering industry. Its basic working method involves acquiring environmental parameters through intelligent sensing technology and combining actual conditions with plastering task requirements to perform intelligent path planning and motion control, achieving good intelligent navigation results. With advantages such as high work efficiency, good plastering quality, high safety, low labor intensity, and low labor costs, smart plastering robots have been widely used in modern architectural engineering wall plastering work^[2]. Especially in indoor plastering construction, the application of smart plastering robots has attracted much attention. Therefore, the intelligent path planning and navigation of such robots have become key research foci for relevant researchers in recent years.

2. Analysis of multi-sensor fusion localization algorithm for smart plastering robots

2.1. Introduction to the dataset

The dataset plays a critical supporting role when the smart plastering robot performs localization through a multi-sensor fusion algorithm. This algorithm aims to solve the position estimation problem of the robot under known scene conditions. Here, the known scene refers to the availability of RGB images and corresponding depth map information for each frame, satisfying the establishment of a 3D model of the scene before estimating the robot's position. Using the robot's position in the first frame as the origin of the camera coordinate system, the ICP algorithm is employed to estimate the camera trajectory and determine the coordinates of each frame in the RGB image within the camera coordinate system^[3]. A point within the scene is selected as the origin in the world coordinate system, and the correspondence between the camera coordinate system and the world coordinate system is calculated. Based on the estimated camera motion trajectory, the corresponding world coordinate positions for each frame of the RGB image can be derived.

2.2. Localization network framework

During the localization process of the robot, the main implementation steps of its localization algorithm include the following:

(1) Scene coordinate regression

The RGB images acquired from the robot's scene are used as the training set, each frame of the images serves as the validation set, and the estimated robot motion trajectory is utilized as the test set, with a data configuration ratio of 7: 1: 2. Using a 640*480px RGB image training set as the basic data, a corresponding network model is established through a combination of BIM and 3D MAX software. The data from the RGB image training set is imported into this model, generating scene prediction coordinates with a specification of 80*60.

(2) Hypothesis sampling and selection

Hypothesis scoring is implemented for the predicted coordinate positions of the robot in the scene using the sigmoid function method. The following is the hypothesis scoring formula:

$$a(h) = \sum_i \text{sig}(\alpha - \beta(e_i(h, \omega))) \quad (1)$$

In the formula, $a(h)$ represents the hypothesis score for the robot's position in the scene; h represents the hypothesis for the robot's position in the scene; α represents the inlier threshold; β represents a function control value; e_i represents the error function in the case of reprojection; and ω represents the learning parameter.

(3) Hypothesis extraction

Based on the actual requirements of the algorithm, initialize the variable ω and continuously optimize e_i during training. Grid optimization is then carried out using the nonlinear Gauss-Newton method until convergence to a specific grid form, followed by validation. To prevent overfitting due to excessive iterations, researchers reasonably determine the frequency of model result storage based on the original network. It is decided that after reaching 50,000 iterations, the model results will be saved every 5000 subsequent iterations. If the error and loss drop below a certain threshold, and the model begins to converge, model training can be stopped. This approach effectively reduces training time, enabling rapid acquisition of robot position information^[4].

2.3. Position information correction

To achieve accurate acquisition of robot positioning data, researchers can adjust the laser information in the four directions (up, down, left, and right) of the robot based on the obtained positioning results. **Figure 1** shows a

schematic diagram of the basic principle of robot laser positioning.

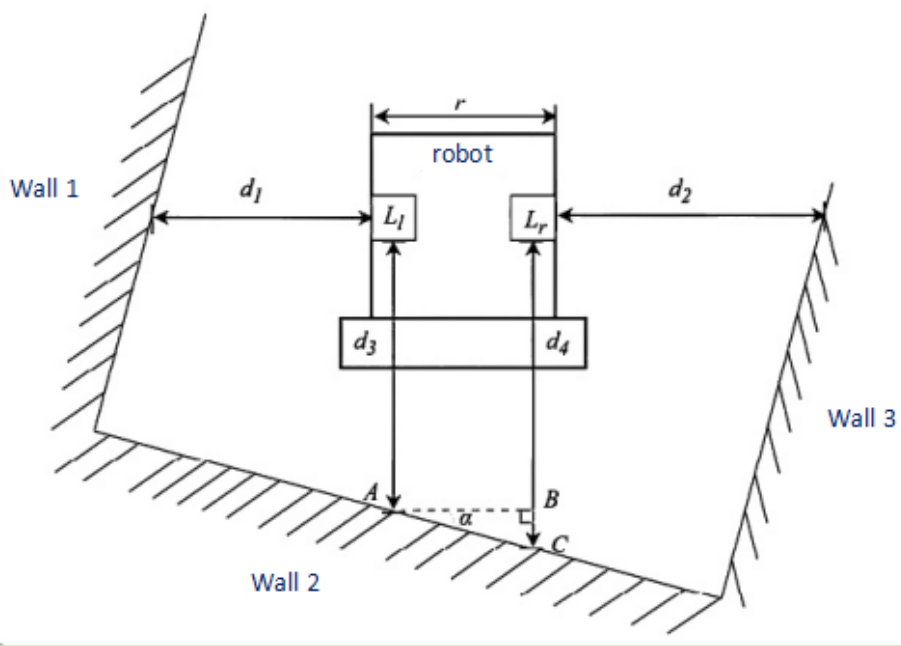


Figure 1. Schematic diagram of the basic principle of robot laser positioning

In this diagram, two single-line LiDARs, Laser1 and Laser3, are set at the L_l position. The Laser1 radar is pointed towards Wall 1, with a ranging information of d_1 ; the Laser3 radar is pointed towards Wall 2, with a ranging information of d_3 . At the L_r position, two single-line LiDARs, Laser2 and Laser4, are set. The Laser2 radar is pointed towards Wall 3, with a ranging information of d_2 ; the Laser4 radar is pointed towards Wall 2, with a ranging information of d_4 . The distance between L_l and L_r represents the width of the robot itself, denoted as r .

Based on the above information, researchers can perform positioning correction on the robot. Assuming that the estimated position of the robot obtained after learning the positioning network framework is p_n , and the true position coordinate of the robot is p_r . Researchers can correct its position in three steps:

(1) Angle correction

Based on the geometric relationship shown in **Figure 1**, the angle of the robot can be calculated using the following formula:

$$\alpha = \arctan \frac{d_4 - d_3}{r} \quad (2)$$

Its parameters can be calculated based on specific laser ranging values. If the angle β between p_r and Wall 2 is not equal to α , then p_n needs to be reasonably corrected based on the actual situation.

(2) Forward and backward correction

First, calculate the distance b between the robot and the wall using the following formula:

$$b = \frac{d_3 + d_4}{2} \quad (3)$$

If the value of b is not equal to the distance between p_n and Wall 2, p_n needs to be reasonably corrected based on the actual situation.

(3) Left and right correction

Assuming that both $d1$ and $d2$ data are valid, if the sum of their distances to Wall 1 from pn is not equal to the sum of their distances to Wall 2 from pn , pn needs to be corrected based on the actual situation. In the process of single-line LiDAR ranging, if the returned data value is very large, it indicates that there may be a window or door in the ranging direction, and such data should be excluded during correction to ensure accurate correction and improve the positioning accuracy of the robot ^[5].

3. Analysis of path planning and navigation function for smart plastering robots

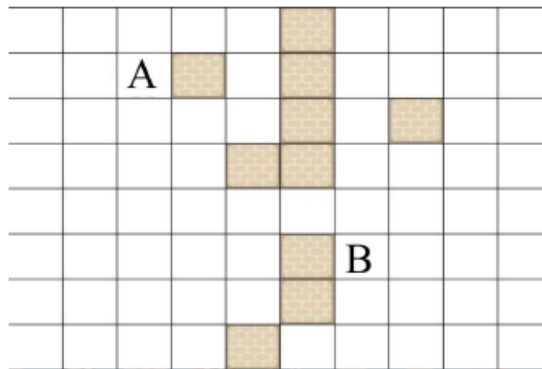
To ensure effective path planning and navigation for smart plastering robots, researchers have proposed an improved algorithm based on the A* algorithm. This enhanced approach incorporates a directional adjustment step at the end of the A* algorithm, tailored to the specific requirements of the robot's application scenario. This additional step, implemented after the navigation process, further enhances the robot's navigation capabilities. The detailed implementation process for path planning and navigation is as follows ^[6]:

- (1) Acquire current positioning information and determine the endpoint for path planning.
- (2) Assess whether path planning has been successful. If not, the process ends; if successful, proceed to the next step.
- (3) Plan the robot's path based on the actual situation.
- (4) Check if the robot has reached the endpoint coordinates. If not, return to step 1; if yes, continue to the next step.
- (5) Adjust the robot's own angle.

In this process, both the original A* algorithm and its improved version are implemented through software calculations. These calculations require only the input of map data and the robot's movement position data, with the specific calculation process not elaborated here.

3.1. Determination of the starting point

Assuming the presence of obstacles on a map, to implement the A* algorithm for searching obstacle areas, the map is divided using the length and width dimensions of the robot as the basic unit. The divided map can be marked using a matrix, denoted as Map. In this matrix, obstacles are represented by the number 2, the current position of the robot is represented by the number 1, and positions without obstacles are represented by the number 0. After image conversion, a corresponding grid diagram is obtained, where white grids represent positions without obstacles and yellow grids represent positions with obstacles. **Figure 2** illustrates the basic situation of the map used in this experiment.



In this diagram, point A represents the current position of the robot obtained through the localization algorithm, while point B indicates the location where the robot needs to perform plastering work. Based on the matrix definition and related operational procedures mentioned earlier, researchers can denote point A as Map^{[1][2]} and point B as Map^{[5][6]}.

3.2. Path planning

Based on the analysis of the improved A* algorithm, the robot's path planning map in the experiment is shown in **Figure 3**:

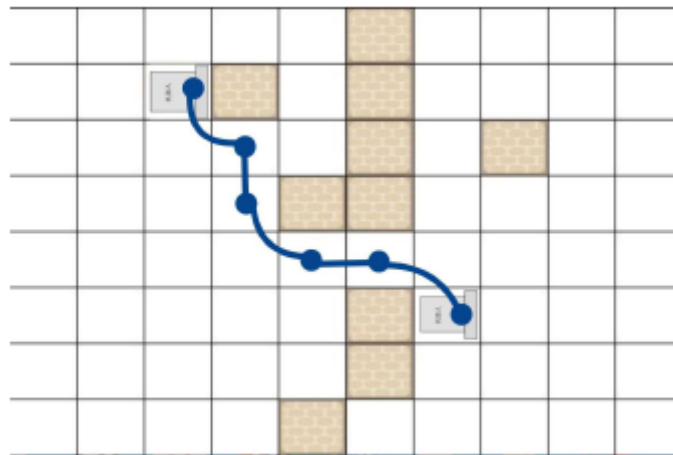


Figure 3. Schematic diagram of robot path planning obtained through improved A* algorithm analysis

It can be seen that for the static path of the robot, during the planning process, the improved algorithm can perform precise obstacle avoidance processing for all obstacles in the scene where the robot is located, to achieve reasonable planning of the robot's operating path. This allows the smart plastering robot to timely and effectively distinguish obstacles under unknown scene conditions, and to make reasonable planning for the next operating step based on the specific location of the obstacles, thereby achieving a good obstacle avoidance effect during operation.

3.3. Rotational navigation

After completing the operating path planning, the smart plastering robot can smoothly move from the starting point to the ending point. However, when the robot reaches the ending point (i.e., the plastering construction location), its actual orientation may not be the one needed for plastering. Based on this, in subsequent planning, researchers still need to continue implementing intelligent rotational navigation control for the robot^[7]. To achieve this goal, researchers can use a multi-sensor fusion work mode to monitor the robot's rotational drive motor in real-time, enabling intelligent adjustment of its rotation angle and speed. In this process, multiple sensors use a wireless communication network to transmit environmental parameters and robot operating parameters obtained in real-time to the drive motor controller. The controller intelligently generates a motor drive strategy based on its path planning results and actual conditions, and promptly issues corresponding control commands to achieve real-time control of the motor's rotation direction and speed, driving the robot to rotate precisely^[8]. This provides precise navigation for the robot's plastering actions, ensuring its plastering efficiency and construction quality.

3.4. Application experiment

Due to the time-sensitive characteristics of path planning and navigation for plastering robots in indoor construction scenes, researchers can create plastering construction scenes with different levels of complexity by setting different numbers of obstacles to verify the application effectiveness of established path planning and navigation methods. The path planning speed of the robot can be compared under different scene conditions. Specifically, during the experiment, it is assumed that the search area divisions of two rooms are completely different, with the matrix size of the first room controlled at 10×10 and the matrix size of the second room controlled at 50×50 . The Visual Studio 2017 analysis software is installed on a Windows 11 64-bit computer system to randomly generate different obstacles and robot paths through coding. The open list and close list are stored in the form of a data structure queue. The feasibility of path planning and navigation effects is judged by calculating the average path planning speed of the robot under different conditions of the same room and varying numbers of obstacles.

Firstly, for the 10×10 room, because the amount of computation is relatively small, the computation time consumed is also relatively short as the number of obstacles increases. Simultaneously, the experiment found that as the number of obstacles in the room continues to increase, the planning time for the robot's reachable path shows a trend of first increasing and then decreasing. When the number of obstacles is 90, there is only one reachable path, so the computation time is significantly reduced. **Table 1** shows the variation in path planning computation time for the robot in a 10×10 room as the number of obstacles increases:

Table 1. Variation in path planning computation time for the robot in a 10×10 room with increasing number of obstacles

Serial number	Obstacle quantity	Path planning duration	Serial number	Obstacle quantity	Path planning duration
1	0	0ms	6	50	16ms
2	10	15ms	7	60	16ms
3	20	16ms	8	70	16ms
4	30	16ms	9	80	16ms
5	40	16ms	10	90	0ms

Next is the 50×50 room. Due to its relatively large computational requirements, researchers modified the source code during calculations. Specifically, the open list and close list, which were originally single-level queues, were improved to multi-level queue formats, and computational experiments continued. Through experimentation, it was found that as the number of obstacles in the room continues to increase, the planning time for the robot's reachable path exhibits a trend of first increasing and then decreasing. When the number of obstacles becomes excessive, the number of robot paths decreases significantly, leading to a noticeable reduction in subsequent path planning time. **Table 2** illustrates the variation in path planning computation time for the robot in a 50×50 room as the number of obstacles increases:

Table 2. Variation in path planning computation time for the robot in a 50×50 room with increasing number of obstacles

Serial number	Obstacle quantity	Path planning duration	Serial number	Obstacle quantity	Path planning duration
1	0	0ms	6	1250	9372ms
2	250	3583ms	7	1500	10848ms
3	500	4623ms	8	1750	9658ms
4	750	7396ms	9	2000	7482ms
5	1000	8239ms	10	2250	2672ms

Based on a comprehensive analysis of the above two experimental scenarios, it can be concluded that when the room matrix is the same, the path planning time for the plastering robot exhibits a trend of first increasing and then decreasing as the number of obstacles gradually increases. However, when the room matrix is different, a larger matrix results in longer path planning time. Nevertheless, considering the actual conditions of ordinary indoor architectural scenes, the path planning time is not excessively long, indicating strong feasibility for the overall path planning and intelligent navigation scheme.

4. Conclusion

In summary, for indoor plastering robots in construction engineering, researchers can conduct experimental calculations on path planning time by varying room matrices and the number of obstacles, provided that the path planning and navigation mechanisms are clearly understood. This approach effectively verifies the path planning and intelligent navigation effects, allowing for the assessment of the feasibility of robot applications.

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An Analytical Perspective on Curtain Wall Project Management

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Abstract: Over the past four decades, propelled by China's reform and opening-up policies, urban construction in the country has undergone rapid and transformative development. Within this context, the curtain wall, serving as both the exterior enclosure and aesthetic façade of buildings, has become a defining element of modern architecture. As a specialized component within the overall construction system, curtain wall projects demand a high level of expertise in both technical execution and project management. This study explores a unique analysis and reflection on the labor management and schedule control of curtain wall projects.

Keywords: Curtain wall projects; Labor management; Schedule control

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1. Introduction

Different companies and project managers have different methods and focuses in the labor management and progress management of the projects. However, in practice, many projects continue to experience significant conflicts with labor subcontractors during the management process. The benefits of labor service companies come from the management of workers, and effective labor management methods are worthy of in-depth research and discussion. Progress management is a critical criterion by which the client (Party A) evaluates the success or failure of a construction project. Delays in project progress can jeopardize timely delivery and may result in significant contractual breaches. Effective schedule control not only ensures compliance with contractual obligations but also contributes to the contractor's professional reputation and the development of long-term collaborative relationships within the industry. When a project experiences delays that lead to a breach of contract, the opportunity to establish trust and long-term partnerships is often compromised. This makes it essential to strengthen progress management practices. Rather than relying solely on traditional methods, project managers should actively seek out more reliable and efficient strategies to ensure timely project delivery.

2. Thoughts on labor management of curtain wall projects

As a highly specialized component of construction, curtain wall projects place significant demands on the labor force. The ability of labor subcontractors to recruit and manage skilled workers directly affects the quality and safety of on-site installation. Selecting a competent and reliable labor service company can greatly enhance efficiency, allowing the curtain wall contractor and project management team to achieve more with less effort. Conversely, partnering with an underqualified subcontractor often results in increased challenges and resource consumption. When selecting a labor service company, the following key considerations should be taken into account:

2.1. Classification management of labor service companies

The curtain walls are mainly divided into framed curtain walls and unitized curtain walls according to the type of surface materials and systems. Among them, the framed curtain walls mainly include: framed stone curtain walls, framed aluminum plate curtain walls, and framed glass curtain walls. The unitized curtain walls are mainly unitized glass curtain walls. The above-mentioned curtain wall types account for 80% of the curtain wall types in the market. There are also curtain wall types such as hanging glass curtain walls, cable-net glass curtain walls, point-supported glass curtain walls, and double-layer breathing curtain walls, whose markets are smaller, but they require more professional labor skills from workers ^[1-5].

For the above common curtain wall types, the unitized curtain wall should be the simplest type of curtain wall for on-site construction because more than 70% of the work is completed in the processing factory, and the amount of labor and construction content required on-site is relatively small. However, since the construction scheme of the unitized curtain wall is mainly hoisting, the equipment and facilities used and the requirements for safety and quality control are completely different from those of the framed curtain wall. If the labor team and workers have only done framed curtain walls before and have no experience in unitized curtain walls, it will be very difficult to do a good job in the unitized curtain wall project.

In frame curtain walls, the construction of frame stone curtain walls is the most difficult compared to frame glass curtain walls and frame aluminum plate curtain walls ^[6]. Because the current mainstream frame stone curtain wall is the dry-hanging stone curtain wall. Due to specific characteristics, such as the heavy weight of the stone panels, dense grid division, numerous joints, and the use of back bolts to connect dry-hanging stone to the structural keel, stone curtain walls are among the most labor-intensive and technically demanding systems in façade construction. The complexity of the construction process, particularly the difficulty of installing back-bolt connections, results in both the highest labor costs and the greatest construction challenges among curtain wall types.

Secondly, the frame glass curtain wall presents its own set of challenges. Due to the transparent nature of glass, these curtain walls typically feature larger grid divisions, which require fewer but significantly heavier individual panels. Handling and installing these large glass units often necessitates the coordination of multiple workers. Moreover, achieving precise installation is particularly complex, as the weight of the glass complicates alignment and adjustment, demanding both skill and careful planning.

Finally, the frame aluminum plate curtain wall is considered the most installation-friendly among curtain wall types. Due to the lightweight nature of aluminum panels and their ease of handling, installation is relatively straightforward, resulting in the lowest labor costs compared to other systems. However, this ease of fabrication also allows for more varied and complex architectural forms. As a result, particular attention must be paid to the quality of detailed shaping and finishing during construction to ensure both visual and structural integrity.

Although aluminum plate curtain walls are the simplest to construct, practical experience has shown that even labor teams skilled in handling complex frame dry-hanging stone curtain walls may struggle with aluminum systems. This is often due to a lack of specific experience in dry-hanging aluminum plate installation, resulting in poor construction quality despite the system's relative simplicity. Therefore, even workers with over a decade of curtain wall construction experience may face difficulties in maintaining quality and meeting schedule requirements when transitioning to a different curtain wall system, particularly if their experience is limited to only one type. The risk factors associated with different types of curtain walls vary significantly. Therefore, it is essential to select labor teams that are specifically experienced and professionally trained for the particular curtain wall system being installed. Some labor service companies employ “versatile” workers who are familiar with multiple types of curtain wall systems. However, due to their broad focus, these workers often lack in-depth practical experience with any single system, which can affect the overall quality and precision of their work. Therefore, compared with the professional teams that focus on a certain type of curtain wall, they often have no advantages in construction quality, progress, and their own safety management.

2.2. Classification management of labor types

For labor service companies that specialize in a specific type of curtain wall construction, achieving the highest standards of quality requires making professional and well-informed choices at every stage of the construction process. This kind of management occurs more frequently in stone curtain walls. High-quality professional stone labor service companies typically assign skilled workers to each key stage of stone curtain wall construction. These stages include measurement and setting out, installation of embedded parts, steel keel installation, welding operations, stone panel hanging and installation, as well as sealant application for joints. Although the labor costs for stone curtain wall installation are relatively high, the quality and efficiency achieved by experienced teams are also significantly better. These specialized workers often travel across the country to undertake stone installation projects. If, in the construction of various curtain wall types, each process is handled by skilled professionals with relevant expertise, the overall construction quality and project outcomes can be greatly improved.

2.3. The sample management system of the curtain wall process

Different curtain wall processes have different technological requirements^[7]. Even for the installation of a post-installed embedded part, it may seem very simple, as it is just a steel plate and four bolts. However, there are many detailed requirements involved, such as the cross positioning of the embedded plate, the depth requirements for drilling the post-installed bolt holes, the cleaning requirements for the post-installed holes, the selection requirements for chemical bolts and expansion bolts, and the depth requirements for screwing the nuts, etc. Before the construction of each process, no matter how small the process is, the project management department should make a construction process sample on the site. Moreover, the sample should be fully disclosed to the workers of this process and retained until the end of the process. This approach helps establish clear standards and procedures for workers, effectively “setting rules” that guide their tasks. At the same time, it provides project management personnel with defined criteria to follow during on-site inspections, which is essential for ensuring consistent and reliable quality across all stages of construction.

2.4. Require and assist the labor service company in carrying out refined management

In general, labor service companies tend to have limited management personnel, and the competence of these individuals can vary widely. Often, there is a lack of effective strategies and proactive thinking aimed at improving work efficiency. To address this, the project management department can implement labor

management measures, such as classification-based oversight and process-based sample management, both during the selection of labor service companies and throughout the construction phase. As labor service companies improve work efficiency, they also achieve higher construction quality. This refined approach to labor management can be maintained and applied in future projects. Furthermore, when such companies provide services for other curtain wall contractors, the good management practices they carry forward can contribute positively to raising the overall standard of labor management across the curtain wall industry.

3. Thoughts on progress management of curtain wall project

3.1. Visualize the daily PDCA progress management

At the present stage, the conventional progress management for curtain wall projects often involves formulating the overall progress plan, annual progress plan, quarterly progress plan, monthly progress plan, and then the weekly progress plan, followed by a cycle of weekly regular meetings for progress management^[8, 9]. However, project construction is often a race against time, especially for projects with high progress requirements, where the construction period is often within one year or even half a year. If the most distal end only achieves weekly progress management, the progress lag this week will likely affect next week, and the accumulation and repetition in the next week may affect the monthly progress, and further affect the quarterly or even the entire project's progress plan. Given that the surface materials of each curtain wall project are of a fixed quantity that can be counted, visual data management can be carried out during progress management to achieve daily progress visibility and thereby achieve visual daily progress management. The specific methods are as follows:

- (1) Count the quantity of the surface materials of the project (count the quantity of the keels at the keel stage, and count the quantity of the unit panels for the unit curtain wall);
- (2) Determine the planned installation days for the keels or surface materials;
- (3) Calculate the theoretical quantity of the keels or surface materials that should be installed each day based on the quantity and the theoretical installation days, and present it in a table form (**Figure 1**).
- (4) Fill in the actual quantity of the installed keels or surface materials every day during the later construction process. The planned and actual installation quantities for each day will be presented completely and intuitively on the table.
- (5) If the actual installation is less than the planned installation, the project management department needs to review which link of design, procurement, processing, or construction the problem comes from and solve it on the same day or at the latest, the next day. Achieve the principle of “finishing daily affairs daily” and conduct the PDCA management of the progress every day.

Unit Curtain Wall Installation Statistics (April 28, 2010)										
Date	Number of workers /Accumulated days worked	Planned number of installations	Actual installed quantity	Plan to add up the number of installations	Actual cumulative number of installations	Current progress ratio	Total installation completion ratio	Same-day arrival/Field accumulation	Cumulative field ratio	Remarks
original	5300	540	512	540	512	94.81%	21.51%	1633	68.61%	
March 17th		40	48	580	560	96.55%	23.53%			
March 18th		40	40	620	600	96.77%	25.21%			
March 19th		40	42	660	642	97.27%	26.97%			
March 20th		40	43	700	685	97.86%	28.78%			
March 21st		40	46	740	731	98.78%	30.71%			
March 22nd		40	47	780	778	99.74%	32.69%			
March 23rd	112/5412	40	38	820	816	99.51%	34.29%	77/1710	71.85%	
March 24th	112/5524	40	43	860	859	99.88%	36.09%	54/1764	74.12%	
March 25th	115/5639	40	42	900	901	100.11%	37.86%	35/1799	75.59%	
March 26th	115/5754	40	46	940	947	100.74%	39.79%	72/1871	78.61%	
March 27th	115/5869	40	43	980	990	101.02%	41.60	45/1916	80.50%	
March 28th	112/5981	40	43	1020	1033	101.27%	43.40	19/1935	81.30%	
March 29th	112/6093	40	45	1060	1078	101.70%	45.29%	0/1935	81.30%	
March 30th	119/6212	40	50	1100	1128	102.55%	47.39%	33/1963	82.69%	
March 31st	119/6331	40	47	1140	1175	103.07%	49.37%	0/1968	82.69%	
April 1st	119/6450	45	36	1185	1211	102.19%	50.88%	94/2062	86.64%	At this stage, only one working face to the west of the podium building was installed
April 2nd	119/6569	26	50	1211	1261	104.13%	52.98%	28/2090	87.82%	
April 3rd	119/6688	26	22	1237	1283	103.72%	53.91%	37/2147	90.21%	
April 4th	119/6807	26	23	1263	1306	103.40%	54.87%	0/2147	90.21%	
April 5th	109/6916	26	17	1289	1323	102.64%	55.59%	0/2147	90.21%	
April 6th	109/7025	26	28	1315	1351	102.74%	56.76%	56/2203	92.56%	
April 7th	109/7134	30	15	1345	1366	101.56%	57.39%	56/2259	94.92%	
April 8th	109/7243	30	27	1375	1393	101.31%	58.53%	86/2345	98.53%	At this stage, the west of the podium building, the window glass of the podium building and the south of the main building were installed simultaneously
April 9th	109/7352	30	33	1405	1426	101.49%	59.92%	0/2345	98.53%	
April 10th	109/7461	45	35	1450	1461	100.76%	61.39%	27/2372	99.66%	
April 11th		45								
April 12th		45								
April 13th		45								
April 14th		45								
April 15th		45								

Figure 1. Unit curtain wall installation statistics (April 28, 2010)

The above table shows the visualized progress management and PDCA progress cycle management adopted in the Chengdu Chunghwa Plaza project. This project is 166 meters high and has a 57,000-square-meter glass curtain wall. All the Welcon glass is imported from the United States. The glass is transported by sea to Shanghai and processed into unit panels at the Shanghai factory of Shanghai Meite Curtain Wall Co., Ltd., and then transported by road for more than 1,600 kilometers to Chengdu for installation. For a project of this scale, characterized by an extensive supply chain and a large installation area, the implementation of the aforementioned management methods enabled the successful completion of all unit curtain wall installations within seven and a half months, representing a significant achievement in project progress control and execution efficiency.

3.2. Advanced progress management of material procurement

In the design, procurement, processing, and construction links of curtain wall progress management, the progress is often most affected by procurement, and the affected progress is the most difficult to recover ^[10, 11]. Because the procurement link is closer to the front end of the project, and all curtain wall materials are custom-sized and produced on order. The types and specifications of the involved materials are numerous, and the materials need to be sent to the factory or the site in a supporting manner to ensure processing or construction. The production cycle of the main materials is about 15 to 30 days. Material delays often happen because the approved manufacturers have limited production capacity at certain times or do not follow the order sequence when processing. This leads to mismatched materials and affects the installation schedule. If procurement progress is not proactively managed at the material factory, and issues such as delayed or mismatched deliveries are only identified upon the scheduled arrival date, the resulting disruptions can significantly impact the project schedule. Therefore, to ensure effective control of material supply, personnel from the project management department should be assigned to key material manufacturers in advance, particularly during the early stages or critical periods of material production and delivery. Only in this way can it be ensured that the materials required for the project can be produced on schedule, and the arriving materials are the required materials. At the same time, material quality inspection should be conducted prior to shipment, ensuring that only qualified materials are delivered to the site. This proactive approach helps prevent project delays caused by the return of non-compliant materials after their arrival.

3.3. Project department-oriented progress management

The mode of project management varies from company to company. Some attach importance to the vertical management of the project management department, while others emphasize the parallel management of various functional departments of the company. Since the project management department is the forefront department facing the project site, it directly deals with various parties such as the project management client, supervisor, and general contractor. Being closest to the site, the project management department is best positioned to receive and respond to the latest project demands. However, if it lacks sufficient authority to coordinate resources across design, procurement, fabrication, and construction, the timely implementation of progress measures may be compromised. This can result in the dilution or delay of critical project information as it is transmitted through hierarchical layers. The ultimate consequence is delayed response, diminished operational efficiency, and weakened execution on site, all of which can adversely affect overall project performance ^[12–15].

To address this, the curtain wall company should fully empower the project management department, particularly the project manager, by ensuring that authority, responsibility, and accountability are properly aligned. Under this structure, the project's lead designer can serve as the technical lead, the procurement

specialist as the purchasing lead, and the fabrication plant representative as the processing lead, all operating under the coordination and direction of the project management department. At the same time, a complete project assessment system should be formulated to ensure that the relevant project design, purchasing, and processing personnel in charge can share the benefits of successful project management and bear the losses of ineffective project management. In this way, the project manager can be like a commanding general in the project, directing wherever needed, and the promotion of various project tasks can be carried out in an orderly manner. The company manages and inspects the daily work of each project at the institutional level, with each performing its own duties, having priorities, and only then can the project progress and other tasks proceed smoothly.

The regular inflow and outflow of project construction funds serves as a fundamental guarantee for the timely supply of materials. Developing a rational financial plan for income and expenditure at both the project and project management levels, alongside promoting the effective execution of external receivables and internal disbursements, constitutes a crucial mechanism for ensuring steady project progress.

4. Conclusion

This study explores advanced strategies and methodologies for labor management in curtain wall construction, focusing on fine-grained material classification, visual template-guided supervision, and detailed daily dynamic worker management. In addition, it examines progress management from the perspectives of segmented visual progress tracking, pre-construction material procurement, and project department-oriented coordination. The aim is to provide insights that may stimulate further reflection and discussion regarding the study.

Disclosure statement

The authors declare no conflict of interest.

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Design Strategies for Roadbed and Pavement Based on the Goal of Green Highway Construction

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Abstract: This article takes the reconstruction and expansion project of the Tianjin section of the Beijing-Tianjin-Tanggu Expressway as an example to systematically explore the design strategies for roadbed and pavement under the goal of green highway construction. During the research, after discussing the goals and policies of green highway construction in Beijing, in-depth research was conducted around the design of protective support engineering, soft foundation treatment, comprehensive utilization of earthwork, drainage systems, and pavement design to explore how the case project can achieve high-quality design based on the goal of green highway construction. It is hoped that this article can provide technical reference and value for China's road and bridge engineering design and construction units, providing a low-carbon practice paradigm for the integration of Beijing-Tianjin-Hebei transportation, while promoting the sustainable development of China's green highway concept.

Keywords: Green highway; Roadbed and pavement design; Protective retaining engineering; Comprehensive utilization of earth and stone

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1. Introduction

The application of green construction technology in highway engineering has two main benefits. Firstly, it contributes to environmental protection by reducing carbon emissions, noise pollution, and water wastage during construction and operation, thereby protecting the ecological environment and biodiversity ^[1]. Secondly, green highway technology can improve resource utilization efficiency during the construction phase, such as adopting renewable materials and energy-saving technologies to reduce resource consumption and energy costs. Therefore, overall, exploring green highway construction in highway engineering and conducting roadbed and pavement design guided by the goal of green highway construction has significant implications for promoting sustainable development in China's road and bridge engineering ^[2].

2. Goals and policy background of green highway construction

2.1. Construction goals

2.1.1. Incorporating ecological concepts

The primary goal of green highway construction is to incorporate ecological concepts into the project, minimizing the negative impact on the natural environment. For example, using permeable pavement and low-fill, shallow-excavation techniques to enhance rainwater infiltration and groundwater recharge capabilities, while effectively reducing the amount of earthwork and minimizing changes to the terrain and landforms caused by highway construction. This approach also protects soil structure and existing vegetation ^[3].

2.1.2. Resource intensification and recycling

In addition to reducing environmental damage, green highway construction emphasizes the efficient utilization of resources ^[4]. For example, during the design phase, it is essential to specify the use of recycled aggregates and industrial waste residues as substitutes for traditional materials in the construction stage. This approach effectively reduces energy consumption and pollution associated with material production while enabling the utilization of waste resources.

2.1.3. Energy conservation, emission reduction, and low carbonization

The third objective of green highway construction is energy conservation, emission reduction, and low carbonization. This involves actively applying advanced energy-saving design techniques, dust control measures at construction sites, and other related technologies during the design and construction processes. These efforts aim to reduce energy consumption while effectively controlling various types of pollution generated during construction, thereby minimizing negative impacts on the lives of surrounding residents. Simultaneously, improving the overall carbon sequestration capacity of highways through measures such as planting carbon-absorbing vegetation in green belts effectively improves air quality and reduces greenhouse gas emissions ^[5].

2.2. Policy background

In September 2019, the Central Committee of the Communist Party of China and the State Council issued the “Outline for Building a Strong Transportation Country,” which clearly proposed the establishment of a safe, convenient, efficient, green, and economical modern integrated transportation system. With the promulgation of policies in Beijing, green highways have become a crucial aspect of achieving “green transportation” in China. In 2020, the “dual carbon” goals were introduced, setting requirements for accelerating the low-carbon transformation in the transportation sector, specifically focusing on reducing emissions and energy consumption through green technologies. In 2021, the State Council issued the “Development Plan for the 14th Five-Year Modern Integrated Transportation System,” urging highway construction enterprises to actively promote green highway construction technologies and enhance resource recycling levels. Additionally, the plan set a target for newly built expressway projects to have a green highway proportion of at least 80%. In the context of these policies, national transportation authorities and local governments across the country have issued technical guidelines for green highway construction, such as the “Technical Guidelines for Green Highway Construction” and the “Guidelines for Carbon Emission Accounting in Expressway Construction,” further advancing the progress of green highway development.

3. Research on roadbed and pavement design based on the goal of green highway construction

3.1. Project overview

The Beijing-Tianjin-Tanggu Expressway, as the first highway in China approved for construction by the State

Council, is also the first inter-provincial highway in the country, with a total length of 142.69km. It starts at Shibaidian in Chaoyang District, Beijing, and ends at Hebei Road, Binhai District, Tianjin, spanning 35.075km in Beijing, 6.707km in Hebei Province, and 100.908km in Tianjin. According to predictions by relevant departments, the long-term traffic volume of the Beijing-Tianjin-Tanggu Expressway will reach 220,000 pcu/d by 2045, which will require at least 3 expressways (including the existing Beijing-Tianjin-Tanggu Expressway) to share the load, with each expressway requiring a design of 8 lanes or more. To cater to the increase in highway traffic volume in the future and further implement the Beijing-Tianjin-Hebei coordinated planning, promoting the integration process of Beijing-Tianjin-Hebei, it has been decided to expand and renovate the Beijing-Tianjin-Tanggu Expressway. This article takes the green highway design project of the Beijing-Tianjin-Tanggu Expressway (Tianjin Section) reconstruction and expansion project (hereinafter referred to as the Tianjin Section Reconstruction and Expansion Project) as an example to conduct in-depth research on the roadbed and pavement design under the goal of green highway construction.

3.2. Protective retaining engineering design

During the design of the protective retaining works for the Tianjin Section Reconstruction and Expansion Project, the design unit adhered to the four principles of safety, economy, environmental protection, and aesthetics. By actively combining biological and engineering techniques during the design process, the goal was to create a green highway that integrates engineering functionality and ecological visuals. The slope protection design of the project emphasizes the synergy between biological and engineering measures. Based on the project requirements and environmental characteristics, the design unit adopted the following innovative protection scheme ^[6].

Firstly, the roadbed protection design mainly focuses on vegetation cover, selecting drought-tolerant and pollution-absorbing plants suitable for the local climate and soil, such as clover. Using these plants to build a biological protection system not only has strong economic and environmental benefits but also enables the roadbed to have good soil and water conservation capabilities and landscape beautification effects. For the design of engineering protection, when the slope height exceeds 5m, a prefabricated, diamond-shaped, frame vegetation structure is used. The diamond-shaped frame is assembled from prefabricated parts, and then the soil and vegetation are filled into the frame to improve slope stability and promote ecological effects.

Secondly, for the protection of filled sections with large water ponds and pits, M10 mortar masonry technology with a thickness of 35cm is adopted, aiming to provide superior drainage and anti-scouring capabilities for the slopes ^[7]. The overall height of the slope protection requires the sum of wave attack, backwater height, and safety height to be greater than or equal to 0.5 meters, ensuring that the protection strategy meets the protection needs under different hydrological conditions.

Finally, for land-constrained road segments, the project adopts balanced weight retaining walls, cantilever retaining walls, and lightweight soil panel solutions for the retaining design. The balanced weight retaining wall can resist external pressure with its own weight. During the design process, the main consideration is the depth and bearing capacity of the pile foundation, and a design standard of 20KN/m² is used to ensure the stability of the structure. The cantilever retaining wall adopts a reinforced concrete frame structure, which utilizes the cantilever principle to provide good deformation resistance and strength in a limited space. The lightweight soil panel scheme uses special materials to meet strength requirements, improve construction convenience, and promote the improvement of the overall lightweight level ^[8].

3.3. Soft foundation treatment and comprehensive utilization design of earthwork

3.3.1. Soft foundation treatment design

The reconstruction and expansion project of the Tianjin section features numerous soft soil foundation segments

from the starting point to the K112 segment. Specifically, the K41 + 840 to K91 + 700 segment includes 7 sections of soft soil foundation, the K99 + 400 to K103 + 100 segment has 3 sections of soft soil foundation, the entire K107 + 231 to K122 + 731 segment is composed of soft soil foundation, and the entire K112 + 731 to K138 + 600 segment is also soft soil foundation. **Table 1** below outlines the distribution of soft soil in the reconstruction and expansion project of the Tianjin section:

Table 1. Distribution of soft soil in the reconstruction and expansion project of the Tianjin Section of the Beijing-Tianjin-Tanggu Expressway

Pile number	Distribution quantity	Total length	Characteristics of soft soil distribution
K41 + 840 – K91 + 700	7 sections	37.08km	(5) Layer 1 is widely distributed; (6) Layer1-1 clay has high compressibility, large void ratio, long consolidation time, and low bearing capacity
K99 + 400 – K103 + 100	3 sections	2.1km	(6) Layer14 muddy soil has a diamond-shaped distribution, large void ratio, high compressibility, a long consolidation time, and low bearing capacity
K107 + 231 – K122 + 731	1 sections	5.5km	(3) Layers 3 and (6)12u muddy soil are sporadically distributed
K112 + 731 – K138 + 600	1 sections	25.95km	(6) Layer 2 muddy soil is continuously distributed; (3) Layers 3 and (6) 12 muddy soil are sporadically distributed

Meanwhile, the project team proposed clear settlement control standards for the reconstruction and expansion project of the Tianjin section, namely, within the 15-year designed service life of the pavement, the post-construction settlement standards should meet the requirements of ≤ 15 cm for general road segments, ≤ 5 cm for bridge embankments, and ≤ 10 cm for passageways and culverts.

For soft foundation treatment, after joint research with the design unit, the project team decided that for general widening sections, when the subgrade fill height does not exceed the treatment limit, no control measures would be taken. The old subgrade would be excavated and cleared, and a 50 cm-thick crushed stone cushion would be set within the widening range. A layer of geocell would be used to isolate groundwater and achieve ground consolidation and drainage. When the subgrade fill height exceeds the treatment limit, CFG piles would be used. For noise-sensitive areas and space-limited areas, high-pressure jet grouting piles would be used, and the pile spacing and length would be determined based on the working conditions, adopting a rectangular arrangement^[9].

In addition, for positions with higher subgrade fill heights in general widening sections, such as high-fill subgrades, bridgeheads, or areas with deep soft soil, PHC high-strength prestressed concrete pipe piles would be used with a pile diameter of 40 cm. The piles would also be arranged in a rectangular pattern. A 50 cm-thick graded crushed stone cushion would be set at the pile top, and a layer of geocell would be installed in the middle. For the treatment of soft soil foundations at bridgehead transition sections and culvert passageways, the spacing of piles at the culvert location would be densified, and the pile length would be appropriately increased. For bridgehead transition sections, it is required to maintain the same height as adjacent subgrades, and lightweight soil would be used for backfilling at the bridgehead to form a variable stiffness road-bridge transition. For newly built bridgeheads and culvert passageways in the interchange area, the pipe piles within 50 m of the newly built bridgehead and 30 m of the culvert would be treated with variable pile lengths in two sections.

3.3.2. Comprehensive utilization design of earth and stone

During the design phase of the Beijing-Tianjin-Tanggu Expressway Tianjin Section Reconstruction and Expansion Project, the design unit and the project unit jointly planned a reasonable earthwork extraction and transportation scheme for the comprehensive utilization of earth and stone. Regarding the selection of earthwork extraction

sites, based on the “Tianjin Land Remediation Planning (2021–2035)”, they chose to extract earth from non-farmland areas such as low-efficiency farmland and wasteland, strictly avoiding ecological red lines such as wetlands and water conservation areas. For earth transportation routes, GIS and BIM technologies were utilized to maximize the shortening of transportation routes, effectively reducing carbon emissions. For inferior soil, the design required lime mixing improvement, utilizing indoor geotechnical tests to determine soil properties. The improvement targeted clay and silty soil with insufficient bearing capacity and high water content. Subsequently, the lime content was determined based on the soil test results, and a forced mixer was used for dry mixing to effectively control the uniformity of the lime and soil mixture. After improvement, it was expected that the CBR value of the original soil could be increased from 3%~5% to 8%~10%, meeting the requirements specified in the roadbed filling specifications. Additionally, for the comprehensive utilization of earth and stone, the project team prioritized the use of construction waste such as demolished abutments and beam slabs from the reconstruction and expansion phase. After crushing treatment, these materials were used as roadbed filling and blind ditch materials, implementing the goal of low-carbon roadbed construction^[10].

3.4. Drainage system design

During the early design phase of the drainage system for the Beijing-Tianjin-Tanggu Expressway Tianjin Section Reconstruction and Expansion Project, trapezoidal soil drainage ditches were used for the old road, with a depth and bottom width of 1.0 m and a slope ratio of 1: 1.5 for the ditch walls on both sides. Through investigation, it was found that the drainage ditches on both sides of the old road had issues of interruption and discontinuity, resulting in a significantly fragmented drainage system. Additionally, many road segments did not have drainage outlets, and the main form of drainage was concentrated on infiltration and evaporation. Some road segments also had problems of external water intrusion into the drainage ditches. Based on these existing issues, a reconstruction plan for the old road drainage system was designed. Firstly, for surface water on the road, a 2% cross slope was utilized to converge the water to both shoulders. Then, a drainage system integrating water barriers, chutes, and drainage ditches was adopted to transport the surface runoff to the outlets. Secondly, a 2-in-1 discharge strategy was implemented for the outlets, utilizing both external drainage channels and pump houses set up at channel locations for pumping and drainage. The first scheme was primarily used during the construction phase, with a requirement that the spacing between each outlet of the drainage ditches along the highway should be ≤ 500 m. Finally, for general road segments with a longitudinal slope of $< 0.5\%$, chutes were set every 25 m, and for those with a longitudinal slope of $\geq 0.5\%$, chutes were set every 35 m. For the bottom of concave vertical curves, a chute was set at the lowest point, and additional chutes were set 3 m to 5 m away on both sides.

Regarding roadside drainage, after comparing three schemes: decentralized drainage, shoulder water barrier + chute, and shoulder drainage ditch + chute, the water barrier + chute scheme was finally selected. For the drainage design of the median strip, the original greenery was removed and the median strip was fully enclosed and retrofitted with an anti-glare net to achieve anti-glare.

3.5. Pavement design

In terms of pavement design, the theoretical program of the multi-layer elastic system (under the action of double-circle vertical uniform load) was used to calculate the mechanical response of design indexes for both the West and East sections of Tianjin in this project. Control parameters such as low-temperature cracking of seasonally frozen soil pavement, vertical compressive strain at the top of the subgrade, and fatigue cracking of the asphalt mixture layer were considered. A comprehensive design was carried out for the thickness, materials, and subgrade improvement of the asphalt pavement structure. For asphalt concrete pavement, a biaxial load design axle load

(single axle 100KN) was used, while a single-axle load was used as the standard axle load (single axle 100KN) for cement concrete pavement. The newly built asphalt concrete widening sections of the main highway were designed for a service life of 30 years, and the original pavement was designed for a service life of 15 years. Cement concrete pavement was designed based on a 30-year design benchmark. Additionally, during the pavement design phase, the project team attached great importance to the utilization of the old pavement, fully leveraging the remaining value of the existing old pavement. They emphasized the recycling of old materials and ecological protection, striving to minimize longitudinal reflection cracks at the joint between new and old pavement while eliminating existing diseases of the old pavement.

4. Conclusion

Based on the research on the subgrade and pavement design of the Beijing-Tianjin-Tanggu Expressway Tianjin Section Reconstruction and Expansion Project, this article summarizes a green highway design paradigm that integrates “ecological priority, resource conservation, and technological innovation”. This paradigm includes multi-dimensional designs such as protective retaining works, soft foundation treatment, and comprehensive utilization of earth and stone. Road and bridge engineering design and construction units can refer to the design ideas and achievements of the Tianjin Section Reconstruction and Expansion Project to actively promote the achievement of green highway construction goals. This not only aligns with social and national development requirements but also establishes a green corporate image, effectively promoting the sustainable development of enterprises and the industry.

Disclosure statement

The author declares no conflict of interest.

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Traffic Safety Management Measures for Highway Reconstruction and Expansion Construction

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Abstract: This article focuses on traffic safety management during the reconstruction and expansion of highways, with the research objective of understanding traffic safety management issues and exploring more effective traffic safety management measures. The research employs practical observation and logical analysis as research methods. Firstly, it elaborates on the connotation of traffic safety management during the reconstruction and expansion of highways, analyzes its key points, and affirms its management value from different perspectives. It provides a detailed analysis of issues such as the weak foundation of traffic safety management systems and the inadequacy of comprehensive traffic safety management, and interprets the restrictive impact of related issues. Based on the manifestation of relevant issues, strategies such as strengthening the institutional foundation of traffic safety management and constructing a comprehensive traffic safety management system are proposed, aiming to provide traffic safety management references for relevant enterprises.

Keywords: Highway; Reconstruction and expansion; Traffic safety management

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1. Introduction

The reconstruction and expansion of highways can have a certain impact on the normal traffic flow of vehicles, making it necessary to ensure traffic safety management during construction to guarantee the safe passage of vehicles. Through analysis, it can be found that many construction enterprises focus more on construction progress, quality, and cost management, while subjectively ignoring traffic safety management during construction. Due to subjective neglect and the influence of many factors, management problems can easily arise, which naturally reduces management effectiveness^[1]. Once there are significant deficiencies in traffic safety management, traffic safety risks will subsequently increase, which may even have many adverse effects on highway expansion construction. Therefore, it is essential to explore more effective traffic safety management measures.

2. Overview of traffic safety management during highway reconstruction and expansion

2.1. Connotation of traffic safety management during highway reconstruction and expansion

Traffic safety management during the reconstruction and expansion of highways refers to a series of management methods and measures adopted during construction to ensure traffic safety in and around the construction area, protect the safety of construction workers, passing vehicles, and pedestrians, and thereby reduce the adverse impact of construction activities on normal traffic flow ^[2]. Management includes personnel safety management, vehicle traffic management, traffic dispersion, and emergency response, covering various aspects that enrich the connotation of traffic safety management.

2.2. Key points of traffic safety management during highway reconstruction and expansion

Traffic safety management during the reconstruction and expansion of highways involves multiple key points. Among them, system construction serves as the foundation for safety management practices, providing an institutional framework for comprehensive management. Ensuring the comprehensiveness of safety management systems is a prerequisite for orderly management, which includes the scientific setup of safety facilities and management evaluation. Safety management cannot be separated from the guidance and regulation of specific systems, making system construction the top priority in traffic safety management during reconstruction and expansion. Secondly, traffic safety management should be implemented throughout the entire construction process, ensuring the simultaneous implementation of various management tasks and a more comprehensive and systematic approach. Apart from these two key points, the scientific arrangement of various facilities in traffic safety management and the evaluation of supervision in management also possess significant importance ^[3].

2.3. Value of traffic safety management during highway reconstruction and expansion

Traffic safety management during the reconstruction and expansion of highways carries significant value, which is reflected in multiple aspects. From the perspective of protecting life safety, traffic accidents inevitably lead to casualties. Given the high traffic volume and fast vehicle speeds on highways, reconstruction and expansion can alter road conditions. Therefore, implementing effective traffic safety management during construction is crucial for ensuring the safety of construction workers, drivers, and passengers. In terms of maintaining road smoothness, effective traffic safety management can create favorable conditions for the normal passage of vehicles in the construction area, which is also helpful for maintaining the basic traffic capacity of the highway during the construction phase and ensuring road smoothness ^[4]. From the perspective of reconstruction and expansion, systematic traffic safety management during construction can guarantee the safety of construction workers and equipment, creating a favorable environment for construction.

3. Problems in traffic safety management during highway reconstruction and expansion

3.1. Weak foundation of traffic safety management systems

Some enterprises have made attempts at traffic safety management during the reconstruction and expansion of highways, investing considerable human and material resources ^[5]. However, upon closer observation, it can be seen that traffic safety management is not standardized, and the institutional foundation for management practices is relatively weak. Many construction enterprises place greater emphasis on construction progress and quality assurance. Although they implement traffic safety management during construction, they fail to establish a solid institutional foundation. Due to the lack of support from comprehensive systems, the level of standardization in traffic safety management is low, and specific management activities are not guided or regulated by these systems.

Affected by this issue, the rights and responsibilities of traffic safety management are not clear, and the content is also ambiguous. This can easily lead to a certain blindness in management practices. More seriously, when the restraining effect of the system is weak, management tends to be more arbitrary. The lack of detailed standards and requirements can easily cause traffic safety management efforts to become mere formalities, potentially burying traffic safety hazards. This can easily lead to construction enterprises becoming increasingly passive in traffic safety management during the reconstruction and expansion of highways.

3.2. Insufficient comprehensiveness of traffic safety management

Traffic safety management during the reconstruction and expansion of highways involves multiple layers of management tasks, requiring distinct management efforts before, during, and after construction. However, many construction enterprises often focus primarily on traffic safety management during the construction phase, while neglecting it during the preparation and post-construction phases. Under the influence of such misperceptions, many construction enterprises fail to conduct detailed planning in traffic safety management, and inadequate planning is a constraining factor that leads to significant limitations in construction safety management ^[6]. These limitations are reflected in the safety management practices during the pre-construction, construction, and post-construction stages, and limitations at any stage can reduce the effectiveness of management. Due to inadequate traffic safety management preparation before construction, insufficient preparation of various safety warning signs can easily have adverse effects on traffic safety management during the construction phase. When post-construction traffic safety management is poor, untimely cleanup of temporary traffic warning signs, diversion facilities, etc., can adversely affect the smooth flow of vehicles. Once traffic safety management has limitations, these limitations can easily reduce management effectiveness. The insufficient comprehensiveness of traffic safety management is also reflected in the inadequate emergency management mechanisms. Untimely accident handling during traffic safety incidents can also easily have adverse effects on road traffic and construction.

3.3. Unreasonable setting of traffic safety facilities

In traffic safety management during the reconstruction and expansion of highways, the reasonable setting of various traffic safety facilities is crucial. The condition of facilities such as warning signs and markings can directly affect the judgment of road conditions by drivers of passing vehicles. Many construction enterprises do not reasonably set up various safety facilities during highway reconstruction and expansion projects, and there is a strong randomness in the setting of safety facilities ^[7]. For example, some warning signs are not placed in prominent positions, which significantly reduces their warning effect. When markings are unclear, their guiding effect is weakened. When fences are unreasonably set up, the width of the highway can be affected, and functions such as isolation and warning cannot be fully utilized. The randomness in setting traffic safety facilities and the non-compliance of some warning signs, markings, and fences with technical standards prevent these facilities from effectively supporting traffic safety management. Moreover, improper setting of traffic safety facilities can even lead to misjudgment of road conditions by passing vehicles, which can increase traffic risks and hinder traffic safety management during construction.

3.4. Lack of effective evaluation in traffic safety management

Traffic safety management during the reconstruction and expansion of highways is a dynamic process, and various factors can easily lead to management issues during this process ^[8]. When the construction duration is longer, there are more uncertain factors in management, which further highlights the importance of management evaluation. However, many construction enterprises do not have a clear evaluation mechanism related to traffic management and do not systematically evaluate traffic safety management during construction. Due to the lack of systematic evaluation of traffic safety management issues, the supervision in management practices is relatively weak, which

is not conducive to timely identifying problems in management practices. Furthermore, inadequate evaluation also hinders construction enterprises from grasping the true status of traffic safety management, leading to a lack of effective references in management decision-making and a disconnection between management efforts and reality. From an optimization perspective, inadequate evaluation also hinders subsequent traffic safety management improvements, as there is also a lack of effective references for management optimization. This indicates that inadequate evaluation is closely linked to issues such as poor process control and inadequate optimization of traffic safety management, and its adverse impact on traffic safety management cannot be ignored.

4. Specific measures for traffic safety management during highway reconstruction and expansion

4.1. Strengthening the institutional foundation of traffic safety management

Traffic safety management during the reconstruction and expansion of highways should first focus on strengthening institutional development, laying a solid institutional foundation to provide institutional support and guarantees for subsequent management practices. For example, a private construction enterprise clarified traffic safety management systems during the construction of a highway reconstruction and expansion project. These systems include the purpose, scope of application, and principles of traffic safety management^[9]. The systems require the establishment of a traffic safety management leadership team, which is fully responsible for coordinating the relationships between the construction unit, the construction enterprise, and the supervision unit in traffic safety management. The systems cover safety management tasks such as traffic flow guidance schemes, arrangement of construction time periods, establishment of emergency mechanisms, and vehicle guidance for split-section construction, highlighting the guiding role of the systems. The systems also contain detailed management standards and requirements, further enhancing the role of basic systems in guiding and regulating traffic safety management. For other construction enterprises, they should also prioritize institutional development during highway reconstruction and expansion projects, strengthening the institutional foundation to enhance the guiding and regulating role of the systems, and conducting safety management in a standardized manner to improve the effectiveness of safety management.

4.2. Constructing a comprehensive traffic safety management system

To avoid limitations in traffic safety management during the reconstruction and expansion of highways, it is of great significance to construct a comprehensive traffic safety management system and conduct comprehensive planning for management practices. For example, a certain enterprise conducted detailed research and planning for traffic safety management during the reconstruction and expansion project of the Liunan Highway in Guangxi. Simultaneously, they formed a management model for the “Five Parties and Three Guarantees” work platform, considering traffic police, road administration, operations, construction (including supervision), and the construction unit as the basic entities of traffic safety management. Under this model, a comprehensive traffic safety management system was established, with detailed arrangements for traffic safety management matters during construction preparation, implementation, and post-construction (as shown in **Table 1**). With the aid of scientific planning conducted beforehand and the detailed arrangements for traffic safety management throughout the construction process, the improvement in management comprehensiveness also promoted the enhancement of management effectiveness.

For other construction companies, they should prepare a traffic safety management plan ahead of time, establish a comprehensive management system, and scientifically coordinate and arrange various management issues. The systematic advantages of traffic safety management should be highlighted to promote the effectiveness of traffic safety management.

Table 1. Traffic safety management system for highway reconstruction and expansion construction

Management Stage	Management Content
Construction preparation	Develop traffic organization plan, prepare safety facilities, conduct propaganda and training, etc.
Construction implementation	Safety facility setup and maintenance, traffic dispersion, management of personnel and vehicles, etc.
Post-construction	Removal of safety facilities, clean-up of construction debris, etc.

4.3. Scientific setup and management of traffic safety facilities

The scientific setup and management of traffic safety facilities are also very important. After preparing various safety facilities ahead of time, construction companies should strictly follow standards and fully integrate the actual traffic safety management in construction to set up traffic safety facilities. For example, in the traffic management of the Maozhan Expressway reconstruction and expansion project, the construction company will set up the first-level warning prompt signs 1.6 kilometers away from the construction area in the direction of incoming traffic, reminding drivers to pay attention to the road construction ahead, and cooperate with electronic displays and dynamic warning facilities to enhance long-distance warning effects. Secondary warning signs are set up 800 meters away from the construction area in the direction of incoming traffic, reminding vehicles to slow down, change lanes, and adjust their driving status in a timely manner through prompts such as “road narrowing”. Speed limit signs are set up 300 meters away, guiding vehicles to change lanes in combination with guiding lines and conical reflective buckets. At the same time, a safety crash-proof buffer vehicle equipped with an active intelligent warning system is created for traffic safety management, providing scientific settings for traffic safety facilities based on technology empowerment ^[10]. The scientific setup of general traffic safety facilities provides strong support for traffic safety management, and applications such as active intelligent warning systems and the deployment of safety crash-proof buffer vehicles also enhance the innovation of traffic safety management, further highlighting the warning role of the scientific setup of traffic safety facilities.

4.4. Dynamic evaluation of traffic safety management

Traffic safety management in highway reconstruction and expansion projects cannot ignore evaluation matters. In evaluations, it is necessary to control the management process and tightly integrate dynamic evaluations with dynamic traffic safety management. Taking the evaluation of traffic safety management in the construction of Jiangxi Jikang reconstruction and expansion project as an example, the construction company will evaluate the implementation of the requirements, the comprehensiveness of traffic safety management, and the reasonableness of the graded warning prompt signs. Based on dynamic evaluations, construction companies should focus on identifying problems in traffic safety management, analyzing the causes of specific problems, eliminating the impact of related deficiencies, and continuously improving them in subsequent management. In addition, it is also very desirable to evaluate the real-time monitoring and evaluation of traffic flow, the standardization of traffic guidance and reform facilities, and the status of emergency support and joint operation. This greatly improves the comprehensiveness and effectiveness of traffic safety management evaluations. For construction companies, traffic safety management should also be adjusted in a timely manner based on changes in the construction area and traffic flow, and normalized traffic safety management inspections should be used as the basic way to evaluate management, strengthening process control in management. After determining the evaluation mechanism in traffic safety management and using it as a protective mechanism, many common management problems can be better avoided, and the implementation of institutional requirements and the implementation of plans can also be more guaranteed, which naturally helps to improve the effectiveness of traffic safety management.

5. Conclusion

Based on this study, it can be found that traffic safety management in highway reconstruction and expansion projects has rich connotations, and different key points need to be taken into account in management. It is also of great value to do a good job in traffic safety management. Considering that some problems are prone to occur in management practices, institutional construction should be carried out first in traffic safety management to strengthen the guiding and normative role of basic institutions. On this basis, a more comprehensive traffic safety management system should also be established, a scientific setup and management of traffic safety facilities should be carried out, and dynamic evaluations should be conducted in management to grasp the true management status. By continuously striving in the above aspects, construction companies can further improve their traffic safety management capabilities in highway reconstruction and expansion projects.

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Advantages and Application Paths of BIM5D Technology in Cost Control of Completed Houses

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Abstract: The purpose of this article is to analyze the advantages and application paths of BIM5D technology in the cost control of completed houses. In the research phase, based on the reading of literature and the combination of project materials, the advantages of BIM5D in the cost control project of completed houses are analyzed after introducing the cost control of completed houses and the connotation of BIM5D technology. Finally, this article starts from multiple perspectives, including BIM5D modeling, cost deviation analysis under dynamic cost control, etc., and finally forms a relatively systematic and complete BIM cost control technology system. It is hoped that this article can provide technical reference value for China's completed housing projects, promote the improvement of the project team's cost control level, obtain considerable economic benefits based on completing project construction with quality and quantity, and enhance the competitiveness of enterprises.

Keywords: BIM5D; Cost deviation; Cost performance; Schedule performance

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1. Introduction

Unlike rough houses, the cost control content designed for finished houses is more complex, incorporating various costs in the process of house decoration. The difficulty of cost control is much higher than that of traditional rough houses. It also involves the cost of household appliances and furniture configuration. Therefore, to achieve cost control of finished housing projects, construction engineering enterprises have begun to explore how to promote the deep implementation of cost management based on digitization^[1]. BIM, as a widely implemented and applied modeling technology in the field of construction engineering in recent years, has the capabilities of visualization and data analysis, effectively solving the problem of human data analysis errors and enabling the entire process tracking of projects. Therefore, research on cost control of finished houses based on the BIM5D model is of great significance to the cost management level of construction engineering enterprises and the future industrial development.

2. Overview of cost control for finished houses and BIM technology

2.1. Cost control for finished houses

Cost control for finished houses refers to the systematic management of costs through scientific management and

monitoring means throughout the entire lifecycle of building construction, ensuring that the project progresses smoothly and is constructed within the budget ^[2]. Typically, the cost control process for finished houses covers various aspects such as budget preparation, cost prediction, cost tracking, cost analysis, and later cost evaluation. The difference in cost management between finished and rough houses lies in the fact that, besides considering the basic construction costs of houses (common building materials, construction equipment, human resources), finished houses also need to consider the management of renovation expenses (including household appliance expenses).

2.2. BIM5D technology

BIM5D refers to the establishment of a traditional BIM-3D model based on BIM building information modeling, combined with the integration of construction progress and cost information to form a 5D multidimensional model. During the project implementation phase, the BIM-3D model is mainly responsible for providing geometric information and spatial relationships of building components, while the BIM-5D model is a further extension of the 3D model, integrating project time dimension and economic dimension data into the model, making the construction management process more comprehensive and visual. The integration of cost information can help the project team achieve real-time monitoring of the difference between the project budget and actual expenditure. This process can be applied throughout the entire lifecycle of the construction project, further enhancing the level of cost control ^[3].

3. Technical advantages of BIM5D technology in cost control of finished houses

3.1. Visual cost management

In finished housing projects, the visual cost management of BIM5D technology transforms traditional 2D drawings into dynamic 3D models, making the cost distribution more intuitive. Through immersive visual displays, project participants can precisely locate high-cost areas and potential waste points. Compared to rough houses, finished houses involve a lot of fine decoration and high-quality requirements. The visual management function provided by BIM5D allows more precise cost control during the design and construction phases, reducing financial risks caused by design changes ^[4].

3.2. Real-time data analysis and integration

During the development process of finished houses, the real-time data analysis and integration function of BIM5D technology allows project managers to keep abreast of dynamic cost changes. Since finished houses emphasize the coordination of progress and quality, real-time data analysis ensures the timeliness and accuracy of information, thereby guaranteeing timely and effective decision-making during the construction process.

3.3. Risk proactive identification

BIM5D technology can enhance the proactive identification of cost risks in finished houses. By predicting construction progress, cost, and material selection data through the 5D model, BIM can help project teams identify potential cost overrun risks early. This proactive identification can avoid quality non-compliance and budget overruns in the context of high-quality requirements for finished houses, allowing for early optimization of various resource allocations such as personnel, materials, and equipment, and avoiding potential risks ^[5].

4. Application paths of BIM5D technology in cost control of finished houses

4.1. Project overview

The Qinghe Jincheng finished housing community project is located on Xueyuan West Road, Tengzhou City, Zaozhuang City, Shandong Province. Its 1# – 6# and 8# buildings have a total above-ground floor area of 52,176 m² and an underground area of 32,950 m². The 7# building has a total construction area of 9,239 m² and is equipped with 72 residential units. During the project development stage, the developer and project team attached great importance to effective cost control. BIM building information modeling technology was introduced during the construction phase, and a BIM platform was established for participating units to manage construction quality, progress, and cost.

4.2. Design of construction cost control model for finished houses

4.2.1. Modeling process

During the construction phase of the Qinghe Jincheng finished housing community project, the project teams modeling of the cost control model based on BIM5D included 3D model construction, input of schedule and cost information, and association of schedule and cost information, as shown in **Figure 1**.

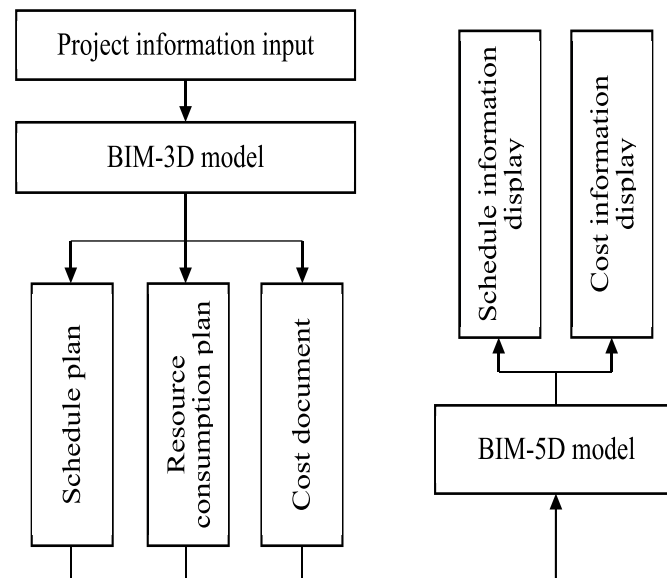


Figure 1. Modeling process of BIM5D Model for Qinghe Jincheng finished housing community

As shown in **Figure 1**, during the modeling of the 5D model, building a BIM3D model is the basic step. After establishing the BIM digital platform, project information is input to generate a physical model that displays the spatial structure and physical characteristics of the project in detail. Subsequently, after the 3D model is generated, schedule and cost parameters are input into the model, including detailed schedule plans, resource consumption plans, and project-related cost documents. This process needs to ensure the comprehensiveness and precision of the above data, covering the specific requirements of all construction stages ^[6]. In the 5D model, the schedule plan is mainly displayed through a timeline, allowing the project team to keep track of the start and end times of each construction link. The resource consumption plan lists the human, material, and equipment resources required at different stages. The cost documents provide the model with information on resource budgets and actual expenditures, enabling cost monitoring and adjustment throughout the entire lifecycle of the Qinghe Jincheng finished housing project.

4.2.2. Model information association

During the cost control phase supported by the BIM5D model, it is necessary to associate cost information with the model accurately. Firstly, a cost database system is introduced into the BIM3D model, which identifies the attributes of building components within the model and links them with the cost database. The cost data for each component, including material unit prices, labor costs, equipment usage fees, etc., is extracted in real-time from the cost database^[7].

4.3. Dynamic cost control based on BIM5D

4.3.1. Cost deviation analysis

During the implementation of the later decoration engineering of the project houses, the entire cost deviation analysis phase based on BIM5D involves integrating design, construction progress, and actual cost data through the BIM5D platform for the Qinghe Jincheng finished housing project team. The design and construction data are provided by the BIM3D model, the construction progress data is taken from project, and the cost data comes from on-site collected financial data and financial databases. After completing data integration, the BIM5 model performs automated cost deviation detection by setting a benchmark budget and expected costs, comparing actual costs with budgeted costs during each project implementation, and calculating deviations in real-time. For example, the decoration engineering budget for the Qinghe Jincheng finished housing project is 6,850,000.00 yuan, of which the budget for the water and electricity renovation sub-project is 380,000.00 yuan, but the actual expenditure is 397,000.00 yuan. The BIM5D automatic detection mechanism immediately identifies a cost deviation of 17,000.00 yuan and visually displays it on the computer interface.

4.3.2. Cost performance analysis

Cost performance analysis evaluates the specific effectiveness of cost control from a holistic perspective, while predicting and optimizing future costs. The cost performance analysis process based on the BIM5D model includes benchmark indicator setting, data collection and deep analysis, simulation and prediction, and performance evaluation.

(1) Benchmark indicator setting

The Qinghe Jincheng project team establishes key cost performance indicators (cost efficiency indicators, schedule cost index) within the BIM software and uses these benchmarks as the basis for cost performance evaluation. For example, the CPI (Cost Performance Index) is calculated as $CPI = EF/AC$, where EF represents the cumulative earned value and AC represents the cumulative actual cost. If the calculation results show that $CPI < 1.0$ or the CPI index is gradually decreasing over time, it indicates insufficient cost control and timely adjustments are needed.

(2) Data collection and deep analysis

The project team automatically collects actual cost data and planned costs through the BIM5D platform. Based on data mining and analysis techniques, they conduct deep analysis on historical cost data to identify cost trends and anomalies. For instance, if it is found that labor costs show a sudden increase during a specific period of the decoration project, further investigation is needed to determine the specific reasons and influencing factors for the increase.

(3) Simulation and prediction

Time series models are used to predict future costs^[8]. For example, if it is found during the decoration project that labor costs increase during winter due to an imbalance in worker supply and demand, the BIM5D model can predict the cost consumption trend for the next few construction stages through simulation, allowing the project team to take preventive measures ahead of time.

(4) Performance evaluation

Based on the results of cost performance evaluation, cost optimization strategies are developed. During the cost performance analysis of the Qinghe Jincheng finished housing project, the overall budget for the decoration engineering was 6,850,000.00 yuan. The BIM5D model detected a cost overrun of 170,000.00 yuan in the hydropower engineering, with actual expenditures reaching 397,000.00 yuan. After identifying this cost deviation issue, CPI calculations revealed that the deviation was due to overspending on concrete materials, with a CPI index of 0.65. In response, the project team re-evaluated the pricing of concrete suppliers and selected a more cost-effective supplier. By adjusting the material procurement strategy in a timely manner, they successfully brought the concrete cost within the budget range, and the CPI index rose back above 1.0.

4.3.3. Progress deviation analysis

The core of the progress deviation analysis for the Qinghe Jincheng completed housing project lies in identifying and addressing deviations during the construction process, ensuring that the project is completed within the established timeframe and controlling additional costs caused by delays. During project implementation, the BIM5D model integrates project plans, cost budgets, and real-time construction data. Each work package is accompanied by a detailed progress plan. The BIM5D model combines progress data extracted from the project with actual data obtained from on-site monitoring equipment (such as drones and sensors) and compares it with the progress plan data within the model, automatically generating a progress deviation report.

For example, during the construction of the Qinghe Jincheng completed housing project, the project team used drones to regularly capture high-precision images of the construction site during the main construction phase. Through image recognition technology, the actual construction points were analyzed and compared with the planned progress in the BIM5D model. When the project plan reached its 20th week, the main structure of Building 1# should have been 70% complete, but actual data showed only 67% completion. This progress deviation was detected by the BIM5D model, which immediately generated a progress deviation report. The project team then analyzed this report and determined that the deviation was caused by quality issues with the steel materials. The supplier had just changed, and transporting the materials took an additional two days, resulting in a delay.

4.3.4. Progress performance analysis

Progress performance analysis aims to evaluate construction efficiency and resource utilization, quickly identifying key factors that affect progress and cost. During project implementation, the BIM5D model compares the progress baseline with actual progress, generating an EVM (Earned Value Management) report to assess the Cost Performance Index (CPI) and Schedule Performance Index (SPI). This allows for the rapid identification of deviations between progress and cost. For instance, during the installation of water supply and drainage pipes in the Qinghe Jincheng completed housing project, the SPI value provided by the BIM5D model was below 1.0, indicating low progress efficiency and construction delays. By analyzing on-site and historical construction data, the project team discovered that some workers were unfamiliar with the new construction methods, leading to slow installation speeds and frequent errors, which increased rework costs ^[9].

4.3.5. Cost warning

For cost warnings in the Qinghe Jincheng project, the BIM5D model updates on-site construction data to the BIM platform in real-time through sensing devices and wireless networks, ensuring data freshness. Based on this, the BIM platform performs cross-analysis on multiple dimensions of cost data, such as material procurement and labor costs, during the project implementation phase, identifying potential cost overruns. Simultaneously, combining

preset cost thresholds for various dimensions and overall costs, the BIM model automatically activates a warning mechanism when cost deviations exceed the threshold, notifying project managers and relevant units via SMS, QQ messages, and emails.

4.4. Cost correction

The BIM5D model enables the generation of cost correction decision schemes for cost overruns. After receiving cost warning notifications, participating construction units can adjust their cost plans. The BIM5D model then simulates and analyzes the adjusted schemes, assessing the specific impact on costs and progress to ensure that the engineering team can select the optimal strategy ^[10].

5. Conclusion

Based on the BIM5D model cost control system studied above, the Qinghe Jincheng completed housing project has successfully achieved precise management and control of construction costs under the cost warning system based on the BIM5D model. This not only ensures the project's financial health but also promotes the transparent management of the construction process, significantly improving the project's overall efficiency and economic benefits. Construction engineering units can learn from the Qinghe Jincheng completed housing project's experience during the cost control phase of completed housing, strengthening the construction and application of the BIM5D model. This will comprehensively enhance the intelligence level of project team cost control, providing effective technical support for obtaining established economic benefits and preventing cost overruns.

Disclosure statement

The authors declare no conflict of interest.

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Discussion on Traffic Organization Design for the Expansion and Reconstruction of Highway Interchanges

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Abstract: As a critically important transportation infrastructure in China, highways play a significant role in supporting socio-economic development. However, due to the rapid growth of the current socio-economic landscape and the dramatic increase in the number of cars, many early-built highways have experienced a surge in traffic volume, making it difficult to meet the growing traffic demand. This has led to various issues such as traffic congestion and inefficient operation. Therefore, it is necessary to expand and reconstruct the highway interchanges, effectively optimizing traffic organization design and significantly improving the overall service level of the highway. This article provides a detailed analysis of the principles and key points of traffic organization design for the expansion and reconstruction of highway interchanges. Additionally, it delves into the design scheme for the traffic organization of these interchanges.

Keywords: Highway; Expansion and reconstruction; Interchange; Traffic organization design

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1. Introduction

Vehicles traveling on highways must strictly adhere to relevant standards and actual road conditions for lane changing. However, this process may be complicated by various factors such as insufficient roadside space and obstructed vision, increasing driving difficulty, and lead to significant fluctuations in driving speed^[1]. Thus, only by expanding and reconstructing corresponding sections of the highway can we minimize traffic conflicts and reduce interference with transportation, thereby further improving the application and operational efficiency of the highway. Nevertheless, China has been late in applying highway expansion and reconstruction, and there are currently no specific standards and norms for traffic organization in this regard^[2]. Consequently, relevant personnel must ensure effective road organization and management to enhance the practical application efficiency of highways and improve road service quality and performance.

2. Principles of traffic organization design for highway expansion and reconstruction of interchanges

2.1. Environmental protection principle

Highway expansion and reconstruction projects will inevitably have some impact on the surrounding environment. Therefore, it is imperative to implement the principle of environmental protection in the traffic organization design process. For instance, measures should be taken to minimize noise, dust, and other pollution during the construction phase, and targeted protective and remedial measures should be adopted to effectively protect the living environment and quality of life of surrounding residents ^[3]. Additionally, the route alignment should be reasonably planned in the design of interchange traffic organization to avoid damaging environmentally sensitive areas. Relevant staff should also focus on green design, planting suitable vegetation around interchanges and in the central median, which can not only enhance the aesthetic appeal of the environment but also contribute to noise reduction, dust prevention, and air purification ^[4].

2.2. Safety principle

Safety is a key principle in the traffic organization design process for the expansion and reconstruction of highway interchanges. At the same time, traffic safety during construction and after operation must be fully considered. For example, safety facilities such as traffic signs, markings, and guardrails can be reasonably set up to guide vehicles to drive in an orderly manner, thereby minimizing the probability of traffic accidents. Additionally, prominent warning signs and isolation facilities should be installed in the construction area to ensure the safety of construction workers and passing vehicles ^[5]. Furthermore, careful design should be given to key areas such as ramps and acceleration/deceleration lanes of the interchange to ensure that vehicles can safely accelerate, decelerate, and turn. The relevant staff should also fully consider the driving characteristics of different vehicle types to clarify the lane width and turning radius, thereby effectively avoiding scratches and collisions between vehicles.

2.3. Economic principle

The cost of traffic organization design and implementation should be minimized while meeting traffic demand. On the one hand, existing road facilities and resources should be reasonably utilized to reduce unnecessary demolition and reconstruction work. For example, roads with good structural conditions can be modified and reinforced to meet new traffic demands, avoiding large-scale demolition and reconstruction. On the other hand, the construction plan and traffic organization design should be continuously optimized and improved to reduce construction duration and traffic control time, thereby lowering construction costs and socioeconomic losses. Additionally, when selecting traffic facilities and equipment, cost-effective products should be chosen through comparison ^[6].

2.4. Smoothness principle

Maintaining traffic smoothness is an important aspect of traffic organization design. Therefore, during the design process, efforts should be made to minimize the interference and impact of construction on traffic, ensuring smooth traffic during construction. Clear planning of the construction situation, sequence, and traffic diversion routes can reduce traffic congestion. Additionally, in the traffic organization design process for the expansion and reconstruction of highway interchanges, not only should the traffic flow be effectively optimized and improved, but also conflicts between vehicles should be minimized to improve driving efficiency ^[7]. For example, reasonable traffic organization design measures can be adopted to effectively separate vehicles traveling in different directions. At the same time, the change in traffic flow should be fully considered, and the number of lanes should be reasonably set to ensure that traffic demand can be fully met during peak hours.

3. Key points of traffic organization design for the expansion and reconstruction of highway interchanges

3.1. Understanding the current traffic situation

Before carrying out traffic organization design work, relevant staff must have a detailed understanding and investigation of the existing interchange traffic conditions. This mainly includes the setting of traffic signs and markings, the number and width of lanes, and the actual use of traffic facilities at the interchange. At the same time, the staff should also investigate the distribution of surrounding roads, traffic flow, and traffic capacity. Through investigation and understanding of the current traffic conditions, problems and deficiencies can be identified, and targeted solutions can be provided for traffic organization design work. For example, if it is found that a certain ramp of the existing interchange often experiences traffic congestion, it is necessary to analyze the actual reasons for the congestion, such as insufficient number of lanes, unreasonable setting of traffic signs, or other factors, so that corresponding measures can be taken to improve and optimize it, thereby reducing the probability of traffic congestion ^[8].

3.2. Reasonable setting of traffic facilities

The reasonable setting of traffic facilities is also the key to ensuring the effective implementation of the traffic organization design scheme. During the expansion and reconstruction of the interchange, traffic facilities such as traffic signs, markings, guardrails, and signal lights should be reasonably set according to the traffic organization design scheme. It is necessary to ensure that the location of traffic signs is reasonable and the information is clear, to correctly guide drivers. Additionally, the setting of markings must comply with national standards and be clear and eye-catching to standardize the driving trajectory of vehicles. Furthermore, relevant staff should pay attention to the maintenance and management of traffic facilities to ensure the normal operation of equipment ^[9].

4. Traffic organization design scheme for the expansion and reconstruction of highway interchanges

4.1. Subgrade construction

During the implementation of highway expansion and reconstruction projects, both unilateral and bilateral widening will directly affect and interfere with the normal operation of the highway. Moreover, the process of removing existing isolation belts will significantly reduce the control of horizontal traffic and lead to increased traffic chaos in the construction area, thereby increasing the risk and probability of traffic accidents to some extent. To ensure the safe and smooth operation of the highway, it is necessary to install isolation belts and prominent warning signs at key locations. Additionally, roadbed construction and road surface construction are mutually supporting and complementary links, and in highway expansion and reconstruction projects, the roadbed and road surface are typically the core focus. Therefore, unilateral roadbed widening without change and separate construction on both sides of the roadbed are two commonly used methods. During the actual construction process, the following strategies can be adopted for traffic organization design: Firstly, maintain the existing guardrail positions unchanged, reasonably adjust the isolation belt positions, and expand outwards, keeping the expansion area on both sides of the road to minimize interference and impact on the original road traffic. Secondly, during the splicing construction of the roadbed, it is necessary to use isolation fences to separate the roadbed on both sides and optimize and improve the corresponding traffic organization design to further enhance the operational efficiency of the highway.

4.2. Pavement construction

The most common practice during pavement construction on highways is to implement fully closed construction and divert traffic to other roads or use opposing lanes to effectively disperse traffic flow. However, such construction methods undoubtedly have a significant impact on the normal operation of the highway. Therefore, when carrying out pavement widening projects on both sides, pavement zoning and half-width construction measures can be applied. The specific construction measures are as follows: Firstly, relevant operators must follow the relevant norms and standards for highway expansion and reconstruction, and implement the construction of the expansion area step by step to ensure a deep understanding and control of the overall situation of the expansion and reconstruction section. This allows for accurate delineation of the specific locations and spacing of each construction area. Additionally, the application of half-width construction measures in highway expansion and reconstruction projects enables the rational use of opposing lanes to effectively transfer and disperse traffic flow. Vehicles return to their original lanes after passing through the construction area, and drivers must slow down to ensure safe driving. Furthermore, prominent protective fences and traffic indication signs should be set up in the construction area to ensure smooth traffic operation on the highway ^[10].

4.3. Interchange construction

Interchanges on highways are mainly divided into two types: interconnected interchanges and separated interchanges. Among them, separated interchanges can provide convenience for the diversion and transfer of traffic flow by setting up temporary passages. However, interconnected interchanges are more common on highways. They not only enable effective combination and connection of route networks in different directions but also allow reasonable distribution and merging of vehicles, thereby significantly improving vehicle operation efficiency. Additionally, during the implementation and construction of interconnected interchanges, it is necessary to ensure the smooth progress of construction work while minimizing the impact on the service quality of the interchanges. Therefore, construction managers need to reasonably divert vehicles upstream and downstream of the interchanges based on different vehicle types and speeds, thereby alleviating traffic pressure in the construction area.

Furthermore, specific measures for traffic organization design during the actual implementation of interchange expansion and reconstruction work include the following two aspects: Firstly, when performing unilateral widening of single-trumpet interconnected interchanges, the design should maintain the original trumpet shape of the interconnected interchange and expand on the outer side of the existing ramp. Half-width closure can be implemented on the original ramp to manage traffic flow using half-width lanes and temporary access roads. After construction is completed, fences should be removed promptly, and road markings and infrastructure should be reset for the interconnected interchange. Secondly, when performing bilateral widening of trumpet-shaped interconnected interchanges, it is necessary to complete the relevant construction work on the pavement, bridges, and other aspects on both sides of the original highway before the expansion and reconstruction work begins. Temporary access roads should then be built for vehicle traffic, thereby minimizing the impact of the expansion and reconstruction work on highway traffic.

4.4. Bridge construction

When designing the expansion and reconstruction of highway bridges, it typically involves various aspects such as culverts, bridges, and underground passages. Meanwhile, there is often a certain similarity and universality in the traffic organization design and traffic organization plans during the expansion of highway bridges. Moreover, during the actual expansion and reconstruction of highway bridges, uneven settlement easily occurs between the newly constructed parts and the existing bridges, which may cause stepped cracks at the junction of the old and new bridges. This issue is quite common in highway bridge expansion and reconstruction projects. Therefore,

during the expansion and reconstruction of highway bridges, construction activities at both ends of the bridge must be adjusted according to core data such as the actual bearing capacity of the bridge and vehicle traffic. Additionally, the construction plan must ensure coordination among various parts to guarantee a smooth connection between the bridge and the road. Furthermore, when constructing the substructure on both sides of the bridge, it is necessary to simultaneously construct the roadbed on both sides of the road. Road surface construction can only be carried out according to relevant standards and regulations after the completion of roadbed construction. During the construction process, relevant staff must base their work on the specific requirements and relevant specifications for roadbed and road surface construction, to maintain highway traffic order and promote the further development and construction of the transportation industry.

4.5. Service area construction

Although the expansion and reconstruction of highway service areas have a relatively minor impact on traffic, these service areas, as an important part of the highway, cannot be ignored. To ensure that vehicles can normally refuel and rest in the service area, it is necessary to carry out scientific and reasonable planning for the traffic organization of the service area during the expansion and reconstruction process. The traffic organization design for the construction of highway service areas can typically be divided into two stages. The first stage involves construction work on the roadbed and road surface on both sides of the road, while keeping the service area entrance and exit unchanged and ensuring its normal operation and application. Secondly, to expand the entrance and exit of the service area, vehicles are required to slowly queue on both sides of the road to enter or leave the service area. After the expansion of the entrance and exit is completed, the temporary fencing can be removed, and traffic signs, markings, and related traffic guidance facilities can be restored.

5. Conclusion

The traffic organization design for the expansion and reconstruction of highway interchanges is a relatively difficult engineering task, involving multiple fields such as traffic engineering, road engineering, and construction organization. During the design process, it is necessary to follow principles such as environmental protection, safety, economy, and smoothness, while adopting scientific design methods and combining actual situations to formulate reasonable traffic organization design plans. Additionally, through the analysis of common traffic organization design plans and case studies of engineering examples, it can be seen that reasonable traffic organization design can effectively solve the traffic problems of interchanges during the expansion and reconstruction of highways, ensure the safety and smoothness of traffic during construction, and significantly improve the operational efficiency of interchanges on expanded and reconstructed highways.

Disclosure statement

The author declares no conflict of interest.

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Organization and Management Approaches for Highway Traffic Engineering Projects

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Abstract: When carrying out highway traffic engineering projects, it is essential to focus on construction organization design as the core, accurately grasp the key points of construction organization design, and adopt appropriate construction organization methods to ensure the smooth completion of the project. In the process of implementing project construction management, it is necessary to focus on strengthening the management of construction quality, construction progress, construction costs, and construction safety, and effectively enhance the competitive strength of construction enterprises. This article explores the construction organization of highway traffic engineering projects and proposes specific construction management approaches, hoping to assist in the smooth completion of highway traffic engineering projects with guaranteed quality and quantity.

Keywords: Highway traffic engineering; Construction organization; Construction management

Online publication: May 30, 2025

1. Introduction

The construction of highway traffic engineering projects plays a significant role in promoting economic development and inter-regional exchanges. To ensure the economic and social benefits of highway traffic engineering projects and better serve the social masses and economic development, it is necessary to attach great importance to project construction organization and management, scientifically and rationally plan project construction, and strictly control the construction quality, construction progress, construction costs, and construction safety of the project, thereby promoting the sustainable development of the highway construction industry.

2. Construction organization of highway traffic engineering projects

2.1. Key points of construction organization design

The design of a construction organization is an important foundation for the smooth progress of the overall construction of highway traffic engineering projects, and it plays a crucial guiding role in the overall construction. Improving the scientificity and rationality of construction organization design can effectively ensure that highway traffic engineering projects are completed within the agreed construction period with guaranteed quality and

quantity, achieve efficient utilization of resources, and effectively control engineering costs ^[1].

When designing the construction organization, the first step is to comprehensively understand the overview of the highway traffic engineering project, including the project location, the surrounding environment, project scale, route planning, length, width, technical standards, etc. For example, when constructing a highway traffic engineering project that needs to pass through mountainous areas, it is necessary to conduct an on-site comprehensive survey of geological conditions, topography, climate, cultural relics, nature reserves, etc., to provide important support for the targeted implementation of subsequent construction ^[2].

A key aspect of construction organization design is to coordinate and deploy the project construction from a holistic perspective. This mainly involves clarifying construction goals, dividing construction tasks, forming construction teams, formulating construction processes, and planning construction schedules. Construction goals not only include construction quality but also cover construction duration, safety, and ecological environmental protection.

2.2. Basic methods of construction organization

The commonly used basic methods for organizing highway traffic engineering project construction are flow production method, parallel operation method, and sequential operation method. Different methods have their own characteristics and are used in different scenarios. When organizing highway traffic engineering project construction, it is usually necessary to combine multiple methods to optimize the construction effect ^[3].

The flow production method divides the entire highway traffic engineering project into different construction sections according to different construction objects, and arranges different professional construction teams to work together in different construction sections, achieving a close connection between the construction of different sections in time and space. The main advantage of this construction organization method is that it can fully utilize the construction surface and construction time, which helps improve construction efficiency. This method is suitable for large-scale and complex engineering projects.

The parallel operation method is a construction organization method that allows multiple tasks to be carried out simultaneously. Its application advantage is that it can shorten the construction period of engineering projects. It is more suitable for engineering projects with tight construction schedules. However, this organization method requires a lot of material and manpower resources, so it has high requirements for resource supply.

The sequential operation method, also known as the sequential work method, requires completing various construction tasks in an orderly manner according to the construction process. Its application advantage is that it does not require a lot of manpower and material resources every day, but the utilization of the construction surface is insufficient, and it takes a long time to complete the construction. This organization method is suitable for small-scale engineering projects with simple construction tasks, limited construction surfaces, and no high requirements for the construction duration.

3. Effective ways to optimize highway traffic engineering project management

3.1. Strengthening quality management of highway traffic engineering projects

The quality of highway traffic engineering project construction not only directly affects the safety of subsequent vehicle operation but also closely correlates with the service life and social benefits of the highway traffic engineering. Therefore, it is imperative to attach sufficient importance to quality management and strictly control the construction quality of each construction link ^[4].

Firstly, it is necessary to strengthen the improvement of the quality management system. Construction enterprises should formulate specific construction operation procedures and quality standards for each construction

link according to the actual situation of the highway traffic engineering project and national standards. At the same time, they should implement quality management responsibilities to various departments and individual staff members, and conduct full-process and comprehensive control over the project construction quality. Moreover, construction enterprises also need to establish a quality inspection department, introduce professional talents, and actively introduce professional testing equipment to strictly inspect the construction quality of various parts of the highway traffic engineering project, thereby ensuring that the overall project construction quality meets the design requirements and standards.

Secondly, strict control of the quality of construction materials is essential. In this process, construction enterprises should attach importance to the procurement of construction materials, select suppliers with reliable quality and good reputation through bidding, and establish long-term cooperative relationships with them. Before construction materials enter the construction site, their quality should be strictly inspected. When implementing material storage management, attention should be paid to avoiding material damage, deterioration, and moisture, etc., to ensure that their quality meets the construction requirements of the engineering project. **Table 1** shows the quality standards of commonly used construction materials.

Table 1. Quality standards for commonly used construction materials

Material type	Quality standard
Cement	Complies with the requirements of the “Quality Inspection Rules for Cement and Its Products”, with a 28-day strength of $\geq 42.5\text{MPa}$, and good plasticity, fluidity, durability, and impermeability.
Asphalt	Needs to meet the GB/T 2414-2006 standard, with a viscosity of 120–200s, and good aging resistance, crack resistance, oil resistance, and water resistance.
Sand and stone	The particle size should meet the required standards, with main particle size grades of 0–5mm, 5–10mm, 10–20mm, 20–31.5mm; mud content $< 3\%$, stone content $< 10\%$.

Finally, strict management of the construction process quality should be strengthened. This is to avoid affecting the performance and structural safety of highway traffic engineering projects due to substandard construction process quality. In this process, construction enterprises need to scientifically formulate construction procedures based on the characteristics of the engineering project itself and the demand for construction processes, and strictly control the construction quality of each construction procedure^[5]. Before proceeding to the next construction procedure, strict acceptance of the construction quality of the previous procedure is required. If the quality is not up to standard, immediate rectification is needed until it meets the standard before proceeding to the next construction procedure. For example, during roadbed filling, strict control of flatness, compactness, and thickness is essential. Filling and compaction should be performed in layers to ensure that the previous layer’s thickness, flatness, and compactness meet the standards before proceeding to the next layer. This approach guarantees the highway engineering roadbed’s stability.

3.2. Strengthening management of construction progress in highway traffic engineering projects

An essential aspect of construction management in highway traffic engineering projects is progress management, which is closely related to improving the efficiency of the engineering project, including both economic and social benefits. A reasonable arrangement of construction progress can ensure that the engineering project is completed smoothly within the agreed time. If the construction progress is not effectively controlled, leading to an extended construction duration, it will not only increase construction costs but also affect the social benefits of the engineering project. Therefore, construction enterprises must scientifically arrange construction progress based

on the actual situation of the engineering project, such as resource supply and construction conditions, according to the contract duration, and clarify the start and end time nodes of each construction link. They should also refine the overall construction schedule, determine the construction schedule to be completed monthly, weekly, and daily, and determine the time nodes for each construction worker to complete their construction tasks.

When implementing construction progress management in highway traffic engineering projects, it is also necessary to actively introduce advanced construction equipment and technology to achieve efficient construction, to put the highway traffic engineering projects into use early while ensuring quality and quantity construction ^[6]. For example, during the construction of the highway's bridge section in the traffic engineering project, using pre-assembled technology can shorten the construction time of this section. In contrast, during the tunnel section's construction, employing shield equipment can enhance efficiency while ensuring safe operations.

In addition, when managing the construction progress of highway traffic engineering projects, it is also necessary to strengthen communication and coordination among various departments, improve their cooperation, and ensure that problems encountered during construction can be solved promptly to avoid adverse effects on construction progress. For example, when design changes occur during construction, the construction team needs to communicate and coordinate with the designers in a timely manner to prevent delays in construction progress.

3.3. Strengthen cost management of highway transportation engineering project construction

Cost management is also a crucial aspect of highway transportation engineering project construction management, as it not only relates to the improvement of project benefits but also to the long-term development of construction enterprises. Especially in today's increasingly competitive industry market environment, construction enterprises need to attach great importance to project cost management if they want to enhance their competitive advantages.

In the specific implementation of cost management, key tasks include evaluating project costs, developing cost plans, controlling cost expenditures, cost accounting, and cost management assessments ^[7]. When conducting cost evaluations, it is necessary to combine the basic characteristics of the project, market price trends of construction materials, and construction conditions to scientifically estimate project costs, providing a reliable basis for the development of project cost plans. When developing cost plans, a comprehensive analysis of resource supply and construction progress should be conducted to determine cost management objectives and specific management measures. When controlling cost expenditures, dynamic and real-time monitoring and control of cost expenses in each construction link of the project are required, providing a reference for later cost management assessment work. Before implementing cost management assessments, clear assessment and evaluation indicators should be established to ensure fairness in the assessments, and a sound incentive mechanism should be constructed to provide corresponding rewards to departments and individuals who reasonably reduce project cost expenditures. Similarly, departments and individuals who are ineffective in cost management, waste resources, and increase project costs should be given corresponding penalties.

In addition, when specifically implementing cost management work for highway transportation engineering projects, it is necessary to follow the basic principle of full participation, establish a sound cost management system, clarify the cost management responsibilities of various departments and individuals, and increase publicity efforts for cost management work. This will strengthen the cost management awareness of every staff member, mobilize their enthusiasm and initiative to control project costs, and thus save project costs.

3.4. Strengthen safety management of highway transportation engineering project construction

Safety management is fundamental to ensuring that highway transportation engineering projects are completed

smoothly with quality and quantity within the specified construction period. It not only affects project benefits and social stability but also relates to the personal safety of construction workers. For highway transportation engineering projects, they involve not only diversified construction techniques but also complex construction environments. Coupled with the relatively weak safety awareness of some construction workers, safety accidents are prone to occur, seriously threatening the lives of construction workers. Therefore, construction enterprises must vigorously implement project construction safety management ^[8].

Firstly, establish a comprehensive safety management system. Construction enterprises need to clarify the operational norms for various construction techniques based on relevant national laws and regulations and the actual situation of the engineering project. At the same time, they should clearly delineate the safety management responsibilities of various departments and individual staff members, forming a safety management network with full process and full participation. Additionally, construction enterprises need to establish a dedicated safety management department responsible for conducting comprehensive and all-around inspections and supervision of the on-site construction safety of the project. This will enable the timely identification and elimination of potential safety hazards in their infancy stage.

Furthermore, strengthen safety training and education for construction workers, enhance the safety awareness of the overall construction team, and urge them to always prioritize safety during construction. Through safety drills, construction workers should be made aware that they will be the direct victims in case of safety accidents, while also improving their responsiveness and safety skills to minimize the occurrence of construction safety accidents.

In addition, intensify safety management efforts at the construction site, requiring all personnel entering the site to be equipped with complete safety protection measures. Regular inspections and maintenance of construction equipment and tools should be conducted to ensure they are in normal and stable operating conditions, avoiding safety accidents caused by malfunctions. At the same time, strengthen the management of gas, fire, and electricity usage at the construction site to prevent explosions, fires, and electric shock accidents ^[9].

Finally, develop scientifically based emergency response plans for safety accidents. During the construction of highway transportation engineering projects, construction enterprises need to develop practical emergency response plans for possible emergencies such as safety accidents and natural disasters. This includes determining the organizational structure for emergency response, clearly defining emergency response tasks, processes, and specific strategies. By simulating emergencies, the ability of staff to handle unexpected situations can be enhanced, ensuring quick and accurate responses to minimize losses in case of emergencies ^[10].

4. Conclusion

In summary, when designing the construction organization for highway transportation engineering projects, it is necessary to accurately grasp the key points of construction organization design, select appropriate organization methods based on the actual situation of the project, and effectively improve the quality and progress of the project construction through quality management, schedule management, cost management, and safety management. This ensures the safety of the construction while achieving effective control of construction costs, thereby empowering the long-term development of the construction enterprise.

Disclosure statement

The author declares no conflict of interest.

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Ecological Functions and Spatial Design of Entrance Waterscapes in Traditional Huizhou Settlements: A Case Study of the Shuikou Area in Chengkan Village

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Abstract: This study explores the ecological functions and spatial composition of the water landscape in the traditional Huizhou settlement of Chengkan Village. The analysis reveals how the estuary integrates the functions of water source protection, microclimate regulation, and cultural expression through a complex layout of ponds and Feng Shui forests. It provides important lessons for modern sustainable landscape design and planning.

Keywords: Huizhou waterscape; Ecological function; Spatial design

Online publication: June 4, 2025

1. Introduction

Water features are a functional part of traditional settlements and a lifeline that sustains the natural environment and cultural spirit of the village. Key elements such as water gates, flowing waterways, village ponds, such as moon ponds, and surrounding streams form a multi-layered system for managing water flow, creating a harmonious balance between environmental sustainability, daily practicality, and cultural expression. This paper takes the water mouth of Chengkan Village as a case study to explore its role in ecological regulation and its spatial expression, to uncover the wisdom of traditional practices and offer insights for modern water landscape design and sustainable landscape planning.

2. Gathering water to form a village: An overview of the spatial pattern and water environment of Chengkan

2.1. Village location and overall layout

The traditional Huizhou village layout is based on the ecological principle of ‘following the contours of land and

water to form a village', which is an homage that exists in harmony with the ecological environment, and natural topography and hydrology as shown in **Figure 1** ^[1]. In the mountainous area of southern Anhui Province, various villages empower a favorable village in a gentle location surrounded by mountains and water in the valley and riverbank, in the concept of avoiding natural disasters and utilizing water sources sustainably. Not only does it make efficient use of resources, but it also improves adaptability to the environment. Huizhou villages are generally designed with the pattern of 'low in front, high in back', where imported water from superior terrain runs through the village and is returned, forming an effective water diversion-use-drainage system. The water run system is a direct influence to the street type and building type configuration, and the streets will follow the shaped of the water run and the alleys will follow the shaped of the ditches. This, then depicts the sculpture of "running water in front of the house, cultivated land behind the house." ^[2]

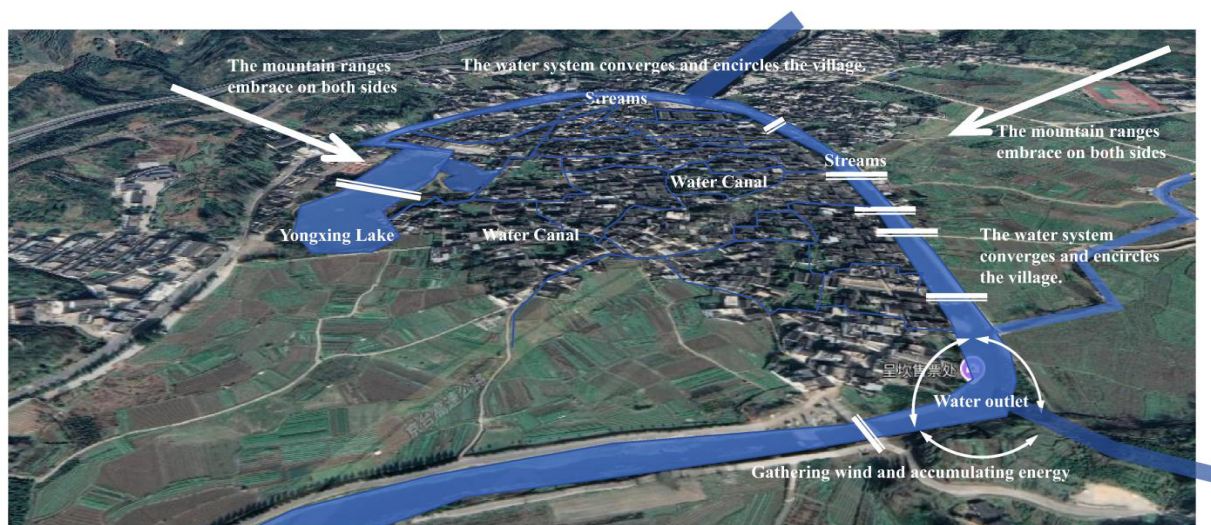


Figure 1. Fengshui layout of Chengkan village source

2.2. The geographical location and overall composition of Chengkan Village

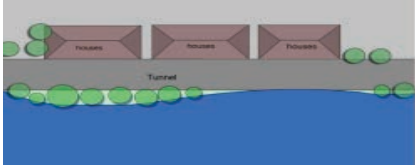
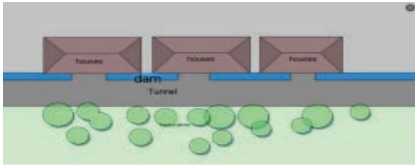
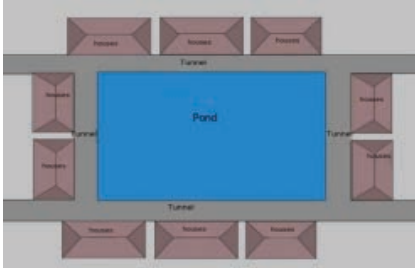
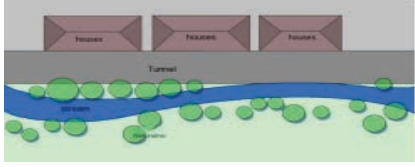
The layout of the Shuikou area in Chengkan Village shows basic Feng Shui ideas. It follows the belief of "blocking wind and keeping energy, treating water as wealth" (see **Figure 1**). The water inlet sits in a lower area near Yongxing Lake. It helps collect water and lowers the risk of flooding ^[3]. People have planned the Shuikou space carefully. They built things like bridges, temples, and Feng Shui stones. Yongxing Bridge goes over the water and gives villagers a way to walk across. It is also used during festivals and important events. Shuikou Temple is where villagers pray to the water god and honor their ancestors ^[1]. It connects their beliefs with daily life. The buildings around the water blend with the natural setting. This makes Shuikou a place that helps manage water, follows Feng Shui ideas, and shows local traditions.

2.3. Overview of the Shuikan Village water landscape

Chengkan Village has a well-planned water system. It includes water outlets, canals, ponds, and streams ^[2, 3]. Based on Table 1, the system begins at Yongxing Lake. This lake stores water and helps prevent floods. It also keeps the water supply stable ^[4]. Tall trees grow along the lake. They help block wind, keep moisture, and build a Feng Shui setting. These trees also add cultural meaning to the space. The irrigation ditches run beside streets and alleys. Some are open, and some are covered. They help with daily water use, farming, and flood prevention. Stone ditches and wooden gates are placed in smart ways. This helps manage water well and keeps the system working smoothly with nearby houses. Ponds are placed in important spots around the village. They store water, help stop

fires, cool the air, and are used during local events. These ponds are shaped like courtyards and often sit at the center of village life. They reflect the idea of “bringing people together with water.” Streams carry water out of the village. Their banks are lined with eco-friendly edges and water-loving plants. This helps stop flooding and keeps the water clean. The streams also create a smooth link between the village and the natural land around it.

Table 1. Spatial pattern table for water features

Elements	Spatial location	Main functions	Pattern diagram
Water outlet	Village entrance/exit	Water regulation, water supply and irrigation, feng shui blessing, cultural rituals	
Water canal	Distribution along streets and lanes	Diversion of water supply, flood control and drainage, shaping the village pattern	
Ponds	Village core	Water storage and regulation, fire protection, public event space	
Streams	Village boundaries	Water purification, flood control, hydropower, cultural support	

Yongxing Lake is the main source and storage place for the village’s water. It also helps to prevent flooding. Irrigation canals run along the streets and alleys. Some are open, and some are covered. Together, they provide water for daily use, farming, and flood control. The reservoir is set up to do many things. It holds water, helps put out fires, cools the air, and serves as a space for local events. Streams carry water out of the village. To protect the land, the banks are strengthened and planted with plants that grow well in wet soil. This helps stop floods and makes the water cleaner. It also creates a smooth area between the village and nature.

3. Symbiosis of water and environment: the ecological and cultural value of the water landscape in Huizhou

3.1. Ecological functions

The water system in Chengkan Village uses the natural terrain to build a layered structure, as seen in **Figure 2**. Rainwater is collected and reused through a simple process: it is first stored in the water mouth, then guided through ditches, kept in ponds, and finally drained out by streams ^[5]. Also, the trees in the Feng Shui forest adds

moisture to the air, and water from ponds and streams slowly evaporates. These two processes help lower the temperature and keep the area humid. This helps keep the local environment stable and full of life.

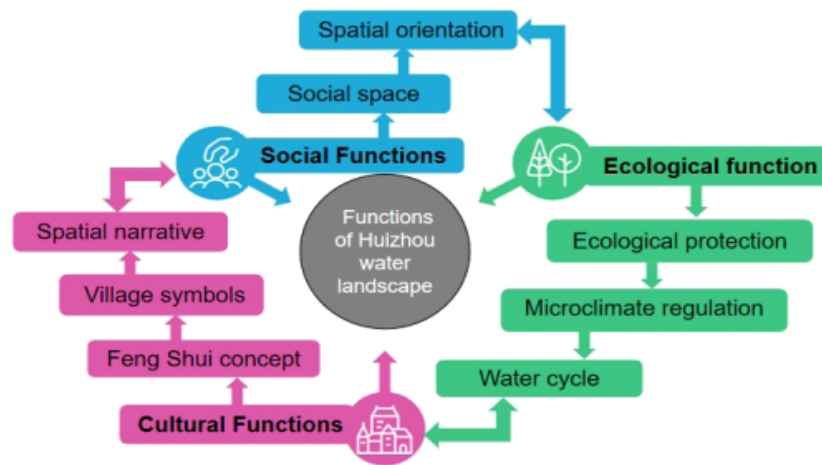


Figure 2. Functional analysis of the water landscape

3.2. Cultural function

In the Chengkan Village ecosystem, the water environment is more than its role as a simple symbol of Feng Shui, it is also a medium for expressing the villagers' beliefs and cultural practices ^[3,5]. The area around the mouth of the water, including Yongxing Lake, a stone bridge, and a Feng Shui tablet, forms a Feng Shui arrangement that is reputed to “conceal the wind and gather the Qi.”

3.3. Social functions

The area around the water landscape is a hub of social and communal life for the villagers. The arrangement of the water system has had a profound impact on the development of streets and pathways, thereby establishing a spatial structure characterized by ‘water-shaped streets’. The impact reinforces the orientation and recognition of the village, thereby positioning the landscape of water as an interface between spatiality and social life, as seen in **Figure 2** above.

4. Inspiration and reference: The guiding significance of traditional water landscapes for modern planning

The water landscape design of traditional Huizhou villages provides a valuable reference point for contemporary urban and rural landscape planning. This is due to its ingenious use of topography, ecological priority principles, and deep cultural integration. Taking the water outlet system of Chengkan Village as an example, it is possible to see that its characteristics of displaying spatial layering and functional complexity have the potential to inspire contemporary landscape planning.

4.1. Create a hierarchical water system to optimize the spatial layout

The ‘water mouth - water ditch - pond - stream’ hierarchical system in Chengkan Village has been demonstrated to achieve effective scientific management of water resources and the harmonious unity of spatial order ^[5]. It is submitted that modern landscape planning can learn from this model and construct a water management system of

‘main water body - branch water network - wetland buffer zone’ to enhance ecological efficiency and the layering of the landscape.

4.2. Strengthen the ecological concept and promote sustainable design

Chengkan Village employs Feng Shui forests to safeguard water sources, ponds to regulate water volume, and wetlands to purify water quality, thereby establishing a closed ecological cycle. Contemporary urban design would be well-advised to take inspiration from this strategy of natural infiltration and minimal intervention, incorporating technologies such as rain gardens and permeable paving, and promoting the concept of sponge cities and the practice of low-impact development (LID).

4.3. Enhance sense of place identity in the context of cultural background

The water landscape in Chengkan Village is not merely a practical infrastructure, but also a space that carries spiritual culture ^[6]. Its cultural symbols and ritual paths provide a new paradigm for place-making in modern water landscape design. By incorporating local traditional elements and spatial narratives, the cultural connotations and humanistic care of the water landscape can be enhanced, thereby deepening the emotional connection and sense of place identity of users.

5. Conclusion

The hydrological pattern of ‘water mouth - water ditch - pond - stream’ in Chengkan Village has created an ecological network whereby ‘a village is formed by water, with water as the pulse’. This research demonstrates the outstanding performance of the Huizhou water landscape in natural adaptability and systemic wholeness, and its broad integration into both the spatial structure and social organization of the village. The research highlights the need to establish a hierarchical water system that integrates ecological functions in the process of restoring cultural values in modern water landscape planning. Follow-up research must investigate adaptation strategies and transformation directions of traditional water landscapes under various environmental conditions with different data resources and methods, and field investigations, to provide both theoretical recommendations and practical recommendations for promoting an ecological civilization and invigorating local culture.

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Application of Carbon Fiber Reinforced Polymer in Bridge Reinforcement

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Abstract: Carbon fiber reinforced polymer (CFRP) is an advanced material widely used in bridge structures, demonstrating a promising application prospect. CFRP possesses excellent mechanical properties, construction advantages, and durability benefits. Its application in bridge reinforcement can significantly enhance the overall performance of the reinforced bridge, thereby improving the durability and extending the service life of the bridge. Therefore, it is necessary to further explore how CFRP can be effectively applied in bridge reinforcement projects to improve the quality of such projects and ensure the safety of bridges during operation.

Keywords: Carbon fiber reinforced polymer; Earthquake resistance; Bridge reinforcement design

Online publication: May 30, 2025

1. Introduction

Carbon fiber reinforced polymer (CFRP) exhibits excellent mechanical properties, ease of construction, and durability, making it a material with tremendous potential in bridge reinforcement projects. The comprehensive application of CFRP can not only improve the quality of bridge reinforcement projects but also ensure the orderly progress of the overall function, achieving high-quality completion of the entire project.

2. Overview of carbon fiber reinforced polymer

Carbon fiber reinforced polymer (CFRP) is a new material with excellent mechanical properties. It is converted from organic fibers through a series of heat treatment processes, with a carbon content exceeding 90%. As a type of inorganic high-performance fiber, it possesses good mechanical properties, inheriting the inherent characteristics of carbon materials while combining the softness and processability of textile fibers. It is considered a new generation of reinforcing fibers. CFRP, in practical applications, plays a pivotal role in the modern industrial sector due to its many advantages such as lightweight, good mechanical properties, flexible structural design, and adjustable performance. It is significant and valuable for promoting the development of the modern industrial

sector. In the field of bridge reinforcement, CFRP has become a highly favored reinforcement material due to its unique performance advantages and is widely used, playing a positive role in improving the safety and durability of bridges.

3. Significance of applying carbon fiber reinforced polymer in bridge reinforcement

In bridge reinforcement projects, the application of carbon fiber reinforced polymer (CFRP) is becoming increasingly widespread. The use of CFRP can enhance the quality of bridge reinforcement projects, improve the durability and service life of bridges, and achieve better completion quality. Specifically, the important significance of applying CFRP in bridge reinforcement projects is reflected in the following two points:

Firstly, it strengthens the bearing capacity of bridges and improves seismic performance. In bridge reinforcement projects, enhancing the durability and strength of bridges is a crucial task. CFRP offers numerous advantages such as lightweight, high strength, and corrosion resistance. Compared to ordinary steel, this material has better tensile strength and a lower density. Therefore, applying CFRP in bridge reinforcement projects has become an important measure. The use of carbon fiber materials can help increase the bearing capacity of bridge projects without adding weight to the bridge structure. Additionally, due to the superior tensile properties of carbon fiber materials, they can be used in the stressed parts of bridges. This utilizes the excellent characteristics of CFRP, such as high strength and rigidity, to enhance the bending and alkaline resistance of the bridge structure. As a result, it improves the overall mechanical properties of the bridge project and reduces vibration and fatigue damage caused by vehicle loads during the operation phase. This strengthens the seismic performance of the bridge during its service life, thereby enhancing the quality of bridge reinforcement projects and prolonging the durability and service life of the overall bridge project.

Secondly, it optimizes the construction process and reduces the impact on public transportation. The integrated use of CFRP in bridge projects is an important measure that can not only improve the overall performance of bridges but also optimize the construction process of bridge reinforcement projects. This minimizes the impact on public transportation during the construction phase. The incorporation of CFRP into bridge reinforcement projects enables the optimization of construction processes, making bridge reinforcement more convenient and simplified. For example, during the bridge reinforcement construction phase, CFRP can be flexibly cut and processed without the need for large machinery. The entire process involves customized processing of carbon fiber boards based on the requirements of the bridge reinforcement project, and there are no overly strict requirements for the construction site space ^[1]. Therefore, the entire bridge reinforcement project can be more conveniently advanced, effectively reducing the impact on the surrounding environment and public transportation. This enhances the efficiency and quality of bridge reinforcement projects.

4. Advantages of carbon fiber reinforced polymer in bridge reinforcement

Carbon fiber reinforced polymer (CFRP) has been widely used as a high-performance reinforcement material in bridge reinforcement projects, positively impacting the quality of these projects. In practice, CFRP exhibits numerous advantages when applied in bridge reinforcement, significantly contributing to the improvement of project quality. Specifically, the advantages of CFRP in bridge reinforcement are reflected in the following points:

4.1. Mechanical performance advantages

The application of CFRP in bridge reinforcement projects demonstrates excellent mechanical performance advantages. This material, composed of a matrix material and carbon fiber reinforcement, exhibits good

mechanical properties, earning it the reputation as “one of the three major diamonds in the material world” in the engineering field. With a specific gravity of less than 25% of steel and a tensile strength exceeding 3500MPa, which is 7 to 9 times higher than that of steel materials, CFRP has become the fiber with the highest specific strength and specific modulus among mass-produced materials in the field of materials science. In bridge reinforcement projects, integrating carbon fiber materials can fully utilize its mechanical performance advantages. For instance, applying CFRP to critical load-bearing parts of bridges, such as beams and columns, helps enhance tensile strength, significantly improving the overall load-bearing capacity of the bridge. Additionally, CFRP offers excellent bending, alkaline, and fatigue resistance. Bridges are often subjected to long-term impacts from vehicles and the natural environment. Therefore, using CFRP in bridge reinforcement projects has become an important measure. The integration of CFRP can enhance the bridge’s bending and seismic resistance, enabling it to maintain excellent mechanical properties even under long-term cyclic loading, thus strengthening the bridge’s service life ^[2].

4.2. Construction advantages

The application of CFRP in bridge reinforcement projects also offers significant construction advantages, facilitating the orderly progress of these projects. It not only improves project quality but also enhances the convenience and efficiency of construction. In practice, using CFRP for bridge reinforcement allows for flexible size tailoring and processing of carbon fiber boards. The entire processing process does not have strict requirements for construction space, making CFRP adaptable to various complex bridge structures in reinforcement projects. To reinforce the mechanical properties of the bridge, it is only necessary to apply CFRP to the stressed parts of the bridge without requiring large-scale removal or modification of the original bridge structure. This significantly enhances the convenience of bridge reinforcement construction and maximizes the retention of the integrity and comprehensive performance of the original bridge structure, contributing to improved construction quality. Additionally, CFRP is lightweight, simplifying the construction process and eliminating the need for large construction machinery. This allows construction workers to complete the process more conveniently, reducing both the difficulty and cost of reinforcement construction. Overall, it promotes the orderly progress of bridge reinforcement projects and improves the quality of the work ^[3].

4.3. Durability advantages

The application of carbon fiber composite materials in bridge reinforcement projects also demonstrates excellent durability advantages, which is clearly a key aspect of improving the construction quality of bridge reinforcement projects. In practice, carbon fiber composites exhibit superior corrosion resistance, enabling them to better withstand natural environmental attacks when used in bridge projects. Even in harsh natural environments, these materials can maintain their mechanical properties well. For example, in bridge reinforcement projects in coastal areas or industrial zones, the application of carbon fiber composites can effectively prevent erosion caused by seawater and chemical substances, avoiding bridge damage due to corrosion issues and enhancing the durability of bridges during use ^[4]. Additionally, carbon fiber composites possess excellent fire resistance. Although carbon fiber materials themselves are flammable, their fire resistance can be improved in bridge reinforcement projects by adding fireproof layers or flame-retardant resins. This prevents greater damage to bridges from fires, enhancing the safety, reliability, and service life of bridge projects ^[5].

5. Application of carbon fiber composites in bridge reinforcement

5.1. Material selection and performance matching to ensure reinforcement effects

When using carbon fiber composites in bridge reinforcement projects, the primary task is to properly select

materials and match their performance to enhance the reinforcement effect. In practice, scientific material selection should be based on the actual requirements of the bridge reinforcement project ^[6]. For instance, if the project requires improving the bridge's flexural bearing capacity, higher-strength carbon fiber composites should be chosen. Carbon fiber cloth with a strength standard often exceeding 3400MPa and an elastic modulus between 150–300GPa indicates stronger rigidity. Applying this material to bridge reinforcement projects can help improve the bridge's flexural bearing capacity.

5.2. Reinforcement scheme design optimization to enhance structural safety

The application of carbon fiber composites in bridge reinforcement projects should focus on optimizing the design of reinforcement schemes, thereby improving structural safety and ensuring high-quality completion of bridge reinforcement projects. In practice, the design of reinforcement schemes should fully consider comprehensive factors such as the structural form of the bridge, the degree of damage, reinforcement objectives, and on-site construction conditions ^[7]. Firstly, a comprehensive evaluation of the bridge's damage situation is required, followed by clarification of the reinforcement objectives and key reinforcement areas based on the bridge's usage requirements. For example, to address cracks in the bridge, carbon fiber cloth can be used for reinforcement by adhering it along the direction of the cracks. This not only prevents further expansion of the cracks but also enhances the overall mechanical performance and stability of the bridge after reinforcement, ultimately improving the construction quality of the bridge reinforcement project ^[8].

5.3. Construction technology and quality control to ensure implementation effects

The integration of carbon fiber composites into bridge reinforcement projects requires proper construction technology and quality control to ensure the effectiveness and quality of the construction and facilitate the smooth completion of the bridge reinforcement project. In practice, preparatory work, such as surface cleaning of the reinforcement areas, should be carried out before construction to remove surface oil, dust, and loose layers, exposing the solid concrete part. Leveling should also be performed before reinforcement construction ^[9]. The quality of this operation often determines the bonding strength between the carbon fiber composite and the concrete, so it is necessary to strictly follow construction specifications for pre-construction treatment. During the bonding stage of the carbon fiber cloth, special adhesives such as epoxy resin should be used, and a dedicated roller should be used for repeated rolling to eliminate the impact of bubbles on the bonding effect. After completing the bonding operation, protective treatments such as applying fireproof and sunscreen paints should be performed on the surface of the carbon fiber cloth to enhance the durability of the material during use and improve the quality of the reinforcement project.

5.4. Strengthening performance monitoring and maintenance to extend bridge service life

The application of carbon fiber composites in bridge reinforcement should also focus on regular monitoring and maintenance to extend the service life of bridges and ensure their safety and durability during use ^[10]. During actual performance testing, it is necessary to detect structural deformations, cracks, and stress changes in the bridge engineering. In the monitoring phase, the comprehensive application of ultrasonic detection technology, infrared imaging detection technology, and other techniques is required. Through the integrated application of multiple technical types, real-time monitoring and control of bridge engineering quality can be achieved, and the performance of carbon fiber composites after being put into use can be timely understood. Problems can then be promptly addressed to ensure the safety and reliability of the bridge engineering.

6. Conclusion

In summary, the integrated use of carbon fiber composites is key in bridge reinforcement projects and an important aspect of improving the quality of bridge reinforcement construction. Therefore, it is crucial to have a deep understanding of the mechanical properties of carbon fiber composites and clarify their advantages in bridge reinforcement. To enhance the design and quality of bridge reinforcement construction, further exploration and research are needed on how to comprehensively utilize carbon fiber composites, such as selecting materials reasonably based on bridge reinforcement construction requirements, optimizing reinforcement schemes based on on-site construction conditions, strengthening construction technology and quality control during construction, and performing bridge engineering monitoring and maintenance after construction. Through multiple measures, the durability and safety of bridge engineering can be improved.

Disclosure statement

The author declares no conflict of interest.

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Innovative Approaches to Revitalizing Urban Riversides for Enhanced Leisure and Well-being

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Abstract: As societal priorities shift towards spatial quality and leisure pursuits, riverside sites offer significant potential for enhancing living environments and promoting leisure activities. This study delves into the relationship between the spatial qualities of riverside areas in old industrial cities and their capacity to foster leisure and human well-being, aiming to formulate design guidelines that preserve the unique characteristics of these sites. Noting the dearth of academic discourse on spatial qualities and design in this context, this research emphasizes the identification of key spatial features that can revitalize urban rivers as leisure destinations, which derives a set of design principles. These principles underscore the importance of diverse and distinctive spatial qualities in successful riverside regeneration, and highlight the role of high-quality spaces in promoting leisure and well-being. Finally, the research concludes with recommendations for creating impactful spatial qualities for future riverside regeneration projects.

Keywords: Riverside landscape; Spatial quality; Leisure activities; Wellbeing; Unique character; Diversity

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1. Introduction

1.1. Background and existing problems

As is known to all, ‘riverside urbanity’ means physical and visual connections with rivers, where everyone can enter through the ‘common land’ along the river ^[1]. Currently, riverside sites are used for various leisure activities. These places should simultaneously meet the demands of daily leisure activities and support the benefits of well-being at the same time. However, environmental quality is an important aspect of riverside sites used for industrial production. Moreover, there are some planning problems during the redevelopment of riverside sites in old industrial cities. In addition, studies on riverside regeneration are underrepresented in the current literature regarding the aspects of life and physical qualities ^[2]. Therefore, the general regeneration of riverside sites has been unable to completely satisfy people’s needs for leisure and well-being; it is essential to build a more meaningful and stronger character for riverside redevelopment.

1.2. Aim and objectives

This research aims to examine how the spatial quality of riverside sites in some old industrial cities can encourage leisure activities and human well-being and develop a set of design guidelines to ensure the individual character of riverside sites.

This study can bring a new dimension to the understanding of urban design concerning the successful use of public spaces. The importance is that the spatial quality of the riverside location can recall the memories of old industrial cities, connecting public services and social leisure activities, thereby encouraging ‘public involvement’ and well-being in urban areas ^[3]. At a larger scale, the regeneration of riverside sites in old industrial cities has been of great concern, and increasing attention has been paid to urban form. Cities are now focusing on rivers and riverside environments to enhance the quality of outdoor leisure activities. Creating different qualities of spaces in riverside sites to attract people, interactive spaces can be built to contain various leisure activities. Therefore, a good experience will be provided for the people who live and engage in leisure activities at riverside sites, benefiting society and human well-being. It is important to examine different aspects of the feelings and experiences of sites near rivers to achieve the goal of ‘social benefits’ and happiness from leisure activities at riverside sites.

2. Research Methodology

The method for this research is based on a review of the literature on how spatial quality can provide the potential for riverside sites for well-being and attachment to place, and a case study analysis to identify good practices and prove that riverside sites are good places to encourage human leisure activities.

To identify opportunities and design guidelines for riverside regeneration, previous theories and academic/official sources from responsible authorities have been referenced, good practices have been investigated and selected, and all the official data referenced are the latest data. The method is based on a qualitative approach, and charts and analysis pictures are provided to facilitate this approach.

2.1. Objective

- (1) The scale of the river itself
- (2) The importance of the river to the city
- (3) The varying topography of the river bank for leisure activities
- (4) At least one particularly unique spatial quality.

2.2. Scale

The scale of the river itself vastly influences the form of the city. The width of the river affects feelings on the riverside, the type of activities occurring on the bank or edge of the river, and also influences the street patterns and connectivity of the city. Width of the selected cases:

- (1) River Limmat: width of riverbed: 60m; width of floodplain: 70m.
- (2) River Wupper: width of riverbed: 25m, width of floodplain: 80m.
- (3) River Isar: width of riverbed: 50-60 meters, width of floodplain: 150m.

2.3. Importance of the river

Each river has a significant effect on the city, not just its historical meaning, but also the needs of today’s city life.

2.4. Diversity

The design of all cases is an attempt to create diversity in the spatial qualities of riverside sites. Consequently, the topography of the riverbank is important for building different stages of leisure activities. All cases have different stages, such as activities on the riverbank, floodplain, river edge, and river.

2.5. Unique characteristic

The design measures are very relevant and at least one particularly unique spatial quality has been presented in each case. Although it may not be transferable to all designs of riverside sites, it may provide some design guidelines and inspire the redevelopment of riverside sites in the future.

3. Good spatial quality encourages leisure activities

The spatial quality of the riverside site has a significant impact on the experience of urban environment. Public spaces on riversides have received increasing attention in recent years and have been conceptualized in two parts of the city: the topography and a place for leisure activities. Topography refers to the physical environment or spatial forms, and the space for activities focuses on social connection and human behavior that may contribute to the psychological aspect ^[4].

Riverside sites may encourage leisure activities and well-being through their spatial qualities or unique environmental characteristics. The subjective consciousness and psychological effects of people can also influence the judgment of the site and value of the river, which is mainly reflected in human behavior and leisure activities. These two proteins interact with and complement each other. A good illustration of this is illustrated in **Table 1**, which is similar to the one created by Stevens ^[5]:

Table 1. Table of the reasons and theories of riverside activities created by Stevens

Environmental experience of leisure	Origin in broader theories of leisure and urbanity	Sources	Spatial context of the urban riverfront
Escape from the everyday	The theory of play as existing in a 'world apart'	Huizinga, 1970; Lyman and Scott, 1975; Cohen and Taylor, 1976	Across the river
Mixing with strangers	Theories of behavior in public space	Goffman, 1963; Sennett, 1971; Lofland, 1998	Pools (of uses) and flows (of people)
Consuming spectacle	'The society of the spectacle', city as theme park	Sorkin, 1992; Debord, 1994; Dodson and Kilian, 1998	The riverbank stage
Exploratory forms of bodily action	Theorization of the forms and objectives of play	Caillois, 1961; Borden, 2001	On the edge

Table 1 shows that the environmental experiences of riverside activities, the various reasons people come to riverside sites, and theories of leisure and urbanity are different. The environmental experience of leisure depends on the spatial context of the site, and the activities and behaviors depend on the quality of the riverside space.

Kondolf illustrated the different types of uses in different river widths (**Figure 1**); draft pictures can indicate these situations more vividly ^[6].

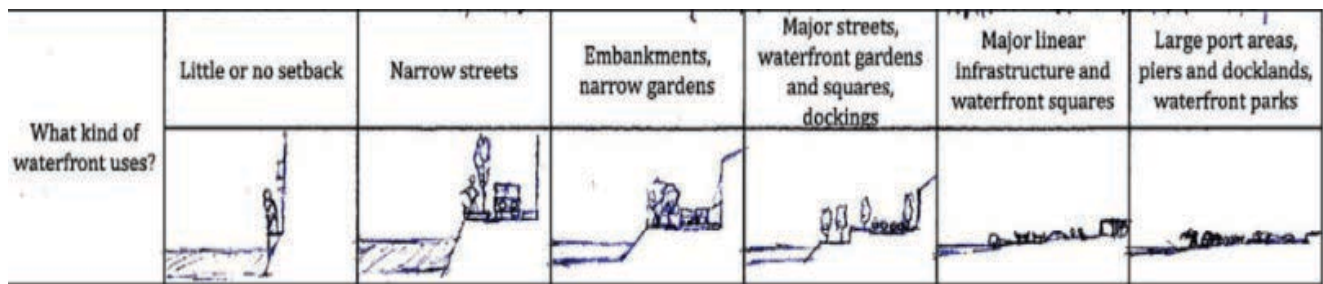


Figure 1. Different uses in different river widths

Linear parks and riverside squares begin to appear, and urban recreational systems can be derived as the riverbank becomes wider. This not only results from the river's width but also from the flood control measures and constraints of the embankment itself. After the urban regeneration of the riverside, the residential houses opposite to the river were demolished, and the remaining houses were facing towards the river. The demolition of the houses provided the riverside with a more open space. The river can be seen as the 'gate of the city'. The landscape of riverside sites is greatly enhanced, and citizens feel the well-being of the public space, reflecting the spatial quality of riverside sites ^[7].

4. Unique characteristics of riverside sites

Another point of the riverside site's potential is the unique environment. Jacobi pointed out the differences in leisure activities between riverside sites and traditional parks ^[8].

Table 2 shows the main differences. Most people believe that riverside sites are open, which increases human integration and promotes more activities, especially when there is easy access to linear parks. The other facilities are riverside locations; some facilities are set in the water, providing a unique experience, and some leisure activities, such as sunbathing, fishing, and swimming, occur near or in the water ^[9].

Table 2. Difference of riverside as leisure spaces

Main aspects mentioned
Open park
Greater movement and integration of people
Ease of access
Conservation of the watercourse
Reduced support and leisure facilities
Pedestrian thoroughfare

5. Good practice of urban riverside regeneration that encourages leisure activities and well-being

5.1. Topography and access to water of Wipkinger Park

Wipkinger Park is located in the Wipkingen district, approximately 2.7 kilometers from the old city of Zurich. The park lies on the north bank of the river limit and is surrounded by a large residential area and some old industrial factories.

Based on **Figure 2**, which shows the systematic analysis of satellite imagery and demographic data obtained from the official local website, a comprehensive insight into the diverse array of leisure activities prevalent at the site can be discerned.

During the peak periods of a typical summer weekend, the site had a maximum occupancy of approximately 400 individuals actively engaged in various leisure pursuits, as shown in **Figure 3**.

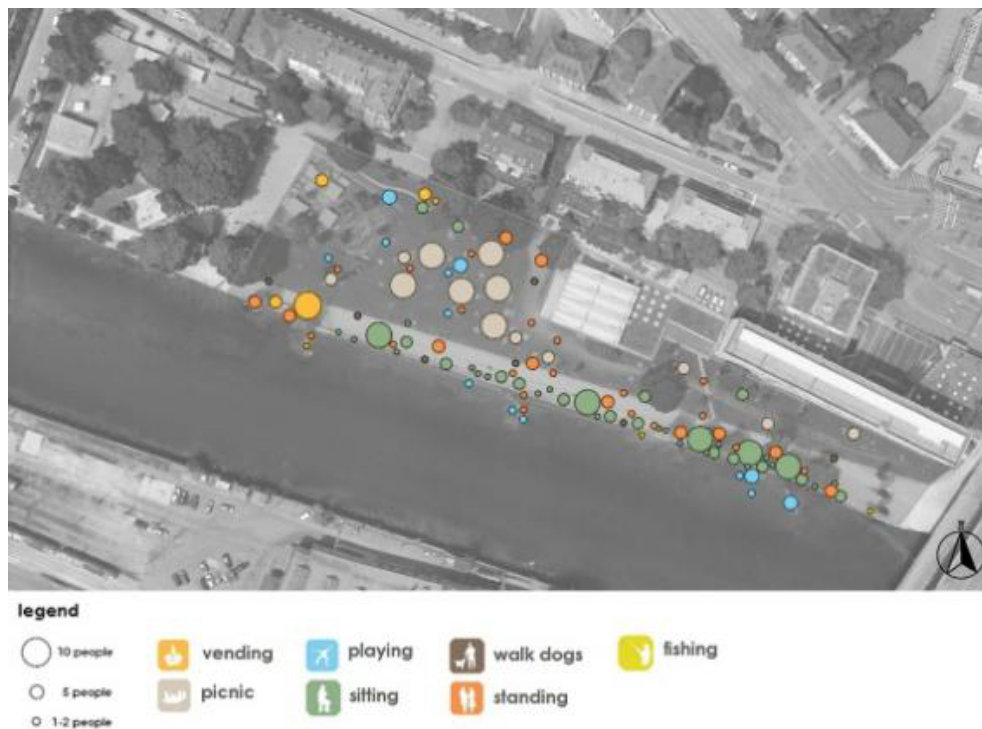


Figure 2. Satellite image and demographic data of Wipkinger Park

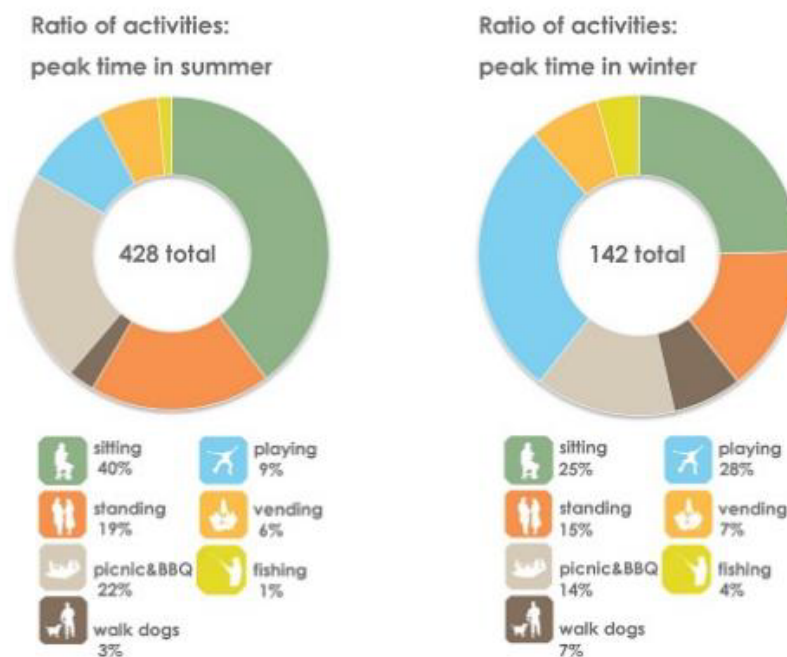


Figure 3. Data illustration of the diverse array of leisure activities at Wipkinger Park

Figure 4 shows the illustration of the topography and visual mapping of the Wipkinger Park site. The detailed visual mapping of the site reveals a discernible pattern: the preponderance of visitors congregates along the river's edge.

Notably, while specific leisure activities necessitate designated zones, such as picnicking on the central lawn or vending within designated park areas, the remainder of leisure activities are predominantly conducted along the river perimeter and beneath the canopy of the trees. The configuration and topography of a site exerts a significant influence on the types of leisure activities that occur within its boundaries. The most frequently visited areas are those that offer shade beneath the trees in proximity to the water's edge and riverside platform, where visitors can experience the refreshing breeze while simultaneously enjoying the picturesque river scenery. Additionally, the incorporation of conceptual kindergarten farms with animals in close vicinity to the site has proven to be a major attraction for both children and adults, fostering parent-child interactions and playful engagements.

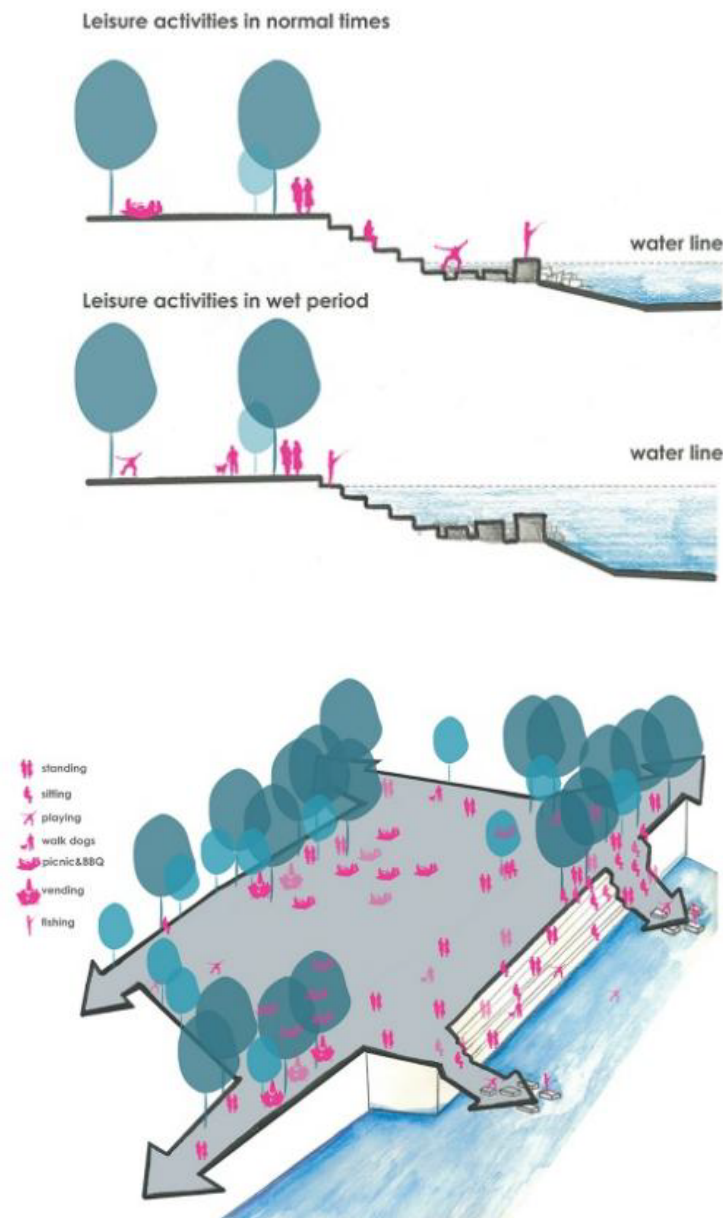


Figure 4. The illustration of the topography and visual mapping of Wipkinger Park

5.2. Topography and access to water of Park Beer-sheva-ufer

Park Beer-sheva-ufer is a linear public space along the river Wupper. Because the width of the riverbed is only 25m, it is not possible to build a promenade path parallel to the river. In addition, the famous suspension railway passes over the river, and there are some industrial and water pipes near the bank, which provides a very strong scenery of the industrial atmosphere. **Figure 5** shows the satellite image and demographic data of Wipkingen Park.

Based on the figure above, the most popular area of the site is the grassy stepped region near the water. Visitors prefer to sit on flat surfaces near water, accessible by stairs, and engage in activities on softer grassy areas. The abundance of greenery, compared to hard structures, encourages this behavior. Trees near buildings create enclosed spaces, while steps, balconies, and suspension railways offer river views. This narrow riverside park showcases diverse spatial features, inspiring riverside design redevelopment. **Figure 6** shows the illustration of the topography and visual mapping of Park Beer-sheva-ufer.

Due to the presence of submerged steps and stones within the water, children have the opportunity to engage in water play, while individuals who are unable to access water at other locations can experience it here. In addition, the pathway along the riverbank is a popular location for dog walking. The shading provided by the riverbank creates varying light conditions within the berm area, which contributes to its unique environmental characteristics.



Figure 5. Satellite image and demographic data of Park Beer-sheva-ufer

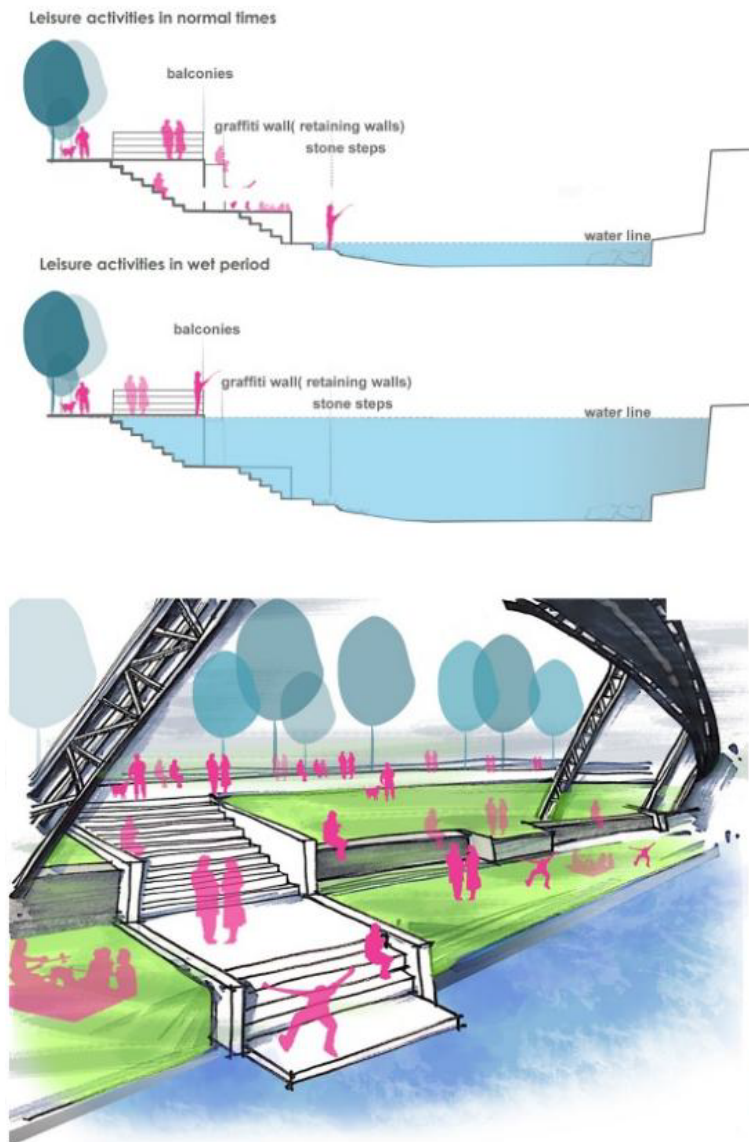


Figure 6. The illustration of the topography and visual mapping of Park Beer-sheva-ufer

5.3. Unique spatial quality for leisure of Flaucher Park

Flaucher Park is the most popular site near the Isar River, which has a large gravel beach, flood meadows, and natural river landscapes. There are two children's playgrounds and a football playground in the park, and the Hellabrunn Zoo is not far from the site. The park attracts people from everywhere in the country to get close to natural water and has sunbaths or grills on gravel beaches.

Based on straightforward visual analysis (**Figure 7**), it is evident that individuals tend to engage in leisure activities on gentle slopes and gravel beaches near the water. Gravel beach, which is a distinctive feature of the entire site with no comparable alternatives along the waterfront, emerged as the most frequented area. Notably, the dynamic population primarily conducts activities around the site, particularly in the water and along the park paths. Conversely, static and seated populations concentrate on gravel beaches and under tree shades, engaging in leisure pursuits such as barbecuing, sunbathing, and resting.

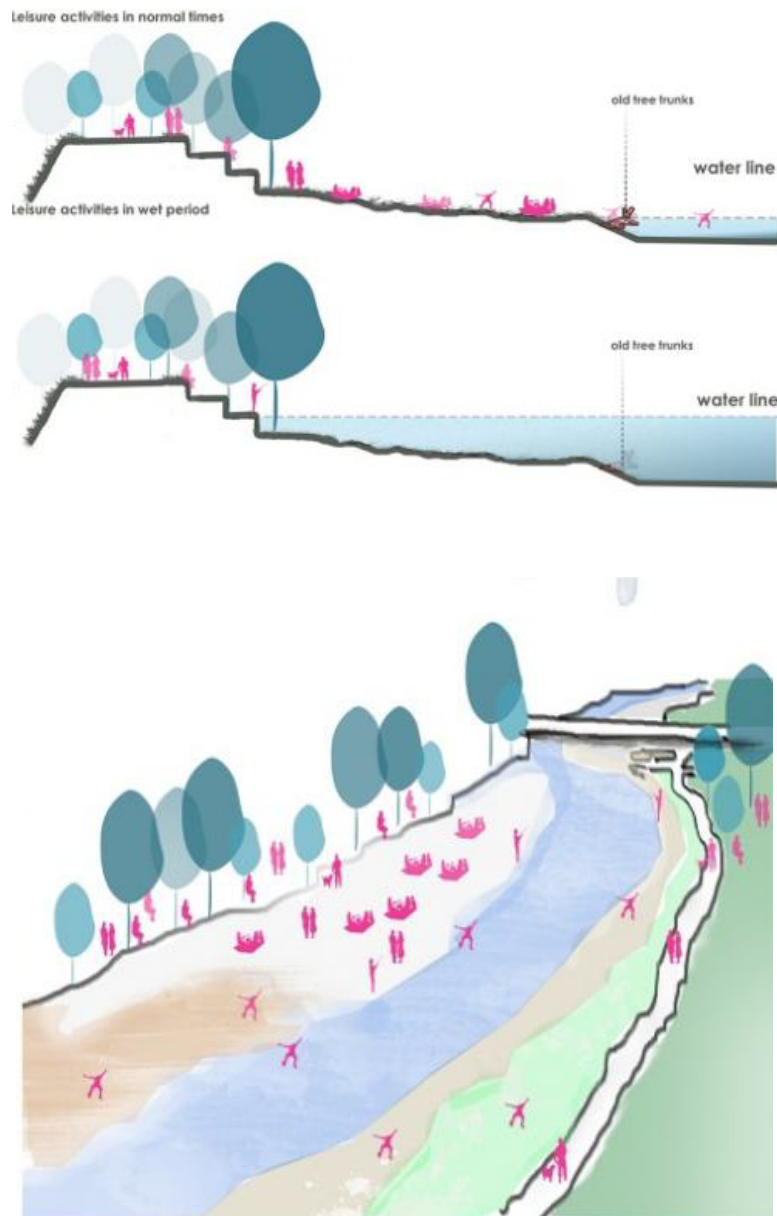


Figure 7. The illustration of the topography and visual mapping of Flaucher Park

Given the shallow nature of the river, the ecological islands and facilities within it serve as leisure spaces. These islands and structures in the river impede water flow, creating dynamic effects that attract individuals to playful activities. Furthermore, an examination of the satellite imagery and visual mapping reveals that the white color of the gravel beach is a notable feature that significantly influences the identity and spatial quality of the riverside site, as shown in **Figure 8**. This unique coloration is a key factor that attracts individuals to distinctive and one-of-a-kind leisure destinations.

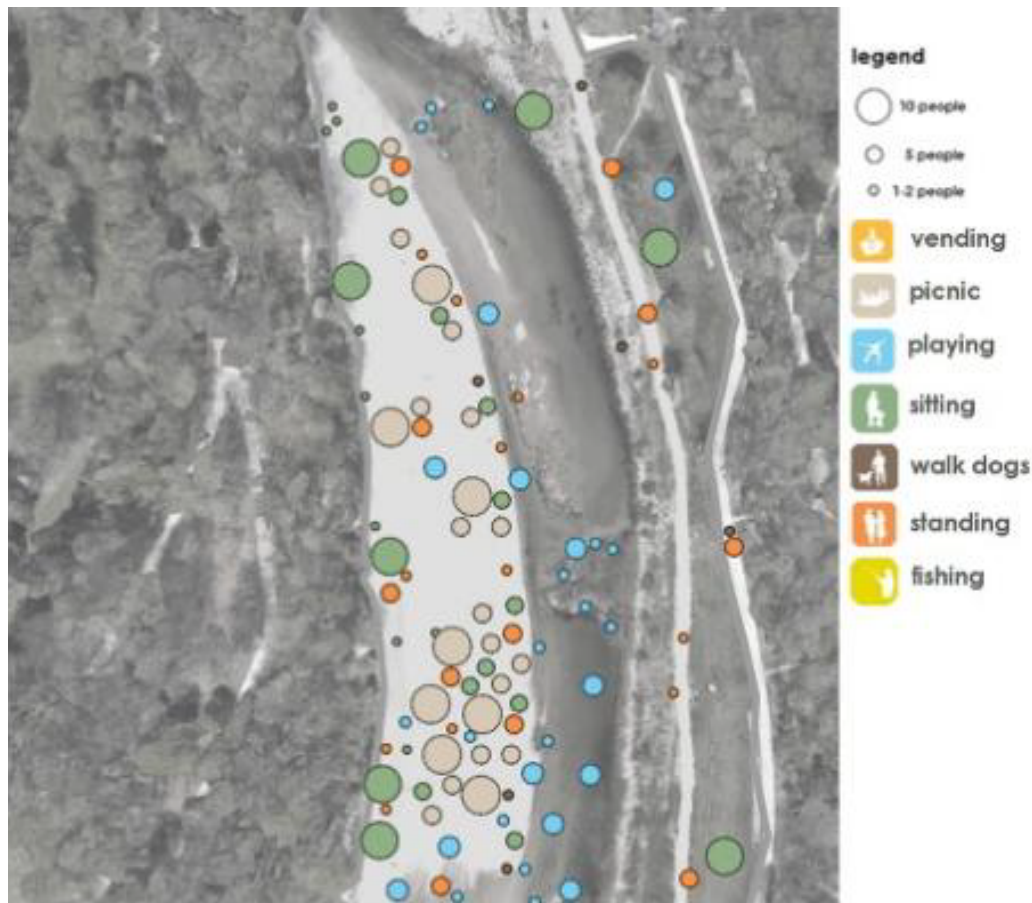


Figure 8. Satellite image and demographic data of Flaucher Park

6. Design principles from cases

Some areas in riverside sites have a blurred function, so-called ‘empty patches’; these sites may be flooded during wet periods but may still have value as ‘ambiguous places’ that people can use as they like^[10]. Therefore, not only do spatial qualities meet human demands, but people can also determine the function of the site.

Prominski emphasized that riverside sites are good educational areas that provide opportunities for leisure activities to contact nature^[11]. People can access water and see the water flow, and know about flood control and water management; this has educational value. The educational function of riverside sites can serve as a foundation for the general development of citizens.

In the planning and development of riverside environments, it is imperative to prioritize the seamless integration of these spaces with the broader urban public realm to enhance both accessibility and spatial connectivity. The incorporation of dynamic and adaptable boundaries can significantly enrich user engagement by facilitating diverse patterns of movement and interaction. Emphasis on natural elements not only contributes to the aesthetic appeal of the site but also supports ecological functionality. Additionally, the creation of visual dynamics through deliberate design interventions fosters spatial interest and orientation. To establish a distinctive sense of place, it is essential to reflect the local cultural context, historical narratives, and chromatic identity. Finally, the provision of attractive amenities, alongside clearly articulated functional zones, is critical to meeting the varied needs of visitors, particularly during peak periods typically characterized by increased use from families and children during temperate daylight hours.

7. Conclusion

Urban riverside sites frequently necessitate an integrated approach that combines various stages of connectivity, thereby linking the city's public spaces into a cohesive leisure space system and facilitating the exchange of activities between the riverbank. Leisure activities serve as a vital force that animates riverside sites, and the quality of these spaces is of paramount importance because they constitute the everyday environment for the majority of individuals. The successful regeneration of riverside areas can present opportunities for daily leisure pursuits and enhance the overall quality of urban life. Both locals and tourists are inclined to engage in leisure activities within these spaces as their connection with spatial quality continues to deepen and broaden.

Riverside spaces with distinct identities and characteristics are crucial for fostering a sense of belonging and encouraging interactions between people and rivers. The quality of these spaces directly impacts the quality of life of residents, providing them with places for leisure and relaxation. It is not just designers who shape the character of these sites; the way people use and interact with them plays a significant role. In recent years, efforts to regenerate urban riverside areas have focused on creating multifunctional and multilevel spaces that cater to the needs of both residents and urban development. This approach, which emphasizes unique spatial qualities and diverse leisure opportunities, is likely to continue in future projects, further enhancing the well-being of communities and promoting interactions with the river environment.

Disclosure statement

The authors declare no conflict of interest.

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Exploring the Living Conservation of Pingyao Ancient City's History and Culture with a Focus on Landscape Memory

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Abstract: This paper discusses the application of traditional architectural restoration techniques, dynamic maintenance of the spatial texture of historical streets and alleys, the construction of a digital monitoring system for building facades, and spatial transformation strategies for the continuity of residential functions. Through the integration of traditional construction techniques with modern technologies, such as dynamic monitoring, evaluative tools, and digital management systems, this approach seeks to sustain the landscape memory and preserve the historical and cultural continuum of ancient cities, while simultaneously balancing the conservation of heritage architecture with the functional demands of contemporary urban life.

Keywords: Landscape memory; Pingyao Ancient City; History and culture; Living conservation

Online publication: June 4, 2025

1. Introduction

As a world cultural heritage site, Pingyao Ancient City carries the glorious memory of the Jin merchant culture of the Ming and Qing dynasties, and its complete ancient building groups and traditional street patterns are precious historical and cultural resources. How to continue the landscape memory in living conservation, which not only keeps the historical and cultural roots of the ancient city but also adapts it to the development needs of modern society, has become an important issue to be solved urgently. This paper focuses on the theory of landscape memory and centers on the architectural characteristics of Pingyao Ancient City to discuss the strategy of living conservation of history and culture, aiming to provide scientific and effective solutions for the sustainable development of the ancient city.

2. Conceptual narrative

2.1. Concept of landscape memory

Landscape memory refers to the shared cultural memory rooted in the combination of physical spaces and intangible heritage within a particular region. It is expressed through tangible elements such as buildings, streets,

and natural surroundings, while also conveying deeper meanings related to historical events, local customs, and cultural values. Through spatial layout, color, texture, and function, landscape memory helps preserve and communicate the unique identity and cultural depth of a place ^[1]. It not only preserves traces of past life but also gains new meaning over time, serving as an important source of local identity and cultural belonging. It plays a key role in shaping regional cultural identity and ensuring the continuity of cultural heritage.

2.2. Concept of living conservation of history and culture

Living conservation of history and culture is the concept of protecting and inheriting cultural heritage with a dynamic and developmental perspective based on respecting historical authenticity, breaking through the traditional static conservation mode ^[2]. This type of protection focuses on the interactive symbiosis between heritage community and environment, allowing historical culture to be revitalized through continuous use, inheritance, and innovation, realizing the organic unity of cultural, social, and economic values, and ensuring sustainable development of historical and cultural heritage in contemporary society ^[3].

3. Living conservation of historical and cultural heritage in Pingyao old town, focusing on landscape memory

3.1. Application of restoration techniques for the authenticity of traditional buildings

A large number of buildings from the Ming and Qing dynasties exist in Pingyao, which not only carry historical information but also contain unique construction wisdom and regional craftsmanship. In the process of restoration, the principle of “raw materials and original technology” should be followed, and local traditional materials such as green bricks and tung oil mortar should be used for the damaged brick and wood structures ^[4]. In the repair of wall cracks, the use of loess, glutinous rice paste, and lime mixed in a specific ratio of traditional mortar, this material and the original wall material compatibility, not only effectively repair cracks, but also maintain the appearance of the building the rustic texture ^[5].

For the problem of decay of wooden components, priority is given to the use of the same type of wood as the original wood species, using mortise and tenon structure to replace the damaged parts, to ensure that the repaired part and the original structure are integrated ^[6]. Actively uncover and preserve local traditional construction techniques by involving experienced craftsmen familiar with Pingyao’s traditional building methods in restoration efforts. Their knowledge should be translated into practical technical guidelines and documented through written and visual materials to guide future restoration work. This approach ensures the authentic continuation of traditional architecture and helps prevent the loss of historical information caused by the inappropriate use of modern materials and methods.

3.2. Dynamic maintenance of the spatial texture of historical streets and alleys

The network of streets and alleys in Pingyao Ancient City, consisting of four main streets, eight side streets, and 72 centipede alleys, is an important manifestation of its unique spatial texture. To preserve the original spatial texture of historic streets and alleys, it is important to trace their historical development using archival maps and documents, clarify their functional roles and spatial relationships, and develop a dynamic maintenance plan accordingly ^[7]. For the direction and scale of streets and alleys changed due to historical changes, the original historical appearance will be gradually restored under the premise of not affecting modern transportation and residents’ lives. Emphasis should be placed on preserving the courtyard layouts and axial relationships characteristic of traditional Pingyao architecture. The traditional courtyards in Pingyao are mostly laid out symmetrically on a central axis, with spatial hierarchies created through architectural elements such as shadow

walls and hanging flower gates ^[8].

In daily maintenance, new construction and alteration projects around the courtyards are strictly controlled to ensure that their heights and styles are coordinated with those of the original courtyards and that they do not destroy the original spatial order. For the spatial deformation of courtyards caused by age and disrepair, a progressive restoration method is adopted to restore the original form and spatial relationship of the courtyards by reinforcing the foundation, adjusting the inclination of the walls, and other measures ^[9]. Additionally, a dynamic monitoring system is established to regularly assess key spatial indicators, such as the scale of streets and alleys and the spacing between courtyards. This system enables the early detection and timely resolution of emerging issues, thereby safeguarding the stability and continuity of the historical spatial texture.

3.3. Digital monitoring system for building façade appearance

The building facades of Pingyao Ancient City are richly decorated with exquisite brick, wood, and stone carvings, which are important visual carriers of its history and culture. Using three-dimensional laser scanning technology, the facades of key buildings in the ancient city are scanned with high precision to obtain data on the geometric dimensions and decorative details of the building facades, and a three-dimensional digital model is established ^[10]. Using high-resolution photogrammetry technology, the color and material information of the building façade is captured to achieve an all-round digital record of the building façade ^[11].

Building on this foundation, a dynamic comparison mechanism is established to conduct regular scanning and data collection of building façades. The newly acquired data are systematically compared with the original digital models to detect subtle changes, such as wall spalling or damage to decorative elements, at an early stage. When such issues are identified, the system automatically issues early warnings and offers corresponding repair recommendations ^[12].

By integrating the digital monitoring system with the daily inspection operations of the management department in the ancient city, the system allows for real-time uploading of identified issues during inspections via mobile devices. This facilitates seamless online and offline management, enhancing the timeliness and effectiveness of building façade preservation efforts. Moreover, it provides scientific data support and technical assurance for the long-term conservation of the building façades in the ancient city of Pingyao.

3.4. Space remodeling strategy for the continuity of residential functions

In the process of spatial transformation, traditional architectural forms should be preserved to the greatest extent possible while meeting the needs of modern life. The “four big and eight small” courtyard layout and kiln-cave architectural features of Pingyao’s traditional houses are important cultural symbols. In the renovation, the strategy of “changing the interior without changing the exterior” can be adapted to reasonably optimize the interior space without changing the appearance and overall structure of the building ^[13]. To address issues of inadequate lighting and poor ventilation in traditional houses, the indoor environment can be enhanced by installing skylights and optimizing the placement of doors and windows. In renovating functional spaces such as bathrooms and kitchens, embedded and modular modern facilities are utilized to meet residents’ needs while minimizing disruption to the original architectural design ^[14].

In the case of insufficient living space, additional buildings of lightweight steel structure can be erected in the courtyard, a form of construction that does not affect the overall appearance of traditional courtyards, but also provides additional space for use ^[15]. Residents are encouraged to participate in the renovation process, and the living habits and actual needs of residents are fully respected, so that the renovated living space can adapt to modern lifestyles and continue the traditional living culture, to realize the sustainable development of the living

function of the ancient city of Pingyao, and to make the ancient city still full of vitality and vitality of life in the new era.

4. Conclusion

The above analysis demonstrates that adherence to the principle of “using original materials and techniques” has effectively preserved the historical knowledge and craftsmanship of building construction. The dynamic maintenance of the spatial texture in historical streets and alleys has ensured the stability of the ancient city’s spatial order. The development of a digital monitoring system for façade preservation, coupled with the application of modern technology, has enabled precise monitoring and timely maintenance of building exteriors. Furthermore, these efforts have successfully maintained the continuity of living spaces. A digital monitoring system for façade preservation has been established, leveraging modern technology to enable precise monitoring and timely maintenance of architectural exteriors. The continuity of residential functionality is achieved through “internal and external modifications,” which strike a balance between preserving traditional architectural forms and accommodating the needs of modern living.

Disclosure statement

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Research on Urban Waterfront Landscape Design Based on the Concept of River Ecological Restoration—Taking the Section of Chongqing Institute of Engineering on Huaxi River as an Example

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Abstract: Since the reform and opening up, the development approach targeting urban economic growth has led to a sharp increase in the proportion of impervious hardened surfaces in cities and significant waste of natural resources. The urgent need for water ecological civilization construction is of great significance to the continuation of human civilization in the long run. This paper focuses on the urban waterfront landscape design of the Chongqing Institute of Engineering section of the Huaxi River in Banan District, emphasizing the concept of “symbiosis”. Using site cultural symbols as a medium to connect the campus and the city on both sides of the river, returning the riverbank to the people, restoring the ecological space of the riverfront, enriching the landscape belt, promoting the protection of bird and fish habitats, and stimulating the vitality of the riverbank space; it aims to pave the way for ecological restoration, functional expansion, landscape renewal, and riverfront space activation at the study site.

Keywords: Waterfront landscape design; Symbiosis concept; Ecological design; Chongqing

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1. Introduction

1.1. Project background

Since the reform and opening up, rapid urban economic development has had a significant impact on the ecological environment. The urban development approach, which prioritizes economic growth, has resulted in a drastic increase in the proportion of impervious hardened surfaces and substantial wastage of urban resources. The 18th National Congress report also emphasized the integration of ecological civilization construction into the “five-in-one” structure of socialism with Chinese characteristics. As we all know, water ecological civilization construction is a closely related and integral part of ecological civilization construction. Undertaking water ecological civilization construction is a major strategic issue of high concern for social development. The concept of “ecological civilization” construction presents new requirements and directions for urban waterfront landscape design.

Historically, most cities were built near water bodies, as water is an essential resource for survival, transportation, and daily life, closely linked to social civilization development and residents' daily activities^[1]. In the context of vigorously promoting policies such as ecological civilization construction and water environment protection, enhancing urban river environments and optimizing waterfront spaces have become crucial issues in environmental construction. Furthermore, with the continuous improvement of urban residents' quality of life, their demands for health, sports, and nature are increasing, and their multifunctional demands for waterfront spaces are also rising. Traditionally constructed waterfront spaces can no longer meet residents' needs for water-friendly activities. Simultaneously, urban development also poses more complex and diversified functional demands on urban waterfront spaces, such as beautiful natural scenery, the embodiment of urban cultural identity, and open and diversified public spaces^[2].

Urban waterfront areas are the birthplace of urban civilization. Chongqing is a city shaped by rivers. How to effectively utilize the resource of Chongqing's public waterfront areas and scientifically transform them into functionally complex, humanized, and ecological spaces is a question worthy of deep consideration and long-term planning^[3]. Chongqing is a typical mountainous city bordering a river, and the waterfront area of Jialing River has become a physical carrier of Chongqing's historical development and changes due to its special geographical location, spatial pattern, and spatial functions. This allows the public to glimpse into the development of Chongqing people's daily life, cultural customs, and historical evolution, reflecting the city's spiritual style in a diversified way. At the same time, it has also become an important gateway and carrier for Chongqing to promote inland opening. Currently, due to factors such as historical construction, natural geography, and planning, there are many problems in the development of Chongqing's urban waterfront space, and many scholars in the field of landscape design are also stepping up their research on this topic.

The public waterfront space in Chongqing mostly extends along the water, with mountains as the boundary. It is characterized by a predominance of linear spaces, and the overall space is relatively narrow and long, inevitably spanning multiple administrative districts. Due to its geographical and hydrological factors, it is difficult to avoid issues such as planning difficulties, management difficulties, inconsistent development timing, and development costs. In addition, before the issue of water ecological civilization construction was raised, there were still problems in the early planning of the waterfront space in the center of Chongqing, which led to problems such as lack of use of public waterfront space, severe hardening, and homogenization of functions. These problems are similar, and they are also issues that need to be considered in combination with various factors when designing Section A of the Huaxi River in Chongqing Institute of Engineering.

Located in the hilly area on the south bank of the Yangtze River, Ba'nán District is the birthplace of Ba culture. Chongqing's Lijiatuo ferry was once an important transportation hub for people in Ba'nán to travel to other places, carrying a unique historical mission. With the opening of the Second Chongqing Yangtze River Bridge, the ferry history of Lijiatuo flowed away with the rolling river, and the bustling dock gradually became silent. This is also the earliest dock culture in Chongqing.

1.2. Design purpose

In recent years, the rapid development of the times has brought many environmental and ecological problems. As a mountainous city, Chongqing has also brought new challenges and requirements to urban waterfront landscape design.

The Huaxi River flows through the Northeastern edge of Chongqing Institute of Engineering, connecting the school with the opposite bank with its unique water system, and connecting the North and South. At the same time, it is also a first-level tributary of Ba'nán District, covering a wide area and closely related to people's production

and life. This study selects the section of the Huaxi River in Chongqing Institute of Engineering, Ba'n'an District, Chongqing as the research object. Based on a brief overview of the development history and research conclusions of waterfront city landscape design at home and abroad, it conducts theoretical and practical research and application on hot topics in the three major sections of ecological design, symbiotic design, and sustainable design from the perspective of waterfront landscape design research in mountainous cities in Chongqing. The aim is to improve problems such as the single spatial function of the Huaxi River section in Chongqing Institute of Engineering, poor habitat in the riparian zone, large sediment deposition, and lack of connection with the opposite bank.

1.3. Design significance

When conducting research on the section of the Huaxi River in Chongqing Institute of Engineering, it is necessary to integrate various factors such as economy, society, ecology, and culture into the consideration system. This has positive significance for strengthening the connection between the two banks of the Huaxi River and the development of urban water environment protection work.

2. Research status at home and abroad

2.1. Domestic research status

Research on urban waterfront landscape design in China has been conducted methodically for many years. Zhang Tingwei is known as the earliest expert in China to study urban waterfront design. In his book “Design and Development of Urban Waterfront”, he introduced numerous examples of foreign waterfront development ^[4]. The motivations and basic principles for the development of urban waterfront areas were proposed. Since then, more and more scholars have begun to pay attention to waterfront space research, and some influential academic achievements have emerged. Yu *et al.*, taking the landscape design on both sides of the Sanzaojiang River in Cixi City, Zhejiang Province, as an example, elaborated on the ideas and methods of landscape design in urban waterfront areas. They proposed a multi-objective landscape design viewpoint aimed at coordinating the relationship between humans and nature. Chen proposed that culture, space, ecology, and carrier are the four elements of waterfront landscape planning and design.

Chinese scholars' research on waterfront space mainly has the following characteristics: Firstly, they attach importance to the study of landscape entity design, focusing on the study of landscape elements such as embankments, water areas, waterfront buildings, landscape sketches, and city skylines. Among them, there is more research on embankments, involving embankment design principles and schemes, emphasizing ecology, safety, visual beautification, waterfront recreation, and systematization principles. Secondly, they pay attention to the study of planning and design methods at the technical level ^[5]. Among them, there is more research on datum lines, namely, water system landscape axes, visual corridors, traffic corridor axes, and vertical shorelines, emphasizing the sharing, three-dimensional design, and multi-functional utilization of shorelines. Zhang *et al.* believe that the datum line can serve as the basic framework for organizing the spatial order of waterfront planning. Thirdly, they attach importance to comprehensive development and management research in waterfront areas, mainly emphasizing the improvement of ecological functions and the exertion of economic benefits. In addition, some people have proposed a multi-objective landscape design concept that coordinates the relationship between humans and nature ^[6].

2.2. Foreign research status

Research on urban waterfront space began in the late 19th century. For example, Howard proposed the “Garden

City” theory in 1898, which used canal water as a protective buffer zone around the core area of the city, combined with green belts to form a riverside green space. The first research paper on urban waterfront areas was published in 1969 by Canadian geographer Forward. The article mainly compared the land use situation of several urban waterfront areas. Since then, some scholars have begun to study the development and construction of waterfront areas from an economic value perspective. In the late 1960s, besides geography, related disciplines such as landscape ecology and urban planning also began to pay attention to waterfront research. The ecological concept was highly respected, and the idea of landscape ecological design developed rapidly in Europe, achieving significant results.

Looking at foreign research results, it is rare to apply symbiosis theory to the study of urban landscape planning and design, especially for urban waterfront landscapes. The depth and breadth of research are also very limited. Most of them explore the symbiotic relationship between landscapes through partial or case study methods, lacking deep exploration and systematic research on the symbiotic mechanism between landscapes. However, the idea of symbiosis has already been reflected intentionally or unintentionally in landscape research and practice.

2.3. Current status of the site

The Huaxi River section adjacent to Chongqing Engineering College borders Nanwenquan, boasting rich landscape resources, high vegetation coverage, and a beautiful environment. It is surrounded by roads, with developed traffic and convenient access. A first-level tributary of the Yangtze River flows through the surface, providing relatively abundant water resources.

The external terrain of the base is relatively flat, with multiple gentle and steep slopes inside, creating a certain height difference. The site has abundant vegetation and a relatively open view, providing basic conditions for urban waterside landscape design. The open vistas also offer advantages for urban waterside recreation, enhancing the scope of viewing. However, long-standing water ecological issues in the Huaxi River have led to a homogenous ecological environment, lacking distinctive waterside landscape features and diversity in functional areas.

3. Principles of urban waterside landscape design

3.1. Ecological principle

The design of urban waterside landscapes should fully respect the natural ecological environment, recognizing the ecological value of waterside areas and the role of landscape in ecological restoration. It is important to integrate ecological landscape elements with the surrounding environment to create continuous natural scenic corridors and improve water quality. For Section A of the Huaxi River at Chongqing Engineering College, the landscape design should aim to enhance the ecological function and visual quality of the riverfront while preserving the site’s original natural and cultural features.

3.2. Flood control principle

The geographical location of the urban waterside landscape determines its special role. As an interlaced zone between terrestrial and river ecosystems, waterside landscape planning not only needs to meet basic functions such as leisure and entertainment for citizens but also, most importantly, must be designed to have certain flood control capabilities. Simultaneously, the adaptability of vegetation in the four seasons landscape belt to different natural disasters, such as floods and droughts, should be considered.

3.3. Landscape diversity principle

In the selection of vegetation for waterside spatial landscapes, it is essential to collect and analyze data on native aquatic plant species. Drawing on successful examples of waterside space transformation in mountainous cities can help ensure that plant configurations adhere to principles of aesthetics, cost-effectiveness, and practicality. When facing high-pressure environments, such as the impact of seasonal floodplain fluctuations on vegetation, flood disasters, natural erosion, and other situations, scientifically and rationally allocate plant species to endow them with sufficient stress-bearing capacity and satisfy the principles of landscape ecology. Creating diverse vegetative landscape belts that simulate natural riverbanks can provide habitats for wildlife, help regulate the urban heat island effect, and contribute to improving the overall quality of the urban living environment.

3.4. Cultural continuity principle

Combine natural landscape protection with the preservation of human cultural landscapes, injecting vitality into urban riverside landscapes, preserving the continuation of historical contexts, and shaping new cityscapes. In the design, respect the diversity of different regional cultures, utilize cultural resources creatively, and form unique waterside landscape features with regional characteristics.

4. Design analysis

4.1. Foundation in vegetation, focus on people

The design concept aims to achieve harmonious coexistence between people, the natural environment, and the cultural environment through a symbiotic approach. This urban waterfront landscape design, guided by the principles of ecological and cultural symbiosis, abandons the traditional method of using buildings to separate the campus from the city environment. Instead, it weakens the barrier function of buildings, connects the campus with the city across the river, and creates a functionally diverse, green, and ecological “sequential symbiosis” waterfront landscape that is loved by the masses.

4.2. Original landscape of mountains and waters, priority to ecology

Guided by national ecological civilization construction and responding to the demands of the broader society for waterfront landscapes, the key to the ecological restoration design of the Huaxi River is to refer to the provincial strategy of “Two Rivers and Four Banks”. The idea of symbiosis, which originated in biology and is one of the fruits of interdisciplinary research, has been applied to urban waterfront landscape design after undergoing long-term development and evolution. As an important component of urban public shared space, waterfront landscapes drive the development of urban economy, society, and culture. Applying the symbiotic idea to urban waterfront landscape design has positive significance for addressing issues such as the fragility of urban ecological chains and human encroachment on animal habitats.

4.3. Reducing homogenization, creating functionally diverse waterfront spaces

By combining ecological waterfront landscapes with ecological knowledge, the design aims to create a city waterfront landscape that is “appreciated, learned, and shared” by all. The three major landscape themes of “ecological symbiosis, ecological tourism, and ecological science popularization” are designed to meet the functional needs of ecological display, ecological environment experience, and ecological knowledge popularization, creating a popular and enjoyable city waterfront landscape.

5. Conclusion

Water is the source of life, and humanity's affinity for water bodies stems from ancient historical contexts. Cities are born near water, and many of the world's megacities follow this pattern. As cities modernize rapidly and economies grow at a high speed, people are presented with both development opportunities and conflicts arising from environmental degradation. The concept of "ecological civilization" proposed at the 18th National Congress of the Communist Party of China underscores the urgency of resolving these conflicts. Finding a delicate balance to manage these conflicting forces is a challenge that designers must strive to address.

This article conducts an in-depth study and analysis of urban waterfront landscape design within the strategic context of "ecological civilization." By examining modern trends in urban waterfront landscape development and analyzing the current status and historical progression of such landscapes both domestically and internationally, it proposes specific strategies tailored to the site conditions of the Huaxi River section of Chongqing Engineering College. These strategies incorporate three key design elements: "mountains, water flow, and emerging fog."

To summarize, a lucrative environment is a valuable asset, just like mountains of gold and silver. This design, based on the concept of "sequence and symbiosis," explores the urban waterfront of the Huaxi River section at Chongqing Engineering College. Guided by the national vision of "ecological civilization" and informed by the historical context of mountainous cities, it takes into account local topography, hydrological features, and other natural conditions. With a thorough understanding of the site's current state, the design incorporates historical elements, makes scientific and rational use of natural conditions, and incorporates humanistic care.

Guided by the national ecological civilization construction and responding to the public's demand for waterfront landscapes, the key to the ecological restoration design of the Huaxi River lies in referencing the provincial "Two Rivers and Four Banks" strategy.

Through preliminary analysis, customer research, data collection, and case study review of the Huaxi River basin at Chongqing Engineering College, the goal is to create an urban waterfront that is "enjoyed, learned from, and shared by all." This reflects the unique landscape characteristics of the Huaxi River section, enriches the functionality of the waterfront space, contributes to ecological waterfront design, and realizes the protection and utilization of water resources in this area.

The study on the Huaxi River section of Chongqing Engineering College proposes a comprehensive waterfront landscape strategy that integrates aesthetic, cultural, and technological values. It also explores the current development status of waterfront landscape design in mountainous cities.

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Application Strategies of Intelligent Transportation Technology in Traffic Safety Management

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Abstract: At present, transportation construction plays a certain promoting and driving role in the economic and social development of our country. At the same time, because of the accelerated pace of transportation construction, the traffic network structure of each region of China has gradually been optimized and perfected. This not only significantly improves people's quality of life and living conditions, but also provides many conveniences for the transportation of goods. However, in the current process of highway construction and development in China, there is still a certain degree of danger, which will also significantly increase the probability of road safety problems occurring. Therefore, it is necessary to apply intelligent transportation technology to effectively enhance the safety of road use. As a result, this study provides a detailed analysis of the overview of intelligent transportation technology, the advantages of the application of intelligent transportation technology in traffic safety management, as well as an in-depth discussion of the role and application of intelligent transportation technology in traffic safety management.

Keywords: Intelligent transportation technology; Traffic safety management; Information

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1. Introduction

By the end of 2023, the national highway mileage was 5,436,800 kilometers, of which 762,200 kilometers were Class II and above, 183,600 kilometers were expressways, and 122,300 kilometers were national highways. There were 1,079,300 highway bridges and 95,288,200 linear meters, including 10,239 special bridges and 18,730,100 linear meters, and 177,700 bridges and 49,943,700 linear meters. There are 27,297 highway tunnels and 30,231,800 linear meters, of which 2,050 are very long tunnels and 9,240,700 linear meters, and 7,552 are long tunnels and 13,213,800 linear meters^[1]. With the significant growth of China's highway mileage, road network traffic is becoming increasingly dense and complex, and people's requirements for traffic safety are soaring. Traditional transportation management methods are increasingly insufficient to meet the growing demands of modern travel, leading to the emergence of intelligent transportation technology. Intelligent transportation

technology refers to the effective integration of advanced technologies, such as information technology, computer science, data communication, sensor systems, electronic control, automatic control theory, operations research, and artificial intelligence, into transportation, service control, and vehicle manufacturing. Its goal is to enhance the connection between vehicles, infrastructure, and users, thereby improving traffic conditions, ensuring safety, and increasing overall efficiency^[1-2].

2. Overview of intelligent transportation technology

Driven by the dual forces of information technology advancement and scientific progress, intelligent transportation technology plays a vital role in modern traffic safety management. The current intelligent transportation technology has formed an all-round, three-dimensional, and diversified road safety protection network, which can accurately identify and control the potential risks in transportation, thus significantly reducing the incidence of traffic accidents. The application of intelligent transportation technology is mainly reflected in two key areas, the first of which is the enhancement of intelligence in traffic safety management. It not only provides traffic managers with relatively complete and accurate road traffic information, but also enables them to grasp the real-time dynamics of road conditions, thereby making more scientific management decisions. The second is the application of the technology can also provide convenience for drivers and passengers to travel. For instance, during the journey, it can promptly remind drivers of traffic accidents and speed limit information ahead, etc., to avoid the occurrence of safety accidents as much as possible.

3. The application advantages of intelligent transportation technology in traffic safety management

3.1. Strong universality

Intelligent transportation technology has gradually become an essential tool for supporting traffic management. It has been widely applied across various administrative processes in different regions, significantly enhancing traffic efficiency, increasing freight and passenger flow, and notably improving traffic safety. In 2023, the total commercial freight volume of the highway industry reached 40.337 billion tons, and the freight turnover volume was 7,395 billion ton-kilometers^[3]. Compared with the total cargo transportation volume of 33.63 billion tons in the highway industry throughout 2016, it increased by 20%^[4]. The total volume of personnel flow on highways throughout the year was 56.556 billion person-times, an increase of 362% compared with 15.63 billion person-times in 2016. In 2023, the number of deaths per 10,000 vehicles in road traffic accidents was 1.38, a decrease of 29.5% compared with 2.1 in 2016^[3,4].

For example, in urban highway traffic management, the application of intelligent transportation technology allows relevant departments to effectively monitor parking space allocation, road conditions, and vehicle positioning. It also enhances the monitoring and regulation of speeding and traffic violations, thereby improving the overall governance capacity and advancing the development of highway traffic safety^[5].

3.2. Higher real-time

In the field of traffic safety management, the advantages of intelligent transportation technology are also reflected in the high timeliness. For example, the event detection capabilities of surveillance cameras can identify traffic accidents, cargo spills, congestion, vehicle fires, and other irregularities. They also enable real-time tracking of hazardous chemical vehicles, oversized cargo transport, and special operation vehicles. For instance, when a road traffic accident occurs, the intelligent transportation system can quickly help relevant departments locate the

accident scene so that rescue operations can be launched immediately. Drivers and passengers can also obtain real-time information through radio, map software, or traffic signs, etc., to make better travel planning. In addition, intelligent transportation technology can also analyze and identify the causes of accidents and the attribution of responsibility, thus greatly improving the accuracy and efficiency of accident handling.

3.3. Wider coverage

At present, intelligent transportation technology is widely used in various fields, especially in the field of traffic safety management, covering almost all application scenarios, from the propaganda of laws and regulations, road safety education, traffic facilities management to traffic safety enforcement. For example, intelligent transportation technology can be used to disseminate safety management information via electronic message boards, address illegal road occupation, unauthorized parking, and support emergency evacuations using drones. In foggy conditions, visibility sensors can automatically activate fog warning systems, while pollutant particle detectors can trigger tunnel ventilation systems as needed. So that the highway traffic management department will be able to quickly take corresponding measures against the illegal vehicles, thus effectively improving the efficiency and quality of road safety management ^[6].

4. The role of intelligent transportation technology in traffic safety management

4.1. Improve the effectiveness of safety management, prevention, and control

Highway is an important part of the transportation network, which carries people's travel safety and transportation safety. Once an accident occurs in the process of highway transportation, it will cause property loss, and in serious cases, it may also cause casualties. Therefore, after the highway construction is put into use, it is necessary to adopt reliable safety management measures, formulate more perfect safety management and protection standards, and put forward practical strategies to minimize the incidence of road accidents. In addition, the application of intelligent transportation technology in traffic safety management is mainly based on its intelligent and automated features to further integrate and analyze the vehicle information on the road, and according to the actual driving needs to do a good job of intelligent planning, thus promoting the effective realization of intelligent driving, as well as help drivers to identify potential risks in the process of driving in advance and to take targeted preventive measures to minimize the probability of safety accidents ^[7].

4.2. Improve accident prevention ability

According to the actual needs of road traffic safety management, more advanced intelligent transportation technology can be reasonably applied to carry out more accurate risk assessment on the dynamic information of vehicles on the road and the condition of bridges and tunnels, to effectively predict potential accident risks in advance. In addition, the effective application of intelligent transportation technology can help predict the likelihood of traffic accidents, providing drivers with valuable decision-making support. This enables them to take preventive measures in advance, thereby significantly reducing the risk of accidents. Moreover, intelligent transportation technology can quickly provide regional driving navigation for drivers by virtue of its excellent data integration, collection, and analysis functions on the road. At the same time, drivers can also choose the driving program recommended by the system according to the real-time feedback of the road conditions. In the face of road congestion, the intelligent transportation system can also obtain and communicate congestion information to drivers promptly, to warn drivers to slow down. In addition, under adverse weather conditions, drivers can more accurately determine the road ahead with the help of intelligent transportation technology, which can effectively control the vehicle distance and driving speed ^[8].

4.3. Accelerate the emergency response speed

Safety accidents are easy to occur in the highway section, and once safety accidents occur, emergency rescue measures must be launched immediately to ensure the safety of personnel to the greatest extent. In addition, to minimize the degree of accident damage in traffic safety management, it is necessary to apply intelligent transportation technology to do a good job of effective monitoring and management. If traffic accidents are detected and reported immediately, the rescue agencies receiving alerts will promptly dispatch personnel to the accident site. At the same time, these agencies can use advanced technology to accurately obtain accident information and conduct analysis and assessment. Moreover, while en route to the scene, they can develop a more comprehensive rescue plan, thus saving valuable time for rescue operations. This approach can enhance rescue efficiency and significantly reduce the negative impact of accidents.

5. The application of intelligent transportation technology in traffic safety management

5.1. Highway traffic safety accident prevention

After the highway is built and put into use, the relevant enterprises and departments must carry out all-round safety monitoring and management, to avoid the occurrence of safety accidents as far as possible. To achieve this purpose, it is necessary to apply intelligent transportation technology, which can provide a strong guarantee for the safety of vehicles. In addition, the application of intelligent transportation technology can also accurately detect the vehicle's driving route and driving trajectory, and through scientific and reasonable planning to achieve the purpose of effective prevention of accidents. Moreover, with the assistance of intelligent transportation technology, a safe and stable traffic environment can be built for the general public, providing a strong guarantee for people's travel safety. At the same time, through the effective use of intelligent transportation technology, drivers can monitor their vehicle's status and plan their travel routes based on relevant information, minimizing the risk of safety issues. In addition, with the ongoing development of road infrastructure in our country, highway construction projects across various regions are progressing systematically. Therefore, the road conditions faced by drivers are becoming increasingly complex during this process. If effective management and planning of driving distance and speed are not implemented when traveling, the probability of accidents will significantly increase. Thus, only by applying intelligent transportation technology to ensure relevant safety precautions can the safety of road use be further enhanced ^[9].

5.2. Data collection and multi-sensor data fusion

The application of intelligent transportation technology in traffic safety management is mainly based on the concept of safety management and focuses on multiple links such as data collection, analysis, and organization. Among them, in the data collection stage, sensors need to be applied reasonably. Currently, there are various sensors on the market suitable for highway information collection. Staff need to flexibly select more suitable sensors based on the specific conditions of the highway and the information collection requirements. In addition, the main concern in environmental monitoring is the highway temperature, humidity, and the surrounding environmental conditions. At the same time, under relatively adverse weather conditions such as rain, snow and heavy fog, it is necessary to monitor weather conditions that may affect the operation of the road, such as hail, mudslides, rain, snow and strong winds, and effectively collect and transmit the corresponding data by installing corresponding sensors on the road. Furthermore, with the wide application of GPS/5G technology in the automotive industry, the driving status information of automobiles can be collected in real time to determine the driving trajectory of the vehicle, thereby assessing the driving safety of the vehicle and promptly detecting any

abnormal situations that exist, and taking targeted control measures ^[10].

5.3. Information transmission and processing

The establishment of an information network centered on traffic safety management can ensure the safe and accurate transmission of data collected by various sensors ^[11]. Moreover, highway management institutions can carry out corresponding tasks through information systems during the processes of data integration, collection, and analysis, thereby obtaining more raw data and information. At the same time, they can also apply data analysis software to deeply explore the value of information. This is a common practice in the information collection stage, which can also ensure the effective transmission of information. In addition, the use of GPS/5G technology in the field of highway traffic monitoring is also a more basic means of monitoring. At present, GPS/5G technology is mainly used for the precise positioning of vehicle positions, and the realization of its functions also relies on the data support of sensors. And through the analysis and sorting of relevant data, the real-time status of highway operation can be presented more clearly, to accurately assess the highway operation ^[12].

5.4. Reduce the degree of accident injury

Through the application of advanced highway traffic accident prediction methods, the potential traffic accident risks for each section of the road can be analyzed and calculated, with corresponding risk values clearly defined. Drivers can then use this information to make informed decisions and minimize the likelihood of accidents. In addition, drivers can predict possible problems and accidents in advance when monitoring vehicle traveling information, to better protect people's travel safety. Furthermore, when intelligent transportation technology is applied to highway traffic safety, once the risk of a safety accident on the highway is detected, the system will make corresponding preparations in advance and promptly convey the relevant information with the support of intelligent transportation technology to ensure that medical rescue is provided to the injured in the shortest time. This can significantly reduce the number of casualties after an accident, and at the same time, it can also avoid long-term traffic congestion caused by safety accidents ^[13].

6. Conclusion

Overall, a thorough analysis of the operation status of the highway system in our country at present reveals that there are many potential safety hazards. Therefore, while promoting highway construction, traffic safety management cannot be ignored either. Hence, in the face of a significant increase in the number of highways and the intensification of safety management tasks, relevant departments need to apply intelligent transportation technologies based on advanced information technology. This can promote the gradual development and transformation of safety management work towards informatization and technological advancement. At the same time, through the application of intelligent transportation technology in traffic safety management, real-time monitoring of road conditions can be achieved, ensuring the safety and stability of highway traffic operations. In addition, the application of intelligent transportation technology in traffic safety management not only enhances the security of travel but also contributes to creating a harmonious social environment and provides strong support for sustainable social and economic growth.

Disclosure statement

The authors declare no conflict of interest.

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Application Strategy of Ultrasonic Non-destructive Testing Technology in Bridge Engineering

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Abstract: The purpose of this study is to analyze the application of ultrasonic non-destructive testing technology in bridge engineering. During the research phase, based on literature collection and reading, as well as the analysis of bridge inspection materials, the principle of ultrasonic non-destructive testing technology and its adaptability to bridge engineering are elaborated. Subsequently, starting from the preparation work before inspection until damage assessment, the entire process of ultrasonic non-destructive testing is studied, and finally, a technical system of ultrasonic non-destructive testing for bridge engineering that runs through the entire process is formed. It is hoped that this article can provide technical reference value for relevant units in China, and promote the high-quality development of China's bridge engineering from a macro perspective.

Keywords: Ultrasonic; Bridge engineering; Non-destructive testing; Signal filtering

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1. Introduction

During the construction and operation of bridge engineering, it will be subjected to long-term dynamic loads and environmental erosion. The early identification of internal damage to the bridge engineering structure directly affects the safety and service life of the bridge engineering. Traditional bridge engineering detection techniques, such as visual inspection and hammering methods, are highly dependent on manual experience and have deviations in subjective judgment dimensions. They can only detect surface defects of the structure and cannot effectively detect concealed problems such as internal cavities in the concrete and corrosion of steel bars. Moreover, traditional techniques often require some damage to the structure itself^[1]. Ultrasonic non-destructive testing technology utilizes the propagation characteristics of sound and analyzes parameters such as sound velocity and waveform to obtain internal compactness information without damaging the structure's surface. This enables precise positioning and quantitative assessment of internal defects in the bridge structure. Additionally, its non-destructive and rapid detection advantages can reduce interference with the normal use of the bridge and establish a structural health archive for the bridge through periodic inspections, effectively compensating for the deficiencies of traditional detection techniques in dynamic detection, detection depth, and accuracy.

2. Principles of ultrasonic non-destructive testing technology and its adaptability to bridge engineering

2.1. Principles of ultrasonic non-destructive testing

2.1.1. Propagation characteristics of sound waves

Ultrasonic waves, as mechanical waves with a frequency greater than 20 kHz, have propagation characteristics that are closely related to the density of the transmission medium. Based on wave theory, within a medium, the propagation speed (v) of sound waves follows a relationship with the elasticity (E) and density (ρ) of the material, represented by $v = \sqrt{\frac{E}{\rho}}$. The relationship between the propagation frequency (f), wavelength (λ), and wave speed

is expressed by $f = \frac{v}{\lambda}$. As the material density increases, the wave speed decreases, the wavelength shortens, and

the frequency response changes accordingly. Simultaneously, the attenuation coefficient (α) is directly proportional to the square of the frequency and is associated with the material density and defects in its internal structure. If cracks appear inside the material, the scattering of sound waves will intensify, leading to significant attenuation of energy.

2.1.2. Classification of waveforms

Based on the relationship between the direction of vibration and the direction of propagation, ultrasonic waves can be classified into longitudinal waves, transverse waves, and surface waves. Among them, longitudinal waves have extremely high propagation efficiency in a medium with uniform density, and the wave speed is significantly affected by density. The vibration direction of the particle in a transverse wave is perpendicular to the direction of propagation. When encountering areas with density changes, refraction and mode conversion phenomena are prone to occur, so they are often used to detect internal defects in buildings and bridge structures. Surface waves propagate along the surface of the material, and energy attenuation is related to the surface roughness and near-surface density changes of the material, making them highly suitable for detecting surface damage in bridge structures^[2]. The frequency, wavelength, and attenuation characteristics of different waveforms can provide multi-dimensional information for highly complex layered detection of bridge structures.

2.1.3. Echo signal analysis

When ultrasonic waves are generated by equipment and encounter interfaces with different acoustic impedances within the material (such as internal defects or internal layers), reflection echoes are produced. By analyzing the arrival time, amplitude, and frequency components of the reflected echoes, the internal structural characteristics of the material can be deduced. Differences in wave speed caused by changes in density will result in changes in echo time delay. Scattering and reflection at defect sites will cause significant attenuation of echo amplitude, and high-frequency components will be preferentially lost. Therefore, combining spectrum analysis and waveform feature analysis can quantify the size, location, and uniformity of internal defects in the material, providing data-level support for structural health evaluation^[3].

2.2. Suitability of ultrasonic detection for bridge engineering

2.2.1. Applicable scenarios

In bridge engineering, ultrasonic detection technology, with its unique penetration characteristics, can precisely locate complex defects inside concrete. For voids inside the concrete of bridge structures, when ultrasonic waves encounter voids during propagation, they will scatter and diffract due to the discontinuity of the medium. The sound time at the receiving end will be extended, and the wave amplitude will attenuate. Based on the analysis of

these acoustic parameter changes, the location and size of the voids can be determined. For the detection of steel corrosion, corrosion will change the acoustic impedance parameters of the steel and concrete interface. When the equipment emits ultrasonic waves, the reflection signal strength and frequency characteristics of the sound waves at this interface will change accordingly. This can be used to determine whether the steel is corroded and the degree of corrosion ^[4]. During the crack depth detection stage, based on the principle of ultrasonic diffraction, diffraction occurs when the wave propagates to the crack tip area. By measuring the sound time during which the sound wave bypasses the crack, combined with the analysis of the speed of sound in concrete, the depth of the crack can be calculated.

2.2.2. Technical advantages

The advantages of ultrasonic detection applied to bridge inspection are reflected in its non-contact, high-resolution, and repeatability. Firstly, the non-contact feature allows the technology to be used in bridge inspection without damaging the surface of the structure, effectively reducing the negative impact of inspection work on the normal use of the bridge. This feature is highly suitable for bridge projects that have already been put into operation. Secondly, the high-resolution characteristic of ultrasonic detection enables it to capture millimeter-level defect changes. Both tiny cracks and subtle voids can be clearly presented in the inspection results, greatly satisfying the precision requirements of bridge engineering inspection. Thirdly, ultrasonic detection technology has strong repeatability. The standardized inspection process, combined with advanced equipment, can stably obtain reliable inspection results at different times and with different inspection personnel backgrounds, which is helpful for continuous monitoring of the structural health of bridges ^[5].

3. Application of ultrasonic non-destructive testing technology in bridge engineering

3.1. Preparation before testing

Before conducting ultrasonic non-destructive testing, multi-dimensional preparation work needs to be completed. Firstly, in terms of testing equipment selection, the inspection team needs to select ultrasonic detectors and probes with appropriate frequencies based on the component size, material characteristics, and inspection objectives of the bridge. For example, for non-destructive testing of large-volume concrete components, low-frequency probes should be preferred to ensure the penetration ability of ultrasonic waves. For the inspection of thin-walled components and near-surface defects, high-frequency probes should be used to improve resolution.

Secondly, before the inspection work, a detailed site survey of the bridge inspection area needs to be carried out, combining survey data to clearly identify the type, size, and appearance damage information of the components. At the same time, key inspection areas such as piers, beam connections, and surrounding areas of prestressed anchors, which are prone to stress concentration, should be determined based on the bridge engineering design drawings. Additionally, special personnel should be arranged to clean the inspection surface, completely removing laitance, oil stains, and loose layer impurities. After grinding and leveling the inspection points, a suitable amount of coupling agent, such as Vaseline or paste, should be applied to ensure that the probe can closely fit the inspection surface and reduce the loss of sound energy during the inspection process ^[6].

In addition, it is necessary to strictly establish reference values for inspection parameters before testing. Acoustic parameters such as sound velocity and sound time should be measured for defect-free areas of components, which will serve as a basis for comparative analysis of subsequent inspection results. **Table 1** shows the reference parameters for ultrasonic inspection of common bridge materials:

Table 1. Ultrasonic inspection parameters for bridge structures

Material type	Applicable probe frequency(kHz)	Reference sound speed(m/s)
Concrete	20–500	3000–4500
Steel	500–1000	5900–6100
Stone	50–300	3500–5000

3.2. On-site operation

Key points of on-site operation include designing the scanning path, setting key detection parameters, and real-time signal detection.

3.2.1. Scanning path design

In the scanning path design phase, reasonable planning should be based on the shape of the component and the predicted direction of defects. For regular-shaped components, such as bridge beams and piers, a grid-like scanning pattern is recommended. The grid spacing can be uniformly set based on the detection accuracy, typically ranging from 10cm to 30cm. For areas of the bridge where cracks or voids are suspected, the scanning path should be densified, and cross-scanning and fan-shaped scanning should be used to ensure effective coverage of defective areas. Additionally, during the scanning process, inspectors need to strictly mark the moving direction and starting position of the probe to facilitate subsequent data analysis and tracing ^[7].

3.2.2. Key parameter settings

During the inspection phase, the reasonable setting of key parameters has a direct impact on the accuracy of the inspection results. In the inspection operation phase, the transmission voltage should be set flexibly based on the sound attenuation level of the material in the bridge inspection area. For example, for high-attenuation materials such as old concrete, the transmission voltage should be appropriately increased to enhance the signal strength. Meanwhile, the sampling frequency should satisfy the Nyquist sampling theorem (the sampling frequency must be at least twice the highest frequency of the signal), and can typically be set to 5–10 times the detection frequency to ensure complete acquisition of the echo signal. **Table 2** provides references for key parameter settings in different inspection scenarios.

Table 2. Key parameter settings for different inspection scenarios

Purpose of detection	Sampling frequency(MHz)	Transmission voltage(V)
Concrete cavity detection	5–10	200–400
Steel corrosion detection	10–20	150–300
Crack depth detection	1–5	100–250

3.2.3. Real-time signal monitoring

During the inspection process, a dedicated person should be arranged to observe the waveform interface of the ultrasonic detector in real-time, monitoring changes in parameters such as sound time, amplitude, and frequency. Once abnormal signals such as a sudden drop in amplitude, prolonged sound time, or multiple occurrences of reflected waves are encountered, scanning should be suspended immediately. Repeated inspections and multi-angle verifications should be carried out for the abnormal areas to ensure the authenticity of the reflected signals. At the same time, a dedicated person should be arranged to record the specific location and signal characteristics of the abnormal signals, providing clues for subsequent deep analysis of the data ^[8].

3.3 Data processing and analysis of inspection results

The key points of data processing and analysis of inspection results lie in signal filtering, defect localization, and damage evaluation.

3.3.1. Signal filtering

The original ultrasonic signals collected by the equipment are highly susceptible to negative effects caused by environmental noise and instrument interference. Therefore, targeted filtering processing is required for the ultrasonic signals. In this process, a band-pass filter device is first used to adjust the filter's passband range based on the center frequency and bandwidth of the ultrasonic probe used during the inspection. For example, if a 50 kHz probe is used, the band-pass filter can be set to 45–55 kHz to effectively filter out all interference signals outside this frequency band. For other random noise mixed with the ultrasonic waves, such as white noise, a median filtering algorithm can be used. The sampling points within the detected signal are taken as the center of the filtering process, and the window length is reasonably set, such as 5–11 sampling points.

Subsequently, the median value within the window replaces the original sampling value, preserving the edge characteristics of the signal while effectively suppressing noise. Additionally, if there is periodic interference in the ultrasonic signal, the LMS (Least Mean Squares) adaptive filtering algorithm can be used. By comparing the reference signal with the original signal, the algorithm automatically adjusts the filter coefficients to dynamically cancel the interference signal. After processing the ultrasonic signal, a spectrum analysis tool should be used to verify the effectiveness of the filtering treatment, ensuring that the defect characteristic frequency components in the signal are completely preserved^[9].

3.3.2. Defect localization

Defect localization can be achieved through the use of the “time-of-flight to distance” method combined with geometric calculations. For internal voids in the concrete of bridge components, the first step is to measure the sound velocity (v) in a non-defective area of the component. Then, test points are set up in suspected defective areas to send ultrasonic waves, and the time (t) it takes for the sound wave to travel from emission to reception is measured. If the measurement results show that the sound travel time at a certain measurement point is greater than that in the normal area, the coordinates of that point are recorded. Subsequently, that point is used as the center for sound travel time measurements in multiple directions. Based on the increase in sound travel time (Δt), the additional propagation distance of the ultrasonic wave after bypassing the void is calculated. This, combined with geometric triangular relationships, allows for the confirmation of the boundary position and size of the void.

During the detection of crack depth in bridge components, the single-sided measurement method can be adopted. Measurement points are arranged on both sides of the crack, and the first wave sound travel time and distance are measured. Then, crack depth calculations are performed using Equation 1:

$$h = \frac{\sqrt{(vt_2)^2 - L_2^2} + \sqrt{(vt_2)^2 - L_1^2}}{2} \quad (1)$$

In Equation 1, v represents the sound velocity of concrete. For complex cracks, the position of the measurement points should be changed multiple times to cross-validate the detection results.

3.3.3. Damage assessment

The main basis for damage assessment is the type of defect and quantitative assessment of inspection data. For concrete voids in bridge structures, the detected void volume can be compared to the total volume of the component. If the proportion of void volume exceeds 3%, it can be judged as severe damage. A level of 1% to 3%

can be judged as moderate damage, and below 1% can be judged as minor damage. For the detection of corrosion of internal steel bars in bridge components, the level of corrosion can be assessed based on the attenuation of the reflected signal amplitude of ultrasonic waves at the steel bar-concrete interface. If the attenuation exceeds 50% of the original signal, it indicates significant loss of steel bar cross-sectional area, requiring special attention. If the attenuation is in the range of 20% to 50%, it can be judged as moderate corrosion, and below 20% can be judged as minor corrosion. For crack damage assessment, the length, width, and depth of the crack need to be comprehensively considered. If the crack length is greater than 1m, the width is greater than 0.3mm, and the depth penetrates through the component, this situation should be regarded as a crack that seriously affects structural safety. If the crack length is 0.5 to 1m and the width is 0.1 to 0.3mm, the crack can be judged as moderate damage. Cracks with a length less than 0.5m and a width less than 0.1mm can be judged as minor damage^[10].

4. Conclusion

This study explores the application of ultrasonic non-destructive testing technology in bridge engineering. After introducing the principles of ultrasonic non-destructive testing and its suitability for bridge engineering inspection, the key points of the application process are discussed in detail. Ultrasonic non-destructive testing can effectively compensate for the deficiencies of traditional bridge engineering inspection techniques, enabling precise detection and evaluation of internal defects in bridges without disrupting their normal operation. In the future, with the development of technology, it is believed that ultrasonic non-destructive testing technology will gradually achieve deep integration with artificial intelligence, big data, and other technologies, further enhancing the level of intelligent inspection. Therefore, relevant enterprises should strengthen research on technology application, actively explore the combination with other advanced technologies, further leverage the technical advantages of ultrasonic non-destructive testing, and achieve new breakthroughs in the field of bridge engineering inspection.

Disclosure statement

The authors declare no conflict of interest.

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Landscape Design of “Four Good Rural Road” in Shuangshi Town, Yongchuan District

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Abstract: The construction of the “Four Good Rural Roads” has benefited thousands of households and serves as a foundational step in promoting rural revitalization. This study analyzes the current status of the project in Shuangshi Town, Yongchuan, and proposes targeted landscape design across four key areas: plant promotion, cultural display, service facilities enhancement, and industrial promotion. The objective is to build a “last kilometer” that truly supports rural revitalization and prosperity for local farmers. Through this integrated approach, the rural roads of Shuangshi Town will be transformed into scenic routes that reflect the charm of rural mountains and forests, showcase characteristic agricultural products, and evoke a sense of nostalgia, creating a travel corridor marked by engineering beauty, cultural beauty, plant beauty, and facility beauty.

Keywords: Shuangshi town; Plants; Facilities; Culture; Estate

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1. Introduction

The “Four Goods Rural Roads” initiative, proposed by General Secretary Xi Jinping, is an important project aimed at improving the livelihoods of rural communities. It focuses on developing rural roads as a key factor in rural revitalization ^[1]. Since its launch in 2015, Chongqing has made significant progress in building “beautiful rural roads,” laying a strong foundation for further development and branding.

In 2025, marking the 10th anniversary of the initiative, the construction of “Four Goods Rural Roads” began in Shuangshi Town, Yongchuan District. This project integrates natural ecology, industrial development, and local history and culture into the road construction process. It also explores the combined development of rural roads, tourism, and modern agriculture. This approach helps local towns and villages promote industry and tourism through improved infrastructure, allowing people to enjoy the beauty of the countryside while supporting the growth of specialized industries.

1.1. Project overview

The project involves the construction of the ‘Four Goods Rural Roads’ in Shuangshi Town, Yongchuan District, Chongqing. The road connects to G246 National Road, with a total length of 14.7 kilometers. It passes through

Fushengqiao Village, Jiaopenjing Village, Xin'guan'yin Village, and Zhongxinqiao Village, serving as an important image showcase road for Shuangshi Town. The area is adjacent to Yongchuan City, making it a popular destination for weekend trips.

2. Project characteristics and key points of landscape design

- (1) Plants: The rural landscape around the road is beautiful, but the green space along the roadside and on the broken platforms is relatively narrow. Although the road landscape has sufficient greenery, it lacks color and continuity, resulting in a poor landscape effect.
- (2) Culture: The route passes through villages with rich local nostalgia and cultural heritage, but the cultural display is inadequate. Shuangshi's 'Little Golden Dragon' has successfully applied for the Chongqing Municipal Intangible Cultural Heritage Project.
- (3) Facilities: There are many townships and residences along the road, as well as gathering places for villagers' spontaneous activities. However, there is a lack of complete convenience facilities, landscape beautification, and humanistic care.
- (4) Industry: The industrial advantages are obvious, but they are not displayed and promoted through landscape design to achieve the effect of promoting production through scenery.

Through detailed investigation and analysis of the entire route, the characteristics of the road are summarized: good road alignment, good native vegetation, sufficient green volume, rich culture, and abundant industries. However, there are also disadvantages such as messy roadside greening, single color, outdated service facilities, lack of cultural landscapes, and low correlation between the landscape and surrounding industries.

3. Landscape design concept and goals

3.1. Design concept— 'Fruitful flowers and beautiful countryside; characteristic agricultural products and strong nostalgia'

The road passes through Fushengqiao Village and Xin'guan'yin Village, featuring characteristic industries such as fruit and flower forests, including industrial parks for hybrid oranges and plum orchards, as well as fishing and barbecue facilities. The design is inspired by local characteristics, focusing on the concept of a fruitful and beautiful countryside.

The road also passes through Jiaopenjing Village and Zhongxinqiao Village, which have characteristic agriculture such as high-standard farmland, tea gardens, and corn and soybean agricultural bases, as well as rural memory points in Jiaopenjing. The design draws on local characteristics to showcase unique agricultural products and evoke a strong sense of nostalgia.

3.2. Design goals—'Creating a green, beautiful, industrial, and cultural Yongchuan'

The construction of the "Four Goods Rural Roads" demonstration project aims to enhance the rural transportation environment, showcase local culture, and support the development of rural tourism. This will showcase a green Yongchuan with beautiful scenery on both sides of the road, flowers in three seasons, and picturesque scenery in four seasons. It will also promote the protection of water resources along the route, showcasing a beautiful Yongchuan with blue skies and clear water. Additionally, the road will drive the green development of industries, boost rural revitalization, and showcase an industrial Yongchuan. Finally, it will promote cultural integration, evoke nostalgic memories, and create a cultural Yongchuan that thrives due to the road."

4. Principles of landscape design

- (1) Safety principle: Highway landscapes should meet the requirements of traffic safety and driving comfort, mainly reflected in guiding the line of sight and reducing visual fatigue.
- (2) Coordination principle: Make full use of the existing landforms and vegetation to effectively organize the landscape layout within the site.
- (3) Native principle: Greening design should be suitable for the local environment, using appropriate environmental plant materials, and local stone materials should be selected for hard paving.
- (4) Regional principle: Extract and explore the cultural connotation of ethnic regions, and appropriately display the local cultural characteristics through highway landscape design.
- (5) Storytelling principle: Consider the function of service facilities, make the road serve people, and enhance the favorability of drivers and passengers as well as residents along the route towards the road.

5. Design strategies

5.1. Landscape design strategies

Ecological design techniques should be adopted by selecting resilient, low-maintenance plants that reflect local characteristics. To ensure safety, appropriate setbacks should be maintained in curved sections during planting. As defined by Sim Van der Ryn and Stuart Cowan, ecological design refers to any design approach that aligns with natural ecological processes and reduces environmental harm.

5.2. Plant design strategies

Existing roadside vegetation, such as Tianzhugui trees and shrubs like Hongyeshinan, Fodinggui, and Chinese rose, should be preserved and supplemented. Additional plant species that are resilient, low-maintenance, and well-suited to the local environment, such as Muxunju, Begonia, Bougainvillea, Canna, and Winter Jasmine, should be introduced. Emphasis should be placed on increasing the use of Begonia, the regional flower, to establish a spring-themed landscape node centered around Begonia blooms, as shown in **Figure 1**.



Figure 1. Begonia's spring

The mountainous rural roads feature rugged terrain full of steep slopes and sharp turns, and the vegetation in the mountain area is lush. Therefore, visual obstacles may occur at the bends, thereby affecting the safety of vehicle travel. Hence, the importance of traffic safety should be emphasized during landscape design, and unsafe

factors should be eliminated as much as possible. Road signs cannot be covered by plants, especially at bends, where visual obstacles caused by forest vegetation should be reduced. Vegetation that does not obstruct the view should be planted reasonably ^[2].

6. Cultural protection countermeasures

A small thematic node should be created to highlight the cultural significance of Shuangshi's "Little Golden Dragon." Recognized in 2016 as a Chongqing Municipal Intangible Cultural Heritage Project, the "Little Golden Dragon" represents an important aspect of local tradition. Its emblem will be incorporated into the design by applying the logo onto the existing slope retaining wall, enhancing the cultural identity and visual interest of the area. An example is shown in **Figure 2**.



Figure 2. "Little Golden Dragon" in Shuangshi

Beautiful waterfront villages should be created as nodes, and the mural on the reservoir management house should be used to evoke nostalgia (**Figure 3**).



Figure 3. Waterfront villages with murals

A cultural post station named "Reminiscing Ancient Well" should be created to strengthen the protection of the regional cultural site "Jiaopen Well" and enhance cultural inheritance (**Figure 4**).



Figure 4. Cultural station “Reminiscing Ancient Well”

7. Facility improvement strategy

Considering the existing functions of the area, the landscape will be improved and upgraded based on these functions. The rest nodes will also be set up.

- (1) Guixiang post station: To meet the needs of parking and grain drying for current residents, the damaged pavement at the entrance will be repaved. The dwarfed *Osmanthus fragrans* on site will be retained, and landscape stones of beautiful villages will be set up to increase the identity of the site.
- (2) Nostalgia station: The site is currently a place for neighboring residents to rest and chat. The design fulfills and enhances the existing functions of the site, uses plants to increase the enclosure of the site, optimizes the pavement, and appropriately adds fitness facilities (**Figure 5**).
- (3) Ascend and look far: On the hills with good viewing effects near the road, design to add viewing pavilions and hiking trails, cleverly borrowing scenery (**Figure 6**).



Figure 5. Nostalgia station



Figure 6. Climbing high and looking far

8. Industry promotion strategy

The area surrounding the route features characteristic industries represented by the corn-soybean intercropping belt planting base, fruit hybrid orange base, and fruit plum planting base. The design incorporates these existing

industrial bases to create distinctive nodes:

(1) Mountains of oranges: Located at the entrance and exit of the Red Beauty picking orchard, the design incorporates decorative elements as highlights, using orange trees as a backdrop to enhance the atmosphere of the picking orchard, as shown in **Figure 7**.



Figure 7. Mountains of oranges

(2) The fragrant plum: Combining the fruit industry in Fushengqiao Village, creating a parking node that offers scenic viewing, rest areas, and supports the agricultural industry, to form a beautiful and fragrant parking node (**Figure 8**).



Figure 8. The fragrant plum

(3) A farm with rice and beans: As shown in **Figure 9**., the surrounding area of the retaining wall is an agricultural technology demonstration and exhibition base, mainly focusing on soybean and corn cultivation. The retaining wall primarily uses text to promote and emphasize modern agricultural technology. The taller section of the wall features acrylic house shapes, harvest-themed figures, and text displays, while the shorter section employs acrylic three-dimensional letters above it. This serves to highlight the soybean-corn strip intercropping technology demonstration and exhibition base. The letters are complemented by glass fiber reinforced plastic bean sprouts to add interest to the roadway.

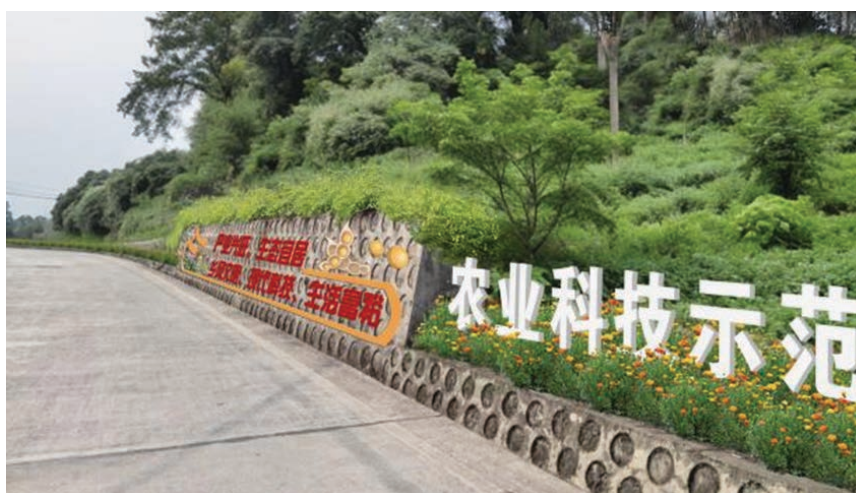


Figure 9. A farm with rice and beans

9. Conclusion

Rural roads connect villages and groups, linking urban and rural areas. The “Four Goods” rural roads carry people’s beautiful expectations for rural travel and open up the “last mile” for rural revitalization and farmers’ prosperity^[3].

The landscape design of the “Four Goods” rural roads requires understanding the region’s resources, culture, industrial development direction, and the needs of local residents. Designers need to conduct various research and communications to carry out targeted designs and implement practical measures. Moreover, the land use for the “Four Goods” rural design is limited and fragmented, requiring careful consideration in selecting nodes, using plants, and choosing materials.

The construction of the “Four Goods” rural roads brings tangible benefits to thousands of households. However, how to create thoughtful, people-centered designs that not only support local livelihoods but also highlight the beauty of engineering, culture, vegetation, and public facilities along these roads is a crucial question for every landscape designer to consider. Successfully addressing this “last mile” is both a challenge and a responsibility that landscape designers must actively embrace and reflect upon.

Disclosure statement

The author declares no conflict of interest.

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Design and Research of the Recliner for the Elderly

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Abstract: Chairs are the most common furniture in household environments, and reclining chairs specifically cater to the functional needs of the elderly. With the gradually increasing aging population, our preliminary research has revealed that current reclining chair designs often fail to align with the physical dimensions and needs of older adults. Many designs appear to prioritize technology over usability, resulting in a homogenous product landscape. Using statistical analysis and the weighted average method, an elderly-friendly reclining chair that considers height, depth, and width is designed. The final design aims to meet the psychological and physiological needs of self-care, semi-dependent, and fully dependent elderly individuals. Adhering to the “people-oriented” design philosophy and targeting “convenience and efficiency,” our ultimate goal is to create a reclining chair that helps the elderly lie down, stand up, and sit down with dignity. This innovative approach offers a new perspective for the market of aging-friendly furniture.

Keywords: Reclining chair; Self-care; Semi-dependent; Fully dependent; Aging-friendly

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1. Introduction

As China’s population aging process continues to deepen, building an aging-friendly society has become an important national strategic initiative. Based on the theoretical framework of actively mitigating aging, there is an urgent need to improve the multi-level elderly care service system through systematic institutional innovation, while ensuring the basic material supply and spiritual and cultural needs of the elderly population. The “14th Five-Year Plan” for National Elderly Care Development and Elderly Care Service System issued by the State Council clearly proposes the construction of a composite elderly care service system with “family-based elderly care as the foundation, community and home-based elderly care as the support, and institutional elderly care as the supplement.” This marks a new stage of institutional construction for China’s elderly care industry and provides essential guidelines for furniture design.

The reclining chair, as a carrier for spatial transformation for the elderly, has evolved from a single resting function to an aging-friendly product that supports the activities of the elderly. Guided by modern ergonomic principles, reclining chair designs integrate multiple functions through modular functionality, effectively

enhancing the independent living abilities of elderly users. In the field of aging-friendly product development, academia has formed multi-dimensional theoretical paradigms such as functional compensatory design, emotional design, and universal design. However, with the increasing diversification of user needs, current products still face issues such as inadequate human-machine adaptation and inappropriate integration of smart technology. There is an urgent need to establish an evaluation system based on evidence-based design to advance the “human-centered” innovation pathway for aging-friendly products and provide design insights for aging-friendly reclining chairs.

2. Research and issues regarding current elderly reclining chairs

2.1. Online research

2.1.1. Classification of online furniture

An online survey was conducted on 60 types of reclining chairs (**Table 1**). The results showed that they could be broadly classified into four categories based on their functions.

With the intensifying phenomenon of population aging and the iterative upgrading of aging-friendly infrastructure, this study conducted a multi-dimensional demand analysis of self-care, semi-dependent, and fully dependent elderly groups through digital user profiling techniques. The data indicated significant differences among these three groups in terms of ADL (Activities of Daily Living) levels, degrees of physical function decline, and reliance on assistive devices. When facing the needs of different populations, different design approaches should be considered. However, the current designs of reclining chairs on the market struggle to meet the physiological and psychological needs of the elderly.

Table 1. Online reclining chairs

Categories of recliners	Medical rehabilitation recliner	Multi-functional office recliner	Leisure recliner	Outdoor recliner
Backrest	Adjustable feature	Designed with user stability and safety in mind,	Adjustable feature	Adjustable feature
Armrests	Made of soft and easy-to-grasp material	Made of strong supportive material, adjustable,	Made of strong supportive material, adjustable	Made of strong supportive material
Cushion	Made of highly resilient and breathable material	Made of relatively comfortable material	Made of highly resilient and breathable material	Made of lightweight material
Smart system	Equipped with a rich smart system	Less introduction of smart systems	Less introduction of smart systems	Less introduction of smart systems
Assisted living	Good comfort, but does not take into account certain activities	Satisfies basic sitting and lying functions, but does not take into account certain activities	Satisfies basic sitting and lying functions, but does not take into account certain activities	Satisfies basic sitting and lying functions, but comfort is poor
Nursing care	Considers the needs of elderly people who sit for long periods, but there are few recliners on the market that fit the elderly, and the data is incomplete	The overall price is relatively cheap, not suitable for long sitting and lying, poor comfort	Good comfort, but cannot meet the nursing needs of elderly people under nursing care	Satisfies basic sitting and lying functions, but cannot meet the nursing needs of elderly people under nursing care
Self-care	Rich in functions, but the cost is too high in the range of recliners used by self-care elderly	Has long-term development experience, but cannot meet the special sizes of the elderly	Has more size data, but fewer sizes that fit the elderly	Satisfies outdoor considerations, but comfort is poor

2.1.2. Literature review

Li *et al.* introduced mechanization principles to address the outdoor needs of the elderly, making reclining chairs portable, lightweight, and comfortable ^[1]. Similarly, Zhou *et al.* studied facilities to assist the elderly in standing up based on ergonomics, using a combined simulation method of ADAMS and ANSYS ^[2]. Building upon functional enhancements, Li incorporated a PVC conveyor device into the design of reclining chairs, facilitating easy bed access for semi-dependent elderly individuals and providing a 180° transfer function for those who cannot self-care ^[3]. Cheng further contributed to innovation by revamping traditional bamboo reclining chairs, integrating new materials, and considering the design trend of multifunctionality and office space integration, offering new ideas for traditional reclining chair innovation ^[4]. In addition, Cui *et al.* emphasized the importance of intelligent systems for aging-friendly furniture, proposing a high-intelligence equipment core to create a comfortable and smart environment for the elderly ^[5]. To support user-centered design, Chen *et al.* analyzed ergonomic data of the elderly, summarizing the range of special sizes for this population ^[6]. Expanding on this, Liu introduced the concept of continuous furniture, matching furniture changes with the aging process of the elderly ^[7]. Huang *et al.* further proposed furniture designs suitable for the daily activities of the elderly, based on their psychological and physiological needs, using a healthcare center as a case study ^[8]. Pan also studied aging-friendly furniture, allowing the elderly to experience the convenience brought by intelligent systems ^[9]. Continuing this trend, Zheng *et al.* modified existing reclining chairs from the perspectives of overall appearance, material, and specific functions, achieving innovation ^[10]. Gao conducted precise research on four levels: scale, form, and color, modern intelligence, safety linkage, and alarm systems, providing data support for aging-friendly reclining chairs ^[11]. Moreover, Hu designed aging-friendly furniture that not only meets the special needs of the elderly but also considers the usage of other family members, improving the utilization rate of reclining chairs ^[12]. Lastly, Wei *et al.* combined traditional Chinese reclining chair manufacturing techniques with special data on the elderly, innovating within the tradition to design aging-friendly reclining chairs suitable for Chinese elderly individuals ^[13].

2.2. Current situation investigation

By analyzing offline market research results, the market's range of reclining chairs and development trends are explored. Based on the visualization analysis of market research data from the offline survey of the Red Star Macalline furniture market in Chongqing (**Figure 1**), there is a significant structural imbalance in the current smart home system integration field. Additionally, an Augmented Reality (AR) operation guidance system that aligns with the cognitive characteristics of the elderly has not been established. It is crucial to focus on breakthroughs in core technologies such as non-contact vital sign monitoring and pressure injury warning algorithms to fill the strategic gap in this market segment and meet the unmet, rigid, and potential long-term needs of the elderly population.

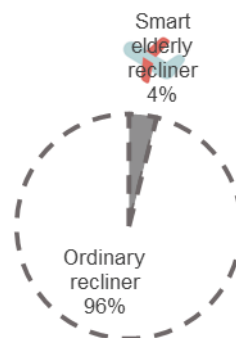


Figure 1. Proportion of smart features integrated into reclining chairs

A survey of 50 elderly people (**Figure 2**) (20 self-care elderly, 15 assisted elderly, and 15 nursing-care elderly) was conducted by distributing 50 questionnaires (Example 1). Among them, the eighth question asks, “What are the uncomfortable features of the reclining chair for you?” From the answers to this question, it can be seen that the two uncomfortable features of poor support (leading to difficulty getting up) and lack of adjustment function (difficult to fit the size of the elderly) account for a relatively large proportion. This can also reflect the growing demand of the elderly for reclining chairs on the market today, and the current market is lacking and ignoring solutions for this segment.

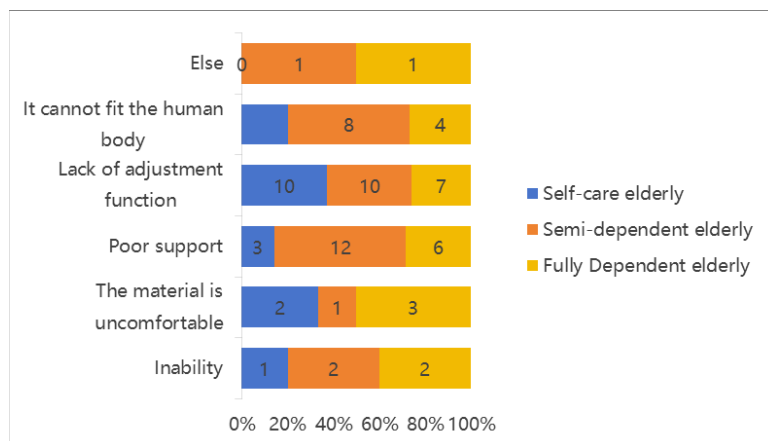


Figure 2. Scores on the uncomfortable features of reclining chairs

2.3. Problem statement

Furniture plays a crucial role in different types of spaces, not only providing practical functionality but also exerting a profound influence on the overall atmosphere and aesthetics of the space. Their functional design directly affects the quality of life and safety of the elderly. However, despite this, there are still some issues with aging-friendly furniture during use.

Firstly, according to Ji’s research on multi-position reclining chairs for the elderly, there are differences in ergonomic dimensions between the elderly and the general population, and existing designs of aging-friendly reclining chairs fail to fully adapt to the special needs of the elderly ^[14].

Secondly, in the face of the material and spiritual needs of the elderly, existing aging-friendly reclining chairs have a single function and ignore essential needs. Currently, the design industry lacks standardized data for aging-friendliness, and most reclining chairs on the market are targeted at a wide range of groups, making it difficult to meet the special needs of the elderly and ignoring their uniqueness, which is the essential demand of the elderly.

In addition, there is a phenomenon of “smart but not wise” in current smart furniture design. The elderly have a low acceptance of new technologies and a poor willingness to use them, resulting in inadequate “aging-friendliness” of smart elderly care products and poor user experience.

3. Mechanism analysis of current issues with elderly reclining chairs

Based on data from the seventh national census, which reveals an accelerating trend of population aging (with those aged 65 and above accounting for 13.5% of the total population), multiple issues have been exposed in the elderly reclining chair industry in the context of economic supply-side structural reform.

3.1. Industry emphasizes economic needs while ignoring quality needs

Over the past four decades of industrialization since China’s reform and opening up, the manufacturing industry

has achieved economies of scale through large-scale standardized production models and reliance on a factor-driven growth path. However, this development model has also given rise to multiple structural contradictions:

Firstly, cost optimization and quality imbalance are out of control, compressing overall product costs through value engineering analysis. Secondly, irrational market competition mechanisms lead to market equilibrium converging towards marginal cost pricing. From a long-term dynamic game perspective, industrial organization deteriorates into low-level repeated competition, resulting in triple failures of welfare economics in the elderly consumer market. In addition, there is a breakdown in user demand insight from a human factors engineering perspective. Due to the failure to integrate elderly physiological degradation curves and cognitive load theory into inclusive design, the usability and emotional design of the human-computer interaction interface are inaccurate in two dimensions, ultimately leading to an explicit deviation between product functionality and the physical comfort of elderly users.

Furthermore, customer asset maintenance fails under a service-dominant logic. Insufficient investment in after-sales service to reduce costs makes it difficult for elderly groups to obtain timely and effective solutions, ultimately leading to an unexpected increase in the discount rate of customer lifetime value. Lastly, the institutional quality signal transmission mechanism fails, and consumers face a sharp increase in information screening costs. This forms a failure of the Stackelberg separation equilibrium under the noise interference of quality signals, ultimately resulting in dual failures of the Pigouvian tax adjustment mechanism and Coasean property rights definition in market resource allocation.

3.2. Design emphasizes marketing needs, ignoring essential needs

With the development of the times, a humanistic paradigm of “ethical guidance and technological adaptation” has emerged within the framework of value-sensitive design. However, there is a dual paradox in the existing practice of embedding AI ethics, leading to a marginal decrease in ethical effectiveness at service contact points, which essentially constitutes a cognitive gap between technological utopia and design realism.

Firstly, the design lacks humanity. Designers overly pursue innovativeness in product appearance and functionality to attract consumers’ attention, thereby ignoring the actual usage needs of the elderly. Secondly, comfort is inadequate. To cater to the market’s pursuit of “high-tech” or “multi-functionality”, various additional functions are incorporated into the reclining chair during the design process. However, most of these added functions do not enhance usage comfort.

In addition, within the framework of degenerative physiological characteristics of the elderly population, existing products lack supportive designs for the compensatory mechanism of the locomotor system. Furthermore, in the process of formalizing the alienation of function principles, there is a mismatch between the utility functions of safety margin and aesthetic value in design decisions. Social interaction is not adequately considered. The design may not take into account the social needs of the elderly, such as the arrangement of reclining chairs that are not conducive to communication with family members, or the lack of communication device interfaces that are easy for the elderly to use. Lastly, sustainability and environmental awareness are weak. In material selection and production processes, environmental protection and sustainability may not be fully considered, which is inconsistent with the increasingly green lifestyle that modern consumers are paying attention to.

3.3. Production emphasizes efficiency needs, ignoring individual needs

In the rapid development stage of the manufacturing industry, in pursuit of higher production efficiency and cost reduction, enterprises often tend to adopt mass production methods. This approach emphasizes speed and efficiency, aiming to increase production volume through large-scale production and gain a dominant position in

the market. However, this production method also poses some problems.

Firstly, product quality is uneven, and there is a lack of innovation. The market offers few products with special indicators for elderly use, resulting in a poor handling of the relationship between supply and demand. Secondly, in the new era, although the requirement to promote high-quality development has been proposed, many enterprises still overly focus on efficiency and output in the actual production process, ignoring research on and satisfaction of individual needs. This has led to severe product homogeneity in the market, making it difficult to meet the increasingly diverse and individualized needs of consumers. Purchasing power declines, and the development of the aging-friendly market is slow.

In addition, the emergence of uniform products has become a phenomenon of the times, greatly hindering the appearance of personalized production products. It also makes it difficult to meet the individualized needs of special groups. Putting product efficiency first ignores the added value of products, leading to vicious competition among enterprises, and the market atmosphere needs to be improved. Therefore, while maintaining a certain production efficiency, the manufacturing industry needs to pay more attention to the research of market segments and the development of customized services to meet the specific needs of different groups and even individuals.

4. Optimal design strategies for elderly recliners

4.1. Focusing on individual dimensions based on demand characteristics

Meeting the basic material and spiritual needs of the elderly population is an important reflection of a country's comprehensive national strength. When designing for the special group of elderly individuals, it is essential to go beyond basic ergonomic dimensions and place greater emphasis on the specific physical and psychological requirements unique to this population. This includes, but is not limited to, features that support their independence and dignity, such as increased storage space, intuitive and easy-to-use controls, and accommodations that enable both semi-independent and fully independent elderly individuals to perform daily actions like sitting, lying down, and standing without assistance.

Additionally, design considerations should include specialized backrest proportions and tilt angles tailored to the aging body's needs. Sitting and lying account for most of the time consumed in the daily lives of elderly people. Fast and convenient designs can reduce the transition time between these three actions. Based on different dimensions of elderly people, a special ergonomics scope (**Table 2**) can be established, laying a good foundation for subsequent designs. Taking Zhong's survey as an example, it was found that there are significant differences in the dimensions of elderly people compared to ordinary people ^[15]. Therefore, in the design of recliners, we should consider the dimensions of the elderly more carefully and create a "people-oriented" design atmosphere for this special group.

Table 2. Basic dimensions of the elderly

Three types of elderly people	Wheelchair height	Wheelchair width	Wheelchair seat depth	Backrest height	Seat surface inclination
Nursing care	500–530 ^[18]	500–530	480–500 ^[18]	800–1200 ^[18]	0–60° ^[19]
Assisted care	520–550 ^[18]	520–550	490–520 ^[19]	800–1200 ^[19]	0–60° ^[19]
Self-care	420–425 ^[17]	420–425 ^[17]	330–350 ^[17]	400–408 ^[17]	5–10° ^[17]
Calculation formula/Based on data	$A1=(439+330)/2+30-7=408$	500–530mm, which is convenient for the elderly to wear thick clothes and place items, etc. ^[23]	Seat depth= $[H(W,5\%)+H(M,95\%)]$	$H=(830+665)/2=748\text{mm}$	0–60° ^[21] is a comfortable recliner seat surface

Table 1 (Continued)

Three types of elderly people	Seat surface inclination	Backrest inclination	Armrest height	Headrest height
Nursing care	0–60° ^[19]	20–180° ^[19]	240–250 ^[19]	500–600
Assisted care	20–180° ^[19]	240–250 ^[19]	500–650	325–360
Self-care	110–130° ^[17]	240–250 ^[17]	640–650 ^[17]	325–400 ^[17]
Calculation formula/ Based on data	20–180° to meet the needs of the elderly in different situations ^[22]	240–250mm, the most suitable distance between the ischial tuberosity and the armrest surface ^[22]	$H=(685+555)/2=620\text{mm}$	82–495mm, to ensure that the arms are naturally adducted and facilitate operation by the elderly ^[23]

4.2. Basic product dimension data

The formula for the ideal working surface of the product^[20] = $[H(W,5\%) + H(M,95\%)] / 2$, where $H(W,5\%)$ represents the sitting height dimension of 5% of Chinese elderly women (aged 60 and above), and $H(M,95\%)$ represents the sitting height dimension of 95% of Chinese elderly men (aged 60 and above). In practical design, issues such as clothing, posture, operation, and psychology of the elderly need to be further considered, so it is necessary to add a certain amount of correction to the theoretical dimensions.

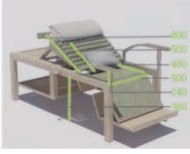


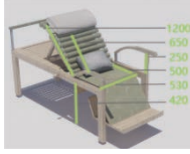

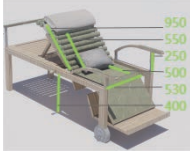

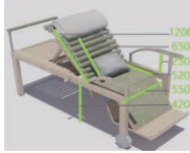
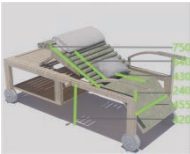
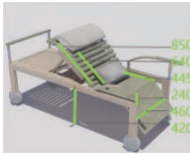
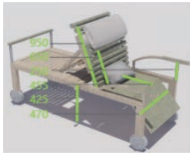
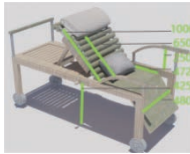
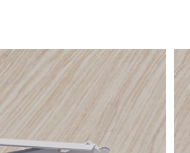


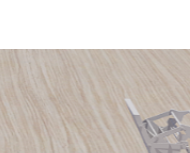
4.3. Focusing on diverse development based on group differences

By deeply understanding the needs and preferences of the elderly population, furniture can be designed that better fits their physical characteristics and lifestyle habits. For example, designing recliners for the elderly with adjustable angles, comfortable armrests, anti-slip functions, and moderate softness and hardness. Experts in ergonomics, furniture design, and geriatric medicine can be invited to evaluate and provide improvement suggestions for aging-friendly furniture, which can then be incorporated into the design to create a more scientific and reasonable recliner design. Liu proposal for furniture functionality can be referenced, using simple nouns to classify the basic attributes of furniture^[16].

The main functions for three types of elderly populations: self-care, nursing care, and assisted care, can be summarized and categorized. Through research on the needs of these three types of elderly people and analysis of different design approaches for different elderly individuals, design ideas can be tailored to their specific needs. For example, for nursing care elders who have lost most of their self-care abilities and require care from others, the main design focus is on how to make it easier for caregivers to care for them and provide them with more comfortable nursing. For assisted care elders who have partial self-care abilities, the recliner design should mainly focus on assisting them to live better. For self-care elders, the recliner design should mainly focus on adding more functional facilities based on existing living facilities (whether to introduce smart facilities is distinguished by their acceptance of new things).

By distinguishing and analyzing the overall needs of these three types of elderly people, adhering to the principle of people-oriented, starting from their needs, and grasping the particularity of contradictions, improvements and innovations can be made to the recliner design to create a recliner facility that better fits the elderly population. Based on the needs of these three types of elderly people, adjustments and modifications can be made to the recliner design, resulting in three different types of recliners (**Table 3**) and their internal settings (**Figure 3**) tailored to the needs of the elderly.

Table 3. Recliners of different sizes and angles for three types of elderly people

Applicable to	Level 1	Level 2	Level 3	Level 4
Nursing care				
	Wheelchair seat height: 360mm Wheelchair seat width: 500mm Wheelchair seat depth: 480mm Backrest height: 800mm Armrest height: 240mm Backrest inclination: 160° Seat surface inclination: 60° Headrest height: 500mm	Wheelchair seat height: 380mm Wheelchair seat width: 510mm Wheelchair seat depth: 480mm Backrest height: 950mm Armrest height: 250mm Backrest inclination: 140° Seat surface inclination: 40° Headrest height: 550mm	Wheelchair seat height: 400mm Wheelchair seat width: 520mm Wheelchair seat depth: 500mm Backrest height: 1100mm Armrest height: 250mm Backrest inclination: 100° Seat surface inclination: 60° Headrest height: 600mm	Wheelchair seat height: 420mm Wheelchair seat width: 530mm Wheelchair seat depth: 500mm Backrest height: 1200mm Armrest height: 250mm Backrest inclination: 120° Seat surface inclination: 60° Headrest height: 650mm
				
	Wheelchair seat height: 380mm Wheelchair seat width: 520mm Wheelchair seat depth: 490mm Backrest height: 800mm Armrest height: 240mm Backrest inclination: 160° Seat surface inclination: 60° Headrest height: 550mm	Wheelchair seat height: 400mm Wheelchair seat width: 530mm Wheelchair seat depth: 500mm Backrest height: 950mm Armrest height: 250mm Backrest inclination: 140° Seat surface inclination: 40° Headrest height: 550mm	Wheelchair seat height: 400mm Wheelchair seat width: 540mm Wheelchair seat depth: 510mm Backrest height: 1100mm Armrest height: 250mm Backrest inclination: 100° Seat surface inclination: 60° Headrest height: 600mm	Wheelchair seat height: 420mm Wheelchair seat width: 550mm Wheelchair seat depth: 520mm Backrest height: 1200mm Armrest height: 250mm Backrest inclination: 120° Seat surface inclination: 60° Headrest height: 650mm
Self-care				
	Wheelchair seat height: 420mm Wheelchair seat width: 455mm Wheelchair seat depth: 430mm Backrest height: 750mm Armrest height: 240mm Backrest inclination: 160° Seat surface inclination: 5–10° Headrest height: 640mm	Wheelchair seat height: 420mm Wheelchair seat width: 460mm Wheelchair seat depth: 445mm Backrest height: 850mm Armrest height: 240mm Backrest inclination: 140° Seat surface inclination: 5–10° Headrest height: 640mm	Wheelchair seat height: 425mm Wheelchair seat width: 470mm Wheelchair seat depth: 455mm Backrest height: 950mm Armrest height: 250mm Backrest inclination: 100° Seat surface inclination: 5–10° Headrest height: 650mm	Wheelchair seat height: 425mm Wheelchair seat width: 480mm Wheelchair seat depth: 472mm Backrest height: 1000mm Armrest height: 250mm Backrest inclination: 120° Seat surface inclination: 5–10° Headrest height: 650mm
				
	Wheelchair seat height: 420mm Wheelchair seat width: 455mm Wheelchair seat depth: 430mm Backrest height: 750mm Armrest height: 240mm Backrest inclination: 160° Seat surface inclination: 5–10° Headrest height: 640mm	Wheelchair seat height: 420mm Wheelchair seat width: 460mm Wheelchair seat depth: 445mm Backrest height: 850mm Armrest height: 240mm Backrest inclination: 140° Seat surface inclination: 5–10° Headrest height: 640mm	Wheelchair seat height: 425mm Wheelchair seat width: 470mm Wheelchair seat depth: 455mm Backrest height: 950mm Armrest height: 250mm Backrest inclination: 100° Seat surface inclination: 5–10° Headrest height: 650mm	Wheelchair seat height: 425mm Wheelchair seat width: 480mm Wheelchair seat depth: 472mm Backrest height: 1000mm Armrest height: 250mm Backrest inclination: 120° Seat surface inclination: 5–10° Headrest height: 650mm

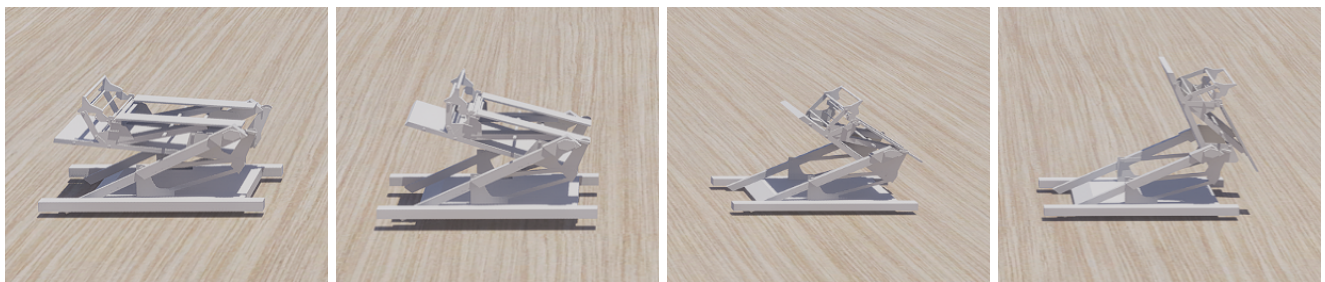


Figure 3. Internal devices of elderly recliners

4.4. Returning to design ethics based on scientific achievements

Based on the heterogeneity characteristics and digital divide effects of technology acceptance (TAM) among elderly groups, this study proposes a differentiated design framework for aging-friendly intelligent systems. The target users are divided into three categories based on their degree of nursing dependence, and differentiated design paradigms are established. Taking nursing care elderly as an example, the main design idea is to assist others in better caring for the elderly's daily life. A smart care ecosystem design model is adopted, with nursing efficiency optimization as the core goal. In terms of system architecture, a multimodal perception network (UWB positioning + flexible biosensor) and a distributed warning system (bed exit/fall detection algorithm) are deployed. In interaction design, a dual-end collaboration platform is constructed (the nursing end integrates a data visualization cockpit, and the family member end supports lightweight mini-program interaction).

For assisted care elders, the main design idea is how to better enable the elderly to take care of themselves and reduce the need for others to care for them. The system architecture is based on a multimodal perception fusion framework, integrating biological/environmental sensors and edge computing nodes. IoT data collaboration is achieved through the MQTT protocol, supporting scalable function modules such as fall warnings. In interaction design, a layered interaction system is constructed that integrates multimodal physical controls, AR visual guidance, and a dual-redundancy fault-tolerant mechanism. This ensures low learning costs and high system robustness through a composite operation layer of physical/voice/emergency devices, a three-step minimalist digital interface, and a self-healing logic for network disconnections.

For self-care elders, the essential demand source should consider the comfort of the recliner and the basic activities of self-care elders. In interaction design, a multimodal perception fusion architecture (biological/environmental sensors + edge computing nodes) and a layered redundant interaction system (AR guidance interface/three-step minimalist operation/composite layer of physical-voice-emergency controls) are adopted. From the system architecture perspective, modular health management function expansion is achieved through the MQTT protocol, and a dual-channel safety confirmation and network disconnection self-healing mechanism are integrated to ensure system reliability under low cognitive load. According to research results, the introduction of smart facilities is desired by the target population, with simplicity of operation, privacy protection, and manual assistance being the top three requirements (**Figure 4**). This also indicates the needs and future development direction of the elderly regarding the introduction of smart systems.

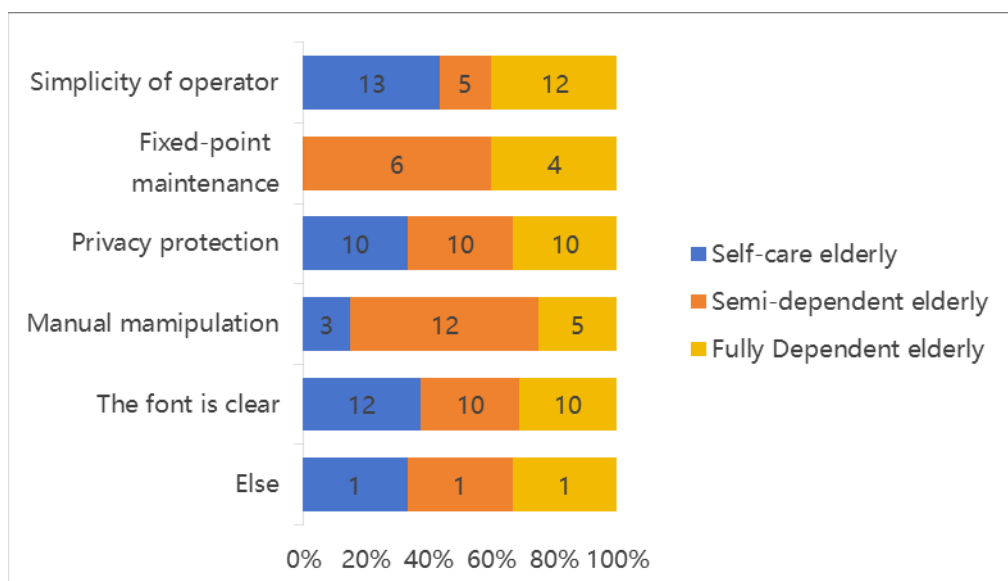


Figure 4. Results to the question “What are the hoped-for requirements for operating smart facilities?”

5. Conclusion

This study addresses the design challenges of recliner chairs for the elderly in an aging society. Through research and data analysis, a design solution more aligned with the needs of elderly users is proposed. Currently, most recliner chairs on the market suffer from poor fit, limited functionality, and difficulty in using smart technologies, making it hard to meet the diverse needs of self-sufficient, semi-dependent, and fully dependent elderly groups. In response, this study, based on the physiological characteristics and behavioral habits of elderly people, designs dimension standards tailored to different groups (such as seat height, backrest angle, etc.), and achieves precise service through modular functional design: focusing on caregiving support for fully dependent elderly, enhancing independent operation for semi-dependent users, and integrating lightweight smart health monitoring for self-sufficient individuals. At the same time, it emphasizes a “usability-first” interaction logic, adopting simple operation methods such as physical buttons and emergency calls to reduce the barrier for elderly users to adopt new technologies.

This design, centered on “practicality, comfort, and dignity,” not only solves the problem of poor ergonomic fit in traditional products but also avoids excessive integration of smart features. In the future, further exploration can be made into the application of eco-friendly materials and the expansion of aging-friendly scenarios, so that the recliner chair becomes not only a functional piece of furniture but also an emotional companion that enhances the quality of life in old age. Through this study, it is hoped to provide a reference idea for aging-friendly furniture design and to promote the industry’s transformation from “standardized production” to “personalized service,” allowing every elderly person to enjoy a comfortable later life through thoughtful design.

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Research on Engineering Quantity List Pricing and Project Cost Management of Construction Enterprises

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Abstract: In the increasingly competitive construction market, the engineering quantity list pricing model, as an important way of project cost management, is of crucial significance for construction enterprises to control costs and enhance benefits. This study deeply analyzes the characteristics of engineering quantity list pricing, and elaborates on the dilemmas faced by construction enterprises in project cost control, such as lagging concepts, imperfect mechanisms, weak risk management and control, and lack of construction-stage management. Based on this, from the dimensions of strengthening management and control concepts, improving supervision mechanisms, enhancing risk management and control capabilities, and attaching importance to construction-stage cost management, this study proposes project cost management and control strategies that are in line with the actual situation of construction enterprises, aiming to promote construction enterprises to achieve scientific management and optimization of project costs under the engineering quantity list pricing model.

Keywords: Engineering quantity; List pricing; Construction enterprises; Cost management

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1. Introduction

With the continuous advancement of the marketization process in the construction industry, the engineering quantity list pricing model has become the mainstream method of project cost management in China's construction market. This pricing model has changed the situation of government-led pricing under the traditional quota pricing model^[1]. It is market-oriented, giving enterprises more pricing autonomy. At the same time, it also puts forward higher requirements for the project cost management of construction enterprises. Under the engineering quantity list pricing model, construction enterprises need to independently determine the bid price based on their own technical levels, management capabilities, and market price information, and conduct full-process management and control of the project cost during the construction process to ensure the economic benefits of the project^[2]. However, at present, some construction enterprises in China still have many problems in project cost management and find it difficult to meet the requirements of the engineering quantity list pricing model, resulting in a disadvantageous position in market competition^[3]. Therefore, in-depth research on engineering quantity list

pricing and the project cost management of construction enterprises, and exploration of effective management and control strategies are of great practical significance for enhancing the market competitiveness and economic benefits of construction enterprises.

2. Characteristics of engineering quantity list pricing

The engineering quantity list pricing has distinct characteristics. Firstly, it is mandatory. Relevant national departments have developed unified engineering quantity calculation rules and pricing specifications, which require strict compliance in bidding, tendering, and project settlement to ensure the standardization and consistency of pricing. Secondly, this model is market-oriented. The comprehensive unit price in the list is independently determined by construction enterprises according to their actual situations and market conditions, fully reflecting the market competition mechanism and being able to truly reflect the market price of construction products. Furthermore, the engineering quantity list pricing is comprehensive ^[4]. It comprehensively considers the costs of engineering entity projects and measure projects, covering all costs such as labor costs, material costs, machinery costs, management fees, and profits required to complete the list items, making the composition of project costs clearer and more comprehensive. In addition, during the performance of the contract under the engineering quantity list pricing, when the engineering quantity changes, it can be adjusted according to the contract agreement, which has strong flexibility and is conducive to the reasonable sharing of project risks.

3. Current dilemmas faced by construction enterprises in project cost control

3.1. Lagging project cost control concepts

Some construction enterprises have a wrong understanding of project cost control. They still simply equate project cost management with cost control, only paying attention to the savings of direct costs during the construction process, and ignoring the impact of the project's pre-investment decision-making, design stage, and completion settlement stage on the project cost. In the pre-project stage, there is a lack of in-depth analysis of project feasibility and precise control of investment estimation, resulting in cost overruns during the project implementation process ^[5]. At the same time, the importance attached to project cost management within the enterprise is insufficient. It has not been incorporated into the enterprise's strategic management category, and there is a lack of systematic project cost management concepts and methods, making it difficult to achieve full-process and dynamic management of project costs.

3.2. Imperfect project cost control mechanisms

Many construction enterprises have not established a perfect project cost control mechanism. In terms of organizational structure, there is a lack of specialized project cost management departments or positions, and the responsibilities of various departments are not clearly defined, resulting in a buck-passing phenomena during the project cost management process. In terms of system construction, there is a lack of perfect project cost management systems and processes. There are no clear standards and specifications for various links, from bid pricing, contract signing, to cost control during the construction process, project change management, and completion settlement, making the project cost management work lack an effective institutional guarantee. In addition, the internal supervision and assessment mechanism of the enterprise is imperfect, unable to scientifically evaluate the work performance of project cost management personnel, and it is difficult to mobilize their work enthusiasm and initiative ^[6].

3.3. Lack of risk management and control awareness

During the project cost management process, construction enterprises have insufficient awareness of risks and a weak risk management and control awareness. In the bidding stage, to win the bid, enterprises often blindly lower their bids without fully considering the risks brought by market price fluctuations, project changes, force majeure, and other factors, resulting in cost-out-of-control situations during the project implementation process. During the construction process, in the face of risks such as rising material prices and construction delays, there are no effective countermeasures, and it is impossible to adjust and control the project cost in a timely manner^[7]. At the same time, enterprises do not manage contract risks well. During the contract signing process, they do not carefully review the contract terms, and do not clearly stipulate some possible risk points, resulting in disputes during the contract performance process and increasing the difficulty of project cost management.

3.4. Lack of construction-stage management and control

The construction stage is a crucial stage for the formation of project costs, but construction enterprises have many problems in the management and control of this stage. In terms of construction organization design, there is no scientific and reasonable planning based on the actual situation of the project, resulting in resource waste, construction delays, and other situations during the construction process, increasing project costs^[8]. In terms of material management, there are problems such as unreasonable procurement plans, lax inspections, and poor warehousing management, causing material waste and cost increases. In terms of project change management, the approval process for changes is not strict, and the design and construction plans are changed at will, increasing engineering quantity and project costs. Additionally, construction enterprises often lack dynamic monitoring of project costs during the construction process, making it difficult to identify and address issues in project cost management in a timely manner.

4. Project cost management and control strategies for construction enterprises under the engineering quantity list pricing model

4.1. Strengthening project cost management and control concepts

Construction enterprises should establish a comprehensive project cost management and control concept and integrate project cost management throughout the entire project process. In the pre-project stage, it is necessary to strengthen the management of the investment decision-making stage. Through in-depth market research and feasibility analysis, reasonably determine the project investment estimate to lay a foundation for the smooth implementation of the project. In the design stage, actively participate in the optimization of the design plan. Through methods such as value engineering, reduce project costs on the premise of ensuring project quality and functions.

At the same time, project cost management should be incorporated into the enterprise's strategic management system to improve the awareness of all employees in the enterprise about project cost management and form a good atmosphere of full-staff participation and full-process management. By carrying out training and publicity activities, enhance the project cost management awareness and professional capabilities of employees, so that each employee can consciously participate in project cost management in their work and contribute to reducing costs and increasing benefits for the enterprise.

4.2. Strengthening the internal supervision mechanism of enterprises

Construction enterprises should establish and improve the organizational structure of project cost management, set up specialized project cost management departments, and clearly define the responsibilities and authorities of

various departments and positions to ensure the smooth progress of project cost management work ^[9]. Improve the project cost management system and process, and develop detailed operation specifications for each link, from bid pricing, contract signing to construction process management, project change control, and completion settlement, so that the project cost management work has rules to follow. Strengthen the internal supervision and assessment mechanism of the enterprise, establish a scientific and reasonable performance assessment index system, regularly assess and evaluate the work performance of project cost management personnel, and link the assessment results with salaries to fully mobilize their work enthusiasm and initiative. At the same time, strengthen the internal audit of project cost management work, timely discover and correct problems in the project cost management process, and ensure the standardized and efficient operation of project cost management work ^[10].

4.3. Improving the risk management and control level of construction enterprises

Construction enterprises should enhance their risk management and control awareness and establish a perfect risk early-warning mechanism. In the bidding stage, conduct a comprehensive risk assessment of the project, fully consider the risks brought by market price fluctuations, project changes, force majeure, and other factors, and reasonably determine the bid price to avoid winning the bid at a blindly low price. During the construction process, pay close attention to market dynamics, timely master the changes in material prices, labor costs, and other situations, and take effective risk response measures, such as signing fixed-price contracts and hedging materials, to reduce the impact of market risks on project costs ^[11]. Strengthen contract risk management by thoroughly reviewing contract terms before signing. Clearly define the rights and obligations of both parties and specify potential risk points to prevent contract disputes. Additionally, establish a risk emergency plan to ensure that, in the event of a risk occurrence, prompt measures can be implemented to respond effectively and minimize losses.

4.4. Focusing on cost management and control during the construction stage

4.4.1. Compiling quotas for competitive construction enterprises

Construction enterprise quotas are important bases for enterprises to make bid prices and control costs. Enterprises should compile construction enterprise quotas that are in line with their actual situations by combining their own technical levels, management capabilities, and construction experience. During the compilation process, fully consider factors such as the enterprise's construction technology, mechanical equipment configuration, and personnel quality to ensure the scientificity and rationality of the quotas ^[12]. By continuously collecting and analyzing project data, dynamically adjust and optimize the enterprise quotas so that they can accurately reflect the actual cost level of the enterprise and improve the competitiveness of the enterprise in bid pricing. At the same time, construction enterprise quotas can also provide a reference for the enterprise's cost control during the construction process, helping the enterprise to timely discover cost deviations and take measures to adjust.

4.4.2. Project cost management and control in bid pricing

In the bid-pricing stage, construction enterprises should deeply study the bidding documents and engineering quantity lists, and accurately understand the requirements and intentions of the tenderer. Carefully analyze the project characteristics and engineering content in the engineering quantity list, and reasonably determine the calculation standards for various costs in combination with the actual situation of the enterprise. When determining the comprehensive unit price, fully consider factors such as market price fluctuations, enterprise management levels, and profit targets to ensure that the bid price is not only competitive but also ensures the economic benefits of the enterprise. At the same time, pay attention to the application of bidding strategies. According to the characteristics of the project and the situation of competitors, select appropriate bidding methods, such as the unbalanced bidding method and the multi-scheme bidding method, to increase the winning rate ^[13]. In

addition, during the bid-pricing process, strengthen the review of bidding documents to ensure the accuracy and completeness of the bid price and avoid economic losses caused by bidding errors.

4.4.3. Strengthening construction management to reduce costs

During the construction process, construction enterprises should strengthen the management of construction organization design. According to the characteristics and actual situation of the project, develop scientific and reasonable construction plans and progress schedules, optimize resource allocation, improve construction efficiency, and reduce construction costs^[14]. Strengthen material management, establish a perfect system for material procurement, inspection, warehousing, and requisition, reasonably determine the quantity and time of material procurement, and reduce material procurement costs. At the same time, strengthen the monitoring of the material use process, strictly control material consumption, and avoid material waste. In terms of mechanical equipment management, reasonably configure mechanical equipment, improve the utilization rate and integrity rate of mechanical equipment, and reduce the use cost of mechanical equipment. In addition, strengthen the management of construction personnel, improve the skill level and work efficiency of construction personnel, and through a reasonable salary incentive mechanism, mobilize the work enthusiasm of construction personnel and reduce labor costs.

4.4.4. Change and visa management

Strictly standardize the management process of project changes and visas, and establish an approval system for project changes and visas. Before a project change occurs, fully demonstrate the necessity and feasibility of the change, evaluate the impact of the change on the project cost, and implement it only after approval by relevant departments and personnel. During the implementation of the project change, strengthen the measurement and review of the changed engineering quantity to ensure the accuracy of the changed engineering quantity. For project visas, handle them in a timely manner. The visa content should be true, accurate, and complete, and be signed and confirmed by relevant personnel. At the same time, establish a project change and visa ledger to record the change and visa situations in detail, which is convenient for verification and review during project settlement and avoids the increase of project costs caused by poor management of changes and visas^[15].

4.4.5. Construction technology informatization management and control

Actively introduce advanced information technology and build an information platform for project cost management. Use the information platform to achieve real-time collection, storage, analysis, and sharing of project cost-related data, and improve the efficiency and accuracy of project cost management. By establishing information tools such as engineering quantity calculation software and cost analysis software, achieve rapid calculation and dynamic analysis of project costs, and timely discover problems in project cost management. At the same time, use the information platform to strengthen the monitoring of the construction process, achieve real-time tracking and management of construction progress, quality, costs, and other information, and provide strong support for project cost management. In addition, through the information platform, strengthen communication and collaboration with construction units, supervision units, and other relevant parties, timely solve problems in the project cost management process, and improve the synergy and effectiveness of project cost management.

5. Conclusion

Under the engineering quantity list pricing model, the project cost management of construction enterprises is a complex systematic project. Facing the many dilemmas in current project cost control, construction enterprises

need to start from multiple aspects, such as strengthening management and control concepts, improving supervision mechanisms, enhancing risk management and control capabilities, and attaching importance to construction-stage cost management, and take effective management and control strategies. By continuously improving the project cost management system and enhancing the project cost management level of enterprises, it is possible to effectively control costs and maximize economic benefits in the fierce market competition, and promote the sustainable development of enterprises. In the future, with the continuous development of the construction industry and changes in the market environment, construction enterprises still need to continuously explore and innovate project cost management methods to better adapt to the requirements of industry development.

Disclosure statement

The author declares no conflict of interest.

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Design Strategies for the Renovation of Arcade Buildings From the Perspective of Zen Aesthetics

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Abstract: As a unique symbol of regional culture, the arcade building carries rich historical memories and cultural connotations. In the process of urban renewal, how to reasonably renovate it so that it can meet modern living needs while preserving cultural continuity has become an important issue. Chan aesthetics, with its unique philosophical ideas and aesthetic concepts, offers new perspectives and approaches for the renovation of arcade buildings. This paper delves into the core principles of Chan aesthetics, combining the characteristics and current status of arcade buildings, to explore design strategies for the renovation of arcade buildings based on Chan aesthetics from dimensions such as spatial creation, material application, decorative design, and cultural inheritance. The aim is to provide theoretical support and practical guidance for the sustainable development of arcade buildings.

Keywords: Zen aesthetics; Arcade architecture; Architectural renovation; Design strategy

Online publication: May 29, 2025

1. Introduction

Riding buildings are widely distributed in the Southern coastal areas of China and Southeast Asia, serving as a product of multicultural integration. They combine commercial, residential, and public activity spaces, witnessing the rise and fall of cities, and possess immense historical, cultural, and artistic value. However, with the development of the times, traditional riding buildings face issues such as functional obsolescence, spatial deactivation, and difficulties in integrating with modern urban environments. Zen aesthetics emphasize nature, ethereality, simplicity, and inner peace, which align closely with the goals of modern architecture, such as harmony between humans and nature and the creation of spiritual space. Introducing Zen aesthetics into the renovation of riding buildings can help uncover their deeper cultural value, creating architectural spaces that blend traditional charm with modern quality.

2. The core connotation of Zen aesthetics

2.1. View of nature: Learning from nature and uniting man and nature

Zen aesthetics revere nature, viewing it as the source and ultimate destination of all things ^[1, 2]. It advocates that

humans should follow natural laws and live in harmony with nature. In architecture, this is reflected in the respect and use of natural elements, such as introducing natural light, air, water, and plants, making buildings part of nature^[3]. This achieves an organic integration of architecture and nature, reaching the realm of “harmony between heaven and humanity.” This natural perspective opposes excessive artificial embellishment, pursuing mutual dependence and coexistence between architecture and its environment^[4].

2.2. Ethereal meaning: The interplay of reality and illusion, simplicity and ethereality

Etherealness is a crucial aesthetic characteristic of Zen aesthetics, emphasizing the conveyance of infinite spiritual essence through finite space and form^[5]. It seeks a minimalist, pure spatial atmosphere, creating an understated and profound ambiance through techniques such as negative space and borrowed scenery. In this ethereal space, people can break free from worldly constraints, achieving inner peace and freedom, experiencing a spiritual transcendence beyond the material realm^[6].

2.3. Simple spirit: Return to truth, simplify complexity

Zen aesthetics advocate a simple and unadorned spirit, opposing luxury and complexity^[7]. It emphasizes returning to the essence of things, removing unnecessary embellishments and forms, presenting their true nature in a simple and pure manner. In the selection and use of building materials, it focuses on the natural texture and original color of the materials, showcasing their raw beauty. In architectural form and decorative design, it pursues simplicity and elegance, avoiding excessive decoration, reflecting a sense of plainness and purity^[8].

3. Characteristics and current situation analysis of arcade buildings

3.1. Characteristics of arcade buildings

The unique spatial form of the arcade building generally consists of a ground-level arcade corridor, upper residential or commercial spaces, and a roof^[9]. The arcade corridor is continuously connected, forming a semi-open public space that not only provides shelter from wind and rain for pedestrians but also facilitates interaction between the street and the interior of the building^[10]. The upper space is compactly laid out with clear functional zoning, typically connected to the ground floor via stairs^[11, 12]. This distinctive spatial form adapts to the climate characteristics and commercial activity needs of southern regions, showcasing distinct regional features^[13].

Diverse architectural styles, the arcade buildings integrate elements of traditional Chinese architecture, Nanyang architectural style, and Western building techniques, forming a multifaceted architectural style. In terms of appearance, they feature both the intricate carvings and painted beams, bracket sets, and overhanging eaves characteristic of Chinese architecture, as well as the gables and louvers typical of Nanyang style^[14]. They also incorporate Western architectural components such as columns and arches^[15]. This fusion of diverse styles reflects the cultural exchanges and collisions experienced by arcade buildings throughout their historical development, endowing them with unique artistic appeal^[16].

3.2. The current problems of the arcade building

3.2.1. Functional obsolescence and spatial inactivity

As society evolves and lifestyles change, the functions of traditional arcade buildings gradually fail to meet modern needs. The ground-floor commercial spaces, due to their limited size and poor layout, struggle to attract modern business formats. Moreover, the residential spaces suffer from inadequate lighting, ventilation, and hygiene facilities, which leads to lower living standards^[17]. Meanwhile, due to a lack of effective updates and management, many arcade building spaces remain idle, losing their former vitality and becoming “lost spaces” in

urban development^[18].

Building damage and cultural loss, eroded by time and unreasonable renovations, have led to structural damage, wall peeling, and missing decorative elements in some arcade buildings^[19]. Moreover, during the process of urban modernization, historical and cultural elements of some arcade buildings have been overlooked or destroyed, blurring traditional architectural styles and regional cultural characteristics. This has put the cultural memory and humanistic connotations embodied in arcade buildings at risk of being lost^[20].

4. Design strategies for the renovation of arcade buildings from the perspective of Zen aesthetics

4.1. Space creation strategy

The introduction and integration of natural elements follow the Zen aesthetic view of nature, actively incorporating natural elements in the renovation of arcade buildings to achieve harmony between architecture and nature. Small landscape ponds and green plants are set up in the ground-floor arcades and corridors, creating a tranquil and natural atmosphere. The gentle flow of water in the ponds not only regulates the microclimate but also adds a sense of vitality to the space. The introduction of green plants softens the hard surfaces of the building, purifies the air, and allows people to feel the vitality and energy of nature as they walk through. At the same time, by reasonably designing internal spaces such as courtyards and atriums, natural lighting and ventilation are increased, allowing sunlight and air to freely circulate within the building, forming a spatial layout that resonates with nature.

The creation of ethereal spaces employs the Zen aesthetic technique of creating an ethereal atmosphere to shape a simple and airy arcade building space. In terms of spatial layout, unnecessary partitions and divisions are minimized, adopting open or semi-open design concepts to enhance spatial fluidity and transparency. By setting up large glass curtain walls or transparent grilles, the interpenetration between indoor and outdoor spaces is achieved, allowing people to experience changes in the natural landscape from indoors. At the same time, the technique of leaving blank areas is used reasonably, creating appropriate empty zones in the space that invite imagination, fostering a tranquil and profound ambiance. For example, in the public rest areas of arcade buildings, simple seating and minimal decoration are provided, conveying an ethereal atmosphere through a minimalist spatial layout, enabling people to relax their minds and bodies and find inner peace here.

4.2. Material application strategy

The selection and expression of natural materials, based on the simple spirit of Zen aesthetics, prioritize the use of natural materials such as wood, stone, and blue bricks in the renovation of arcade buildings. Wood has a warm texture and natural grain, providing a sense of warmth and comfort, suitable for doors, windows, stairs, and railings. Stone is durable and robust, with its natural texture and color, ideal for flooring and wall decoration, conveying a sense of stability and weightiness. Meanwhile, the blue bricks, commonly used in traditional arcade architecture, have an ancient hue and unique quality that evokes memories of history. In renovations, original blue brick walls can be preserved or restored, or used for partial decoration to continue the historical charm of the arcade. Throughout the process of material application, emphasis is placed on showcasing the raw texture and natural appearance of the materials, avoiding excessive processing and embellishment, allowing the natural beauty of the materials to be fully expressed.

The harmonious coexistence of old and new materials is inevitable in the renovation of arcade buildings, where modern building materials such as steel and glass are used. To achieve the harmony and unity pursued by Zen aesthetics, attention should be paid to the combination and integration of old and new materials, achieving a harmonious coexistence through contrast. For example, based on retaining the original blue brick walls, steel

structures are used as the supporting system. The simplicity of the steel structure contrasts sharply with the ancient simplicity of the blue bricks, yet they complement each other, showcasing a dialogue between tradition and modernity. Glass curtain walls are set at the entrance or public spaces of the building, where the transparency of the glass complements the heavy texture of the surrounding natural materials. This not only enhances the modern feel of the space but also preserves the overall ancient atmosphere.

4.3. Decoration design strategy

The creation of a minimalist decorative style adheres to the Zen aesthetic principle of simplification. In the design and decoration of arcade buildings, it discards intricate and complex decorative elements in favor of a simple and elegant style. It reduces unnecessary carvings and moldings, focusing instead on clean geometric lines and shapes to highlight the structural and formal beauty of the building. For example, in window and door designs, it uses simple window frames and glass partitions, avoiding excessive decorative patterns. As for wall decorations, it can use simple colors or textures as accents, creating a simple yet refined atmosphere. Through this minimalist decorative style, arcade buildings return to their essential functions and forms, showcasing a plain and pure beauty.

The refinement and application of cultural symbols, the arcade buildings carry rich regional cultural connotations. In decorative design, emphasis should be placed on the refinement and application of regional cultural symbols to inherit and promote local culture. Delve into the historical and cultural elements embedded in arcade buildings, such as auspicious patterns in Chinese style and mountain flower designs in Nanyang style. After simplifying and abstracting these cultural symbols, they can be applied to architectural decorative components like lighting fixtures, railings, and signboards. By skillfully using cultural symbols, not only can the cultural recognizability of arcade buildings be enhanced, but they can also add unique cultural charm to the architecture, allowing people to appreciate the beauty of regional culture while admiring the buildings.

4.4. Cultural inheritance strategy

The preservation and recreation of historical memory, Zen aesthetics emphasize respect and the inheritance of tradition. In the renovation of arcade buildings, it is important to focus on preserving and recreating their historical memory. Protecting and restoring architectural components, decorative elements, and spatial layouts with historical value ensures that they truly reflect the historical appearance of arcade buildings. For example, repairing damaged carved doors and windows, pediments, and other decorative elements while retaining the original architectural structure and spatial scale allows people to intuitively experience the historical changes of arcade buildings. At the same time, by setting up cultural history exhibition areas and museums, the development process, cultural connotations, and related historical artifacts and documents of arcade buildings can be showcased, enabling future generations to better understand and inherit the historical memory carried by arcade buildings.

The integration of modern life with traditional culture, while preserving historical and cultural heritage, combines the needs of modern life with traditional culture to endow arcade buildings with new vitality and functions. In terms of functional layout, modern commercial, cultural, and leisure activities such as specialty bookstores, cafes, and art studios are introduced, making arcade buildings an urban public space that integrates cultural experiences and recreational entertainment. At the same time, traditional cultural elements are incorporated into architectural space design, such as hosting traditional folk activities and cultural exhibitions, allowing traditional culture to continue and develop in modern life, achieving an organic fusion of history and the present.

5. Case analysis: Haikou Qilou street renovation project

The renovation project of the arcade district fully draws on the aesthetic concepts of Zen Buddhism, achieving

excellent results. In terms of spatial creation, designers have set up small landscape flower beds on both sides of the arcade corridors, planting local specialty plants such as *Bougainvillea* and banyan trees, infusing the corridors with natural vitality. At the same time, the internal courtyards of some arcade buildings have been renovated, adding water features and rest facilities, creating tranquil and comfortable public spaces inside. By removing unnecessary partition walls, the spaces between adjacent buildings have been connected, enhancing the continuity and transparency of the space, thus creating a serene atmosphere.

In the use of materials, a large number of original blue brick walls and wooden doors and windows have been retained, with damaged parts repaired and replaced to restore their ancient simplicity. At the same time, modern materials such as steel and glass have been used in new public facilities and decorative elements. For example, a landscape pavilion combining steel structure and glass has been set up at the entrance of the block. The simple lines of the steel structure contrast sharply with the transparent quality of the glass, forming a striking contrast with the surrounding blue brick arcade buildings while also blending harmoniously, showcasing the harmonious coexistence of tradition and modernity.

In terms of interior design, a minimalist style is adopted, removing the original intricate decorations and outlining the building with simple geometric lines. For lighting design, traditional Chinese lantern shapes are used, which, after simplification, retain cultural elements while meeting modern aesthetic requirements. Additionally, murals reflecting local history and culture are painted on the building's walls, using simple lines and understated colors to showcase the development of arcade architecture and regional cultural characteristics.

In terms of cultural heritage, a Qilou culture museum has been established within the district, showcasing the historical evolution, architectural features, and related folk culture of Qilou buildings. Traditional folk activities such as dragon and lion dances, opera performances, and others are regularly held, attracting many residents and tourists to participate, making the Qilou area an important venue for inheriting and promoting local culture. Through these renovation measures, the Qilou area has not only regained its former vitality but also become a cultural landmark of the city, achieving an organic combination of historical and cultural value with modern functionality.

6. Conclusion

Zen aesthetics provide unique design ideas and methods for the renovation of arcade buildings. By introducing natural spaces, creating ethereal spaces, using natural materials, fostering a minimalist decorative style, and integrating historical and cultural heritage, these design strategies can effectively address issues such as functional aging, spatial deactivation, and cultural loss in arcade buildings, achieving their sustainable development. In actual renovation processes, it is essential to fully understand the core essence of Zen aesthetics and combine them with the characteristics of arcade buildings and regional cultural features. These design strategies should be applied flexibly to create spaces that are rich in traditional cultural heritage while meeting modern living needs. Additionally, the renovation of arcade buildings is a systematic project that requires joint efforts from the government, designers, residents, and other stakeholders. Enhancing conservation awareness, increasing financial investment, and paying attention to detail are crucial for rejuvenating arcade buildings in urban renewal, making them important carriers for inheriting regional culture and showcasing urban charm.

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Design and Finite Element Analysis of a New Type of Skeleton-Free, Traversing Secondary Lining Trolley

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Abstract: To effectively address the challenge where the speed of tunnel lining construction struggles to match that of tunnel face and inverted arch construction, and to enhance the quality of secondary lining, a new type of skeleton-free, traversing secondary lining trolley has been developed. This trolley features a set of gantries paired with two sets of formwork. The formwork adopts a multi-segment hinged and strengthened design, ensuring its own strength can meet the requirements of secondary lining concrete pouring without relying on the support of the gantries. When retracted, the formwork can be transported by the gantries through another set of formwork in the supporting state, enabling early formwork support, effectively accelerating the construction progress of the tunnel's secondary lining, and extending the maintenance time of the secondary lining with the formwork. Finite element software modeling was used for simulation calculations, and the results indicate that the structural strength, stiffness, and other performance parameters of the new secondary lining trolley meet the design requirements, verifying the rationality of the design.

Keywords: Tunnel; Secondary lining trolley; Skeleton-free; Traversing; Finite element analysis

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1. Introduction

With China's increased investment in infrastructure construction and the development of urban transportation, tunnel projects such as subways, railway tunnels, highway tunnels, and urban utility tunnels have developed rapidly ^[1-5]. As the main equipment for tunnel lining construction using the drilling and blasting method, the technical level of the secondary lining trolley directly restricts the construction quality and progress of the tunnel ^[6, 7].

Traditional secondary lining trolleys basically use a gantry to support the formwork and bear the load of secondary lining concrete pouring ^[8]. The supporting rods are densely distributed, resulting in high work intensity and limited vehicle access space ^[9]. The ideal monthly construction efficiency of the secondary lining can only reach about 180m. In the case of long tunnel construction, it is difficult to keep up with the excavation efficiency of the tunnel face and inverted arch, affecting the overall construction progress of the tunnel ^[10].

Given the mismatch between the tunnel lining construction line, the excavation line of the tunnel face, and the inverted arch construction line, traditional secondary lining trolleys cannot meet the comprehensive efficiency

of tunnel construction ^[11]. Through improvements to the traditional secondary lining trolley structure, based on the 350km/h high-speed railway tunnel section, this article studies a new type of traversing skeleton-free secondary lining trolley. Innovatively, the supporting role of the gantry during the secondary lining pouring process is eliminated, and the formwork structure is strengthened.

The stability of the structure during secondary lining concrete pouring can be ensured by using the internal rod support of the formwork, expanding the internal access space. The gantry structure and function have been improved, and the gantry function has been changed from bearing the secondary lining concrete load to bearing the formwork's own weight. The gantry carries the formwork forward and allows two sets of formwork to pass through each other, which can effectively accelerate the construction progress of the tunnel's secondary lining, increase the maintenance time of the secondary lining concrete with the formwork, and improve the quality of the secondary lining concrete in alpine regions.

2. Design proposal and key technologies

2.1. Design proposal

The traversing skeleton-free secondary lining trolley mainly consists of traversing formwork (two sets), a carrying gantry, a traveling mechanism, a screw rod assembly, auxiliary structures, a hydraulic system, and an electrical system, as shown in **Figure 1**. The trolley adopts a skeleton-free design, and the traversing formwork can meet the strength and rigidity requirements of secondary lining concrete pouring without additional supporting skeletons. The formwork in the retracted state can be carried by the gantry to pass through another set of formwork in the supporting state, achieving alternating lining construction. The advantage is that the second board lining construction can be carried out without removing the formwork of the first board lining, realizing continuous construction of the secondary lining concrete and improving construction efficiency.

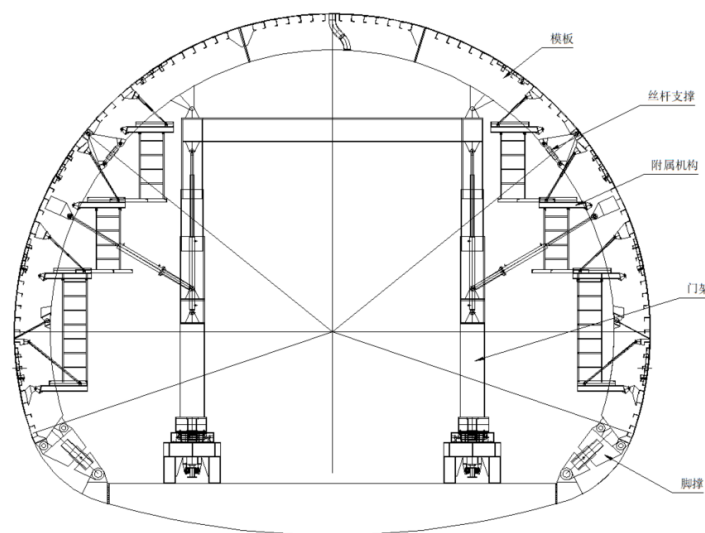


Figure 1. Overall scheme of the traversing type secondary lining trolley without framework (Translation from left to right: Template; Screw support; Auxiliary support; Door frame; Foot support)

2.1.1. Design of the traversing formwork

Compared with traditional formwork, the traversing formwork can bear the load of secondary lining concrete pouring without relying on the gantry, and its internal clearance can allow another formwork in the retracted state to pass through.

There are two sets of traversing formwork with the same structure, which is arched. Each set of formwork includes a top formwork, two shoulder formworks connected at both ends of the top formwork, two side formworks connected below the shoulder formwork, a flipping formwork connected to the side formwork, and bottom foot supports. The shoulder formwork and side formwork are connected in a way that allows the formwork to be extended and retracted. Through the gantry, foot supports, and auxiliary devices, the formwork can be extended and retracted, allowing it to alternately traverse between the formwork and achieve continuous secondary lining construction.

The bottom foot supports are supported on the inverted arch fill layer. During the secondary lining pouring process, it is necessary to strictly control the pouring speed and height difference of concrete on both sides to balance the lateral pressure on both sides of the formwork. The formwork itself has relatively high rigidity, which can transmit the lateral force at the arch waist positions on both sides to the inside, ultimately canceling each other out. The vertical concrete pressure at the arch top position is transferred through the formwork to the bottom screw rod supporting the ground, maintaining the overall stability and rigidity of the structure during the secondary lining pouring process. The schematic diagram of the formwork structure in the working state is shown in **Figure 2**.

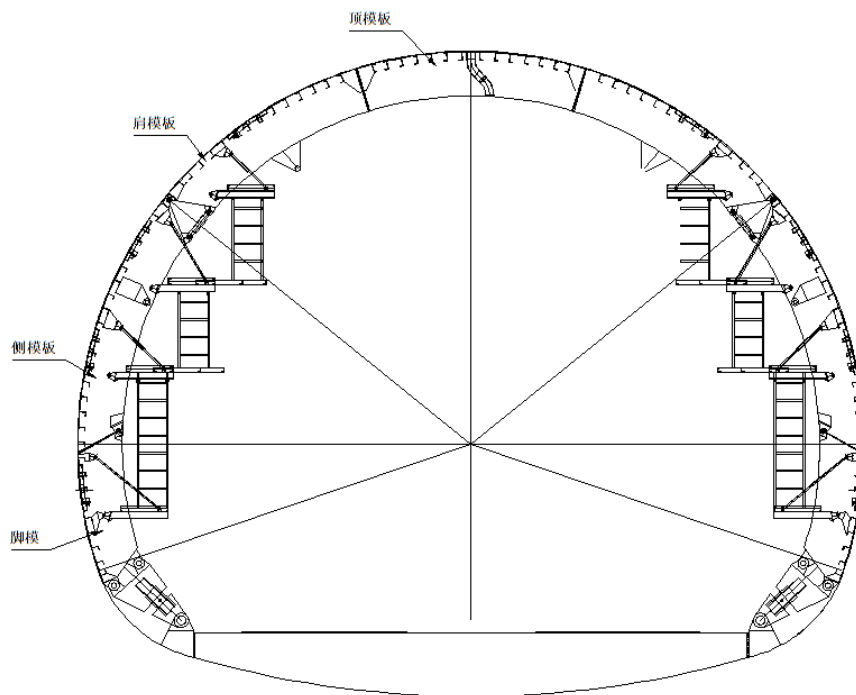


Figure 2. Schematic diagram of traversing formwork structure (Translation from left to right: Foot mold; Side mold; Shoulder mold; Top mold)

2.1.2. Design of the carrying gantry

Compared to traditional trolley gantries, the carrying gantry only bears the weight of the trolley itself and no longer assists the formwork in bearing the casting load. At the same time, it adopts a flexible connection with the formwork, allowing for quick installation and removal.

The carrying gantry employs a large gantry structure that can be raised and lowered separately. It consists of two sets of front and rear columns equipped with large-stroke lifting mechanisms that can operate in tandem or independently. The top of the gantry is equipped with hinged ear seats to support the formwork. The columns are connected by longitudinal beams and truss beams to form an integrated structure, enhancing the overall stability and rigidity of the structure. The lower end of the gantry is equipped with a transverse lifting mechanism and a

traveling mechanism, along with a self-feeding track function. The customized track is suspended on the traveling mechanism through supporting wheels. The carrying gantry can be adjusted in the transverse, longitudinal, and height directions, assisting the traversing formwork in actions such as formwork support, formwork removal, and movement. When the formwork deviates from the centerline or during curved tunnel construction, the formwork can be adjusted to the correct position with the help of the gantry's transverse shifting mechanism. The schematic diagram of the gantry structure is shown in **Figure 3**.

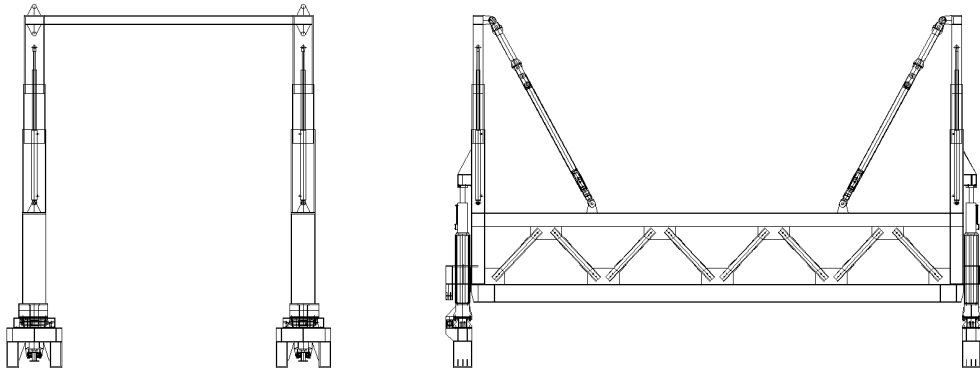


Figure 3. Schematic diagram of the structure of the carrying gantry

2.2. Key technologies

2.2.1. Formwork under-passing technology

Formwork under-passing refers to the process where the formwork in the retracted state passes through and advances under the formwork in the supported state, enabling alternating construction. The main challenge lies in spatial limitations. The external formwork structure of the traversing formwork is divided into three sections: the top form, side form, and flipping form. The formwork adopts foldable platforms and ladders. During formwork support and casting, workers operate on the ladder platform. During the solidification period after casting is completed, the ladder and platform are folded and stored inside the waistboard of the formwork, not occupying internal space. When the other formwork is retracted, the flipping form rotates 160 degrees around the hinged ear, the side form rotates 20 degrees around the hinged ear, and the top form descends 1.8 meters. At this time, the minimum clearance between the outer contour of the retracted formwork and the supported formwork is 21cm, enabling traversal under the carrying of the gantry, as shown in **Figure 4** and **Figure 5**.

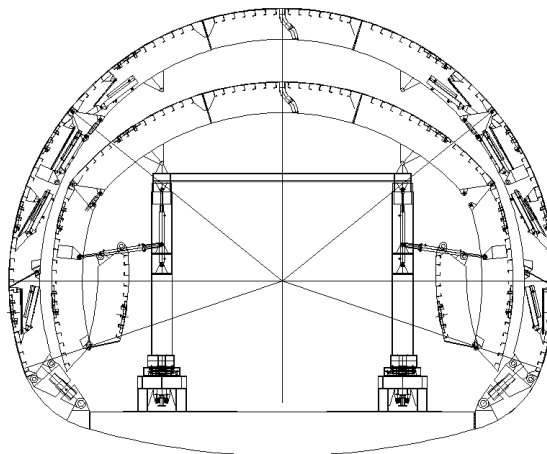


Figure 4. Front view of the gantry carrying formwork passing through

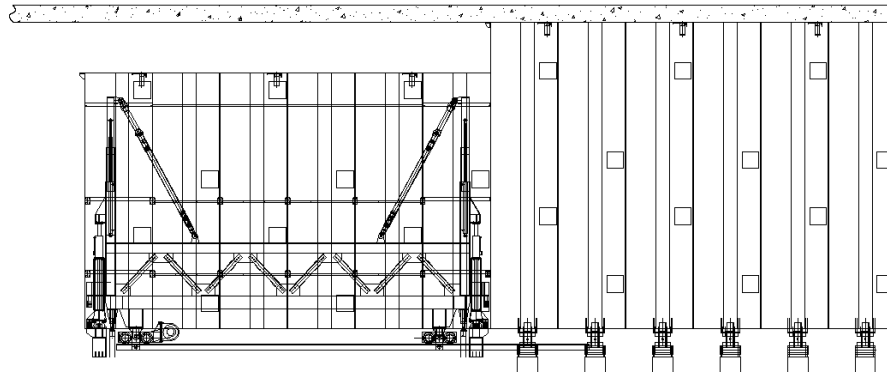


Figure 5. Side view of the gantry carrying formwork passing through

2.2.2. Rapid construction technology

The traversing skeleton-free secondary lining trolley solves the problem of traditional secondary lining trolleys being unable to remove the formwork for the next board lining construction before the concrete strength reaches the standard through continuous construction with two sets of formwork. This greatly improves construction efficiency. The process follows a cyclic sequence: support of formwork 1, concrete casting, retraction and under-passing of formwork 2, support of formwork 2, casting, retraction and under-passing of formwork 1, followed by the next support of formwork 1. The specific steps are as follows:

- (1) Formwork 1 forms a stable overall structure through screw rods and hydraulic cylinders, and the connection between the gantry and formwork 1 is released.
- (2) Concrete pouring operations for formwork 1 begin.
- (3) The gantry travels to the underside of formwork 2 and connects with it.
- (4) The side forms of formwork 2 are retracted, and the top form is lowered, reducing the outer contour size to allow traversal within formwork 1.
- (5) The gantry carries formwork 2 through formwork 1 to the next secondary lining construction position. The gantry assists in completing the formwork support for formwork 2, as shown in **Figure 6**. After formwork support, the connection between the gantry and formwork 2 is released.
- (6) Concrete pouring operations for formwork 2 begin.
- (7) After formwork 2 completes the pouring, the gantry travels to the underside of formwork 1 and connects with it, assisting in formwork removal.
- (8) The gantry carries formwork 1 through formwork 2 to the next secondary lining construction position. After the gantry assists in completing the formwork support for formwork 1, the connection between the gantry and formwork 1 is released.

By repeating the above operations, the two formworks alternate in traversal, working continuously until the tunnel secondary lining construction is completed.

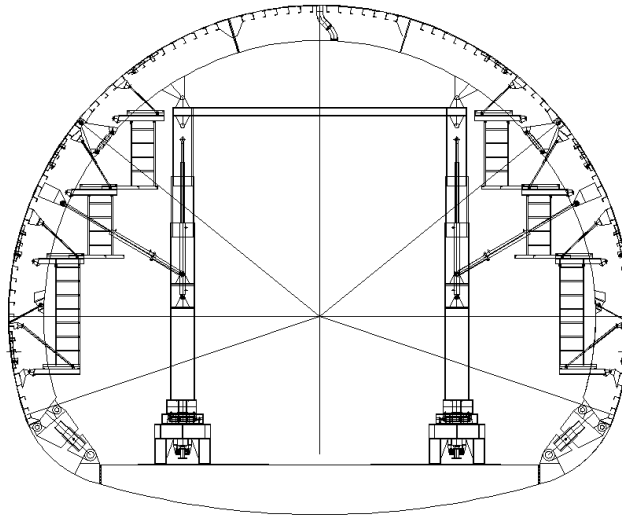


Figure 6. Front view of gantry auxiliary formwork

3. Finite element calculation

3.1. Calculation of mechanical parameters

The design effective lining length of the traversing skeleton-free trolley is 12m, and the thickness of the formwork panel is 12mm. The strength and rigidity of the main stressed components of the trolley are checked to verify whether the mechanical properties of the trolley can meet the requirements of use ^[12, 13].

(1) Calculate the pressure generated by the concrete on the top formwork. The pressure on the top formwork is mainly lateral pressure, and the effective pressure head height is calculated as shown in Formula (1).

$$h = 1.53 + 3.8 v/T \quad (1)$$

Calculate the maximum lateral pressure generated by the concrete on the top formwork as shown in Formula (2).

$$P_1 = \gamma h \quad (2)$$

In the formulas: P_1 - The maximum lateral pressure on the top formwork caused by the freshly poured concrete; γ - The volumetric weight of concrete (KN/m^3), $\gamma = 24 \text{ KN/m}^3$; T - The temperature of the concrete when poured into the formwork ($^{\circ}\text{C}$), where $T = 20^{\circ}\text{C}$ in the formula; v - is the concrete pouring speed (m/h). Due to the reduced arc slope during top formwork pouring, the pouring speed is taken as 1 m/h . When calculating the side formwork, the concrete pouring speed is taken as 2 m/h .

Using Formula (2), the maximum lateral pressure on the top formwork caused by concrete is calculated as $P_1 = 41.28 \text{ KN/m}^2$.

(2) The pressure exerted by concrete on the side formwork is shown in Formula (3).

$$P_2 = 0.22 \gamma T \beta_1 \beta_2 v^{1/2} \quad (3)$$

In the formula: P_2 -The lateral pressure on the side formwork caused by freshly poured concrete; β_1 - Correction coefficient for the influence of admixtures. When no admixture is added, it is taken as 1.0. When adding a retarder admixture, it is taken as 1.2. The influence of admixtures is considered in the calculation; β_2 - Correction coefficient for the influence of concrete slump speed. When the slump is less than 30mm, it is taken as 0.85; 50–90mm, taken as 1.0; 110–150mm, taken as 1.15. For calculation purposes, it is taken as 1.15.

When calculating the side formwork load, the impact load P_3 generated by pouring concrete should also be considered, taking $P_3 = 4 \text{ KN/m}^2$.

(3) The maximum lateral pressure on the side formwork of the trolley during pouring is calculated as shown

in Formula (4).

$$P_4 = P_2 + P_3 \quad (4)$$

Using Formula (4), the maximum lateral pressure on the side formwork during pouring is calculated as $P_4 = 64.4 \text{ KN/m}^2$. The calculated loads are applied as uniformly distributed pressure to the corresponding top and side formwork.

3.2. Analysis of simulation calculation results

When the skeleton-free secondary lining trolley is operating, the formwork relies on its own structure to bear the load of the secondary lining concrete, while the gantry does not bear any load and is therefore not involved in the calculation. **Figure 7** shows the finite element model of the trolley in working condition. The finite element calculation results are shown in **Figure 8** and **Figure 9**, with a maximum stress of 114 MPa and a maximum deformation of 2.5 mm.

The main structural steel of the secondary lining trolley is Q235B carbon structural steel, with a gravity density of 78.5 KN/m^3 and an elastic modulus of 206 GPa. Referring to the “Steel Structure Design Standards” (GB5017-2017), the structural strength safety factor is taken as 1.5, and the allowable stress $[\sigma]$ is 156 MPa. According to the finite element calculation results, the maximum stress of 114 MPa during the trolley’s working state is less than the allowable stress $[\sigma]$, indicating that the strength meets the design requirements. The maximum deformation of 2.5 mm also satisfies the design specifications.

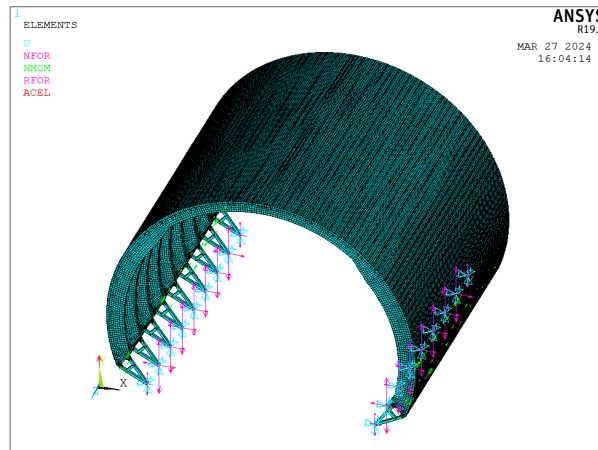


Figure 7. Finite element model of trolley without framework

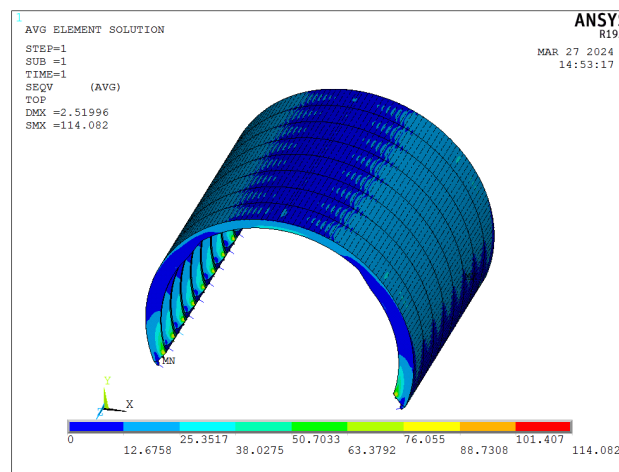


Figure 8. Stress calculation results

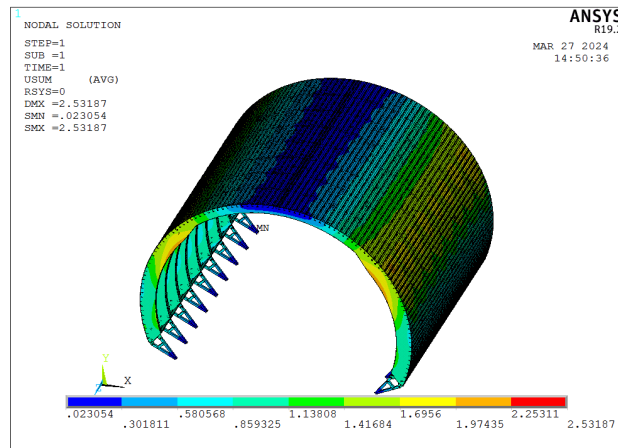


Figure 9. Deformation calculation results

The force models used in the above mechanical analysis process are calculated using simplified methods that tend to be safe. After analysis, each component can meet the force and deformation requirements.

4. Conclusion

Through the application of the traversing skeleton-free secondary lining trolley, continuous operation of the secondary lining can be achieved, enabling dynamic support construction. The efficiency of secondary lining construction has been improved from one form (12m) every two days to one form per day, accelerating the progress of tunnel construction.

By using one set of gantries to transport two sets of formwork for interchangeable and alternating construction, the curing time of the secondary lining concrete with the form can be increased, significantly improving the forming quality of the secondary lining concrete in alpine regions.

The new traversing skeleton-free secondary lining trolley can accelerate the efficiency of tunnel secondary lining construction, help improve the efficiency and quality of tunnel construction, ensure safe step distances during tunnel construction, reduce variable costs, and enhance economic and social benefits.

Disclosure statement

The author declares no conflict of interest.

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Architecture is Made for People, A Holistic-Phenomenological Approach to Architecture: A Case Study of Kibbutz Ma'agan Michael, Israel

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Abstract: The aim of this article is to present my interpretation of the holistic-phenomenological worldview in practice. This study demonstrates how this approach, as well as the planning process that I followed (a process fundamentally different from conventional ones) was implemented in a residential neighborhood I designed and built in the social, economic, and physical structure of the collective known in Israel as a 'kibbutz'. The intention is to raise a broad public discussion and pose a challenge to 21st-century architecture regarding how to intervene in a moral and human way within an existing environment, urban or natural, which must be respected and preserved, when integrating within it a new contemporary architecture.

Keywords: Holistic; Phenomenology; Architecture; Kibbutz; Residential neighborhood

Online publication: June 4, 2025

1. Introduction

The aim of this paper is to present my interpretation of the holistic-phenomenological worldview in practice, through a selected project I designed and built in Israel. This worldview stands in recent years at the forefront of the scientific discourse as a whole in disciplines like cosmology, neurobiology, psychology, particle physics, and brain sciences, and is linked to recent theories of complexity, and is in convergence with the fundamentals of Buddhist teaching^[1].

The purpose of architecture is, first and foremost, to create a human environment for human beings. The real challenge of current architectural practice is to make the best use of the potential inherent in our modern technological age. Yet, modern society has lost the value of man and thus created a feeling of alienation between man and the environment.

Buildings affect human lives and the fate of the physical environment in which they live over the course of many years, and therefore, their real test is the test of time. The great buildings, villages, and temples in which man feels 'at home', the places to which people always long to return to, thus with timeless relevance are the

ones that touch the hearts and have the power to create a deep emotional experience. There are different ways to describe buildings that have this timeless quality, buildings that convey an inherent spiritual experience. Frank Lloyd Wright called them “the ones which take you beyond words”. Quoted by Stephen Grabow, Christopher Alexander says: “The buildings that have spiritual value are a diagram of the inner universe or the picture of the inner soul” ^[2]. Stephen Grabow, in “Christopher Alexander: The Search for a New Paradigm in Architecture”, explores this concept of timeless quality. The Dalai Lama refers to this same essence as “the great self” or “the nature of reality”, as described in “The Joy of Living and Dying in Peace” ^[1].

Although this timeless quality exists in buildings rooted in different cultures and traditions, the emotional experience they generate is common to all people, no matter where or from what culture they come from. Thus, Christopher Alexander’s basic assumption was that behind human architecture there are universal and eternal codes common to us all as human beings, and that there is absolute truth underlying beauty and comfort that reflect the “innate patterns”, a term borrowed from Chomsky’s theory of spoken language, which suggests these patterns are already embedded in the human mind ^[3].

Contemporary architecture (and art) sought to dissociate themselves from the world of emotions and connect the design process to the world of ideas, thus creating a rational relation between building and man, devoid of any emotion.

The basic argument presented here is that in order to change the feeling of the environment and create places and buildings that truly feel like home and are desirable to live in, what is needed is not a change of style or fashion, but a transformation of the mechanistic worldview underlying current thought and approaches ^[4].

This presentation demonstrates how this approach, along with a unique planning process derived from it and deeply rooted in the spirit of the place, was applied by me in the design of a residential neighborhood in Kibbutz Ma’agan Michael, facing the Mediterranean Sea. The process was generated from spatial patterns that have consistently underpinned human experience in all timeless buildings and was carefully tailored to the distinct physical and social context of the site (**Figure 1** and **Figure 4**).

It is hoped that by presenting an approach, which tries both to identify and base the design process on those spatial patterns that generate a positive feeling shared by people of all cultures ^[5], as well as apply a planning process which structurally responds to the identity of each cultural and social group it is build for, it will contribute something towards replacing current conceptions and approaches, whereby unhuman alienated architecture derived only by the egotistical ambitions of the creator forms a real threat to the physical and human environment we live in.



Figure 1. Panoramic view of the neighborhood

2. Structural changes in Kibbutz life require a new concept of housing

2.1. From quantitative uniformity to qualitative equality

The social, economic and physical structure of the collective known as a 'kibbutz' was founded in Israel in the early 20th century. Its uppermost value since its very beginning was equality, translated in most realms of community life not as equality of opportunities, in its qualitative sense, but rather in its quantitative sense, as formal uniformity. This dogmatic equality obliterated the self-identity and uniqueness of the individual and saw him only as part of the collective.

In recent years, however, this old conception of equality has been redefined in many respects. The social structure reverted back to the nuclear family, with children raised at home, and no longer in a communal house where they were regarded as the possession of the community as a whole. Wages, previously based on the notion that every member contributed according to his or her own ability, but was supported according to his or her needs, have now become differential, based on one's contribution.

Housing in the kibbutz is perhaps the last fortress of the old and simplistic conception of equality, a conception that now more than ever can change. According to this conception, houses are regarded as static models of predetermined uniform shape, arbitrarily positioned on the building site. Environmental factors, such as the direction of light or the angle open to the view on any specific plot, are disregarded, and the result is that all houses have an identical plan, including the same elevations. Thus, a tenant whose window happens to face the orchard has the advantage on the one whose window faces the cow shed.

This approach created a qualitative inequality between the houses and inequality of opportunities among the tenants. Moreover, the outcome of this dogmatic approach was that houses built in the desert environment of the Negev, or the hilly Galilean environment was exactly the same.

The new model I implemented in the design of the new houses in kibbutz Maagan Michael was fundamentally different. The planning process adopted was based on patterns that were common to all the houses, patterns that grew out both of the social structure of the kibbutz and the geographic location facing the sea. When these common patterns were used in different site conditions, a variety of houses emerged, sharing one architectural language. (**Figure 2** and **Figure 3**)



Figure 2. House type A



Figure 3. House type B

Kibbutz Ma'agan Michael is situated on a hill, with the new neighborhood on the Western side that faces the sea (**Figure 4**).

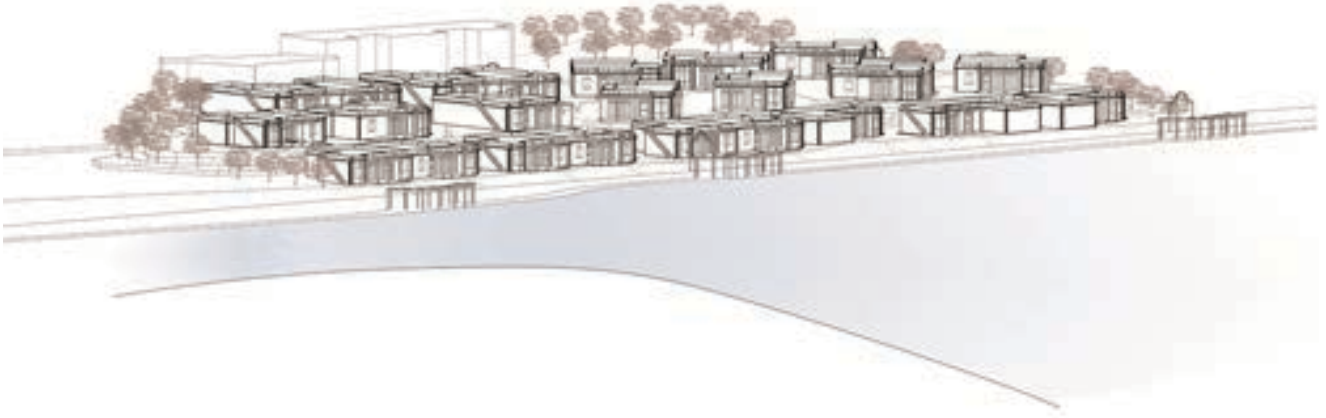


Figure 4. To determine the level of each house so that one could see the sea while sitting on the terrace, I used a crane to lift me up to where I could see the sea.

Each planning decision, from the positioning of the house on the site, through the determination of the direction of its entrance in relation to the path, and unto the location of each window, was taken on the site of each plot. (**Figure 5**)



Figure 5. Each planning decision was taken on the site literally marked on the ground

The position of each house in relation to the others was determined to ensure that each one has an open view to the water and can enjoy the breeze coming from the sea (**Figure 6**).

To determine the height of each house so that the sea would be visible from the terrace while seated, a crane was used to lift and identify the exact elevation at which the sea became visible. This height was measured, and the level of the house was determined accordingly. (**Figure 7**)

At the center of the neighborhood, a path was planned to connect the promenade that runs along the water and the path that runs from the communal dining hall at the heart of the kibbutz to the neighborhood.

The course of the path was guided by the intention to ensure a view of the sea from every point along its length (**Figure 8**).



Figure 6. The position of each house was determined on the site, in relation to the other houses, to ensure an open view to the sea



Figure 7. View of the water from a house's terrace



Figure 8. What dictated the course of the path was the wish to see the water from every spot along it.

The houses were arranged in small clusters, sharing a communal open space. Unlike the traditional pattern in the kibbutz, where all open spaces, called 'the lawn', are communal and the buildings are dispersed arbitrarily in between, here the secondary paths running between the houses defined in a non-formal way, with no fences, the "private" zone of each family (**Figure 9**).

This sense of "private territory" unexpectedly created a new reality in which each family started to grow its own garden. This new pattern of behavior could not have developed in the traditional model, where the open spaces in between the houses were planned as a property used and maintained by everyone, and therefore of no one.

At this stage the site plan was completed. The position of each house in the neighborhood in relation to the paths and its position in relation to the sea produced different types of house plans. On plots where the entrance from the path was in the same direction as the sea view, type A plan emerged (**Figure 10**).

On plots where the entrance was from the opposite direction of the sea view, type B plan developed, and the entrance was through the opposite side of the garden and living areas (**Figure 11**).



Figure 9. The "private" zone of each family (new in the collective) defined in a non-formal way by the paths running between the houses generated a new pattern of behavior where each family started to grow its own garden.



Figure 10. House type A; The entrance to the house from the path is through the garden. Both are in the direction of the sea view.



Figure 11. Type B - Entrance floor. The entrance to the house from the path is from the opposite side of the garden and has a direct view to the sea through the living room and dining area.

In front of each house there is a bicycle rack (the only means of transport allowed within the boundaries of the kibbutz). Next to the entrance door, a place for muddy boots was allocated, a prominent symbol of the kibbutz. The walls are all whitewashed light blue, complemented by regionally quarried sandstone characterizing the construction details. The introduction of a conceptually new model in a very rigid social framework became possible now as a result of an overall change in the reality of the kibbutz communities, a change that was inevitable in the twenty-first century.

3. Conclusion

It is my hope that a holistic phenomenological approach will guide the creation of buildings, streets, neighborhoods, cities, and villages that people truly want to live in and feel at home in, across all cultures, places, and times. This would replace current conceptions and approaches that pose a real threat to both the physical and human environment we live in.

Disclosure statement

The author declares no conflict of interest.

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Research on Multi-Functional Excavation Trolley for High-speed Railway Double-Track Tunnel

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Abstract: With the rapid development of high-speed railway tunnel construction mileage and technology, the construction of the tunnel face is a key part of tunnel construction in high-speed railway tunnel projects. As mechanization and intelligence levels continue to increase, supporting equipment mainly includes rock drilling trolleys, arch installation trolleys, wet spraying robots, anchor trolleys, etc. To address the issues of high construction costs and the need to replace equipment for different processes, this paper designs an economical and practical multi-functional integrated trolley for high-speed railway double-track tunnels based on engineering cases. This trolley can adapt to various tunnel face excavation methods such as the full-face method and the bench method, enabling integrated functions such as drilling and blasting holes, anchor holes, advance grouting holes, pipe roof construction, charging, anchor installation and grouting, and arch mesh installation. This reduces the number of operators, improves the working environment of high-speed railway tunnels, lowers construction costs, and enhances construction efficiency.

Keywords: High-speed railway; Double-track tunnel; Excavation trolley; Full-face method; Bench method

Online publication: June 5, 2025

1. Introduction

Currently, China's railway construction is developing rapidly. It is estimated that by 2035, the national railway network will reach an operating mileage of about 200,000 kilometers, including about 70,000 kilometers of high-speed railway ^[1]. During the construction of railways in the Central and Western regions, a large number of complex geological conditions and long tunnels have emerged, posing higher requirements for the safety, efficiency, and quality controllability of high-speed railway tunnel construction ^[2]. In this context, the construction of high-speed railway tunnels should keep up with the pulse of the times, widely apply new technologies, new equipment, and new materials, promote the deep integration of the new generation of information technology and tunnel construction technology, and facilitate the development of the railway industry. Developing new tunnel equipment and promoting the application of new equipment and new processes will help drive technological innovation in the field of tunnel construction.

Currently, there are mainly two construction methods for tunnel face construction. One is to use a working

platform, mainly relying on manual operations. The advantage of this method is its flexibility and adaptability, especially suitable for complex and varying surrounding rock conditions, and it is relatively efficient ^[3]. However, manual operations have high intensity and risk, especially with the rapid growth of labor costs, and the continuous development and innovation of construction equipment manufacturing technology, the advantages of manual excavation compared to drilling jumbos have ceased to exist. The second method is mechanized construction using drilling jumbos as the main construction equipment ^[4]. The advantage of this method is its fast construction speed and reduced labor, but the equipment is expensive, has a single function, and has high usage and maintenance costs, making it difficult to form an advanced mechanized operation line in most projects.

Tunnel construction is gradually developing towards mechanization, automation, and intelligence to improve construction quality, safety, and efficiency. For complex strata, to achieve requirements such as “quality, safety, schedule, and environmental protection,” it is necessary to comprehensively consider tunnel length, section size, surrounding rock geology, excavation method, schedule requirements, environmental and site conditions, and reasonably configure construction machinery to achieve economic applicability and overall efficiency ^[5].

Based on the analysis and research of existing construction methods and equipment, it is necessary to develop a multifunctional tunnel construction equipment that integrates multiple functions, such as tunnel drilling and arch installation. This equipment not only facilitates workers to load explosives but also allows other process equipment to pass through the gantry, significantly improving the efficiency of tunnel excavation using the drilling and blasting method. Compared with traditional equipment, this multifunctional equipment can effectively reduce equipment procurement and maintenance costs for tunnel construction, facilitate equipment scheduling in narrow tunnels, and save time and labor. The adoption of integrated equipment will significantly improve the excavation speed, ensure construction safety, reduce the operational complexity caused by numerous equipment, optimize the construction process, improve construction accuracy, and ensure the quality of the tunnel section.

2. Scheme design and key technology research

2.1. Scheme design

The high-speed rail dual-track multifunctional integrated excavation trolley is designed based on a 350km/h high-speed rail dual-track tunnel. It can be applied to full-face excavation method and bench excavation method, realizing the integration of auxiliary manual pneumatic drill blasting holes, anchor rod holes, charge loading, anchor rod installation and grouting, arch frame mesh installation, and other work. It mainly consists of a traveling mechanism, a platform frame, a movable arch frame, an arch frame lifting mechanism, an arch frame raising mechanism, an arch frame installation mechanism, auxiliary mechanisms, an electrical system, and a hydraulic system ^[6]. **Figure 1** shows the mobile arch frame in a retracted state while **Figure 2** shows the mobile arch frame in a extended state.

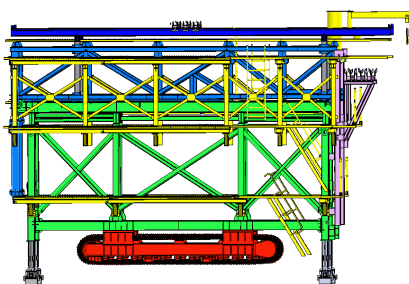


Figure 1. Mobile arch frame retracted state

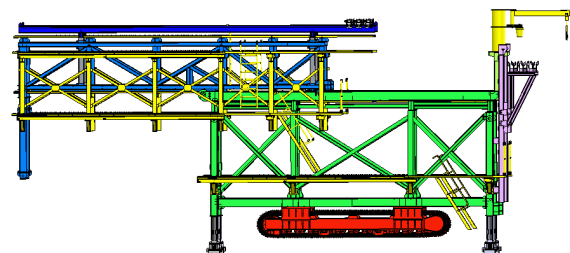


Figure 2. Extended state of the mobile arch frame

2.2. Research on key technologies

(1) Research on movable arch frame

Figure 3 shows the schematic diagram of the movable arch. The movable arch frame consists of a framed structure composed of 4 sets of arch frames and longitudinal beams. The lower end of the arch frame is equipped with a load-bearing track connected to the gantry beam. The load-bearing track is equipped with tugboats and reverse hanging wheels, which are driven by chains to achieve relative movement between the arch frame and the gantry. The front end of the arch frame is equipped with a retractable leg. During step construction, the arch frame extends to support the upper step.



Figure 3. Schematic diagram of movable arch frame

(2) Arch frame lifting mechanism

The arch frame lifting mechanism consists of a guide frame, a lifting trolley, and a driving mechanism. There are two sets, installed on the rear columns of the trolley frame, mainly used to lift the arch frame from a low position to a high position, facilitating the transfer of the arch frame on the trolley frame by the trolley. The effective lifting height of the mechanism is 4m, and it can lift 3 arch frames at a time. **Figure 4** shows the diagram of the arch frame lifting mechanism.

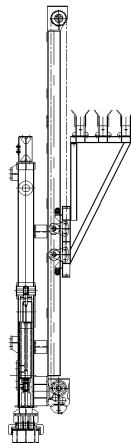


Figure 4. Arch frame lifting mechanism

(3) Arch frame installation mechanism

The arch frame installation mechanism mainly consists of a telescopic sleeve, a running track, and an arch frame moving trolley. Two sets are installed on the truss beam of the movable arch frame, mainly used to receive the steel arch frame from the lifting mechanism and transport it to the front end of the trolley, and then lift it to the installation position.

(4) Auxiliary mechanisms

The auxiliary mechanisms mainly consist of a platform, platform supports, and a ladder. Telescoping cylinders are installed in the ladder supports of the gantry and the movable arch frame, enabling the telescoping of some platforms. The platform within approximately 7m of the trolley near the tunnel face adopts a mesh structure welded with threaded steel bars and rectangular tubes, mainly used to support the air leg of the pneumatic drill during manual drilling^[7]. The strip on the arch frame can be extended with the arch frame to facilitate manual drilling, charging, and framing operations using the step method.

3. Information technology research

The construction environment of the multi-functional integrated excavation trolley in the tunnel face is harsh, and the safety risks are high. Therefore, it is necessary to conduct research on the information system. This involves developing systems for data statistics, data analysis, and data display control, as well as real-time monitoring and video transmission. Additionally, status monitoring systems with features like fault alarms and diagnostics will be developed.

3.1. Safety monitoring terminal for the trolley

To enable real-time monitoring of the working status of the integrated excavation trolley and the stress conditions of its main components, safety monitoring terminals need to be arranged on the excavation trolley. This will be achieved by installing various instruments and sensors on the trolley for information collection, using PLCs and controllers as the equipment control and data processing centers, and utilizing a Human Machine Interface (HMI) for display and alarm functions^[8].

3.2. IoT wireless communication module

This module collects data on the working status of the integrated excavation trolley and the stress conditions of its main components. When there are multiple devices, data transmission and integration are necessary to facilitate unified backend management. Utilizing IoT technology, this module is responsible for transmitting data collected by controllers, HMI, and various sensors to the cloud platform.

3.3. Trolley monitoring cloud platform

The role of the monitoring cloud platform is to decode the information uploaded by the terminals and store it in a database. It performs data analysis on the health status of the trolley, provides fault warnings, and enables remote graphical displays. Sensors are arranged at key locations on the trolley, and the collected data is sent to the cloud platform using IoT communication technology. Simultaneously, algorithms are applied to the uploaded data to provide safety warnings regarding the trolley's operating status. This allows backend managers to accurately understand the trolley's condition in real-time, minimizing the risk of safety incidents.

4. Construction technology research

4.1. Research on face drilling technology

4.1.1. Full-face construction

The mobile arch frame is retracted, and manual drilling operations on the tunnel face are performed using pneumatic rock drills through the trolley's working platform. **Figure 5** shows the diagram of the pneumatic rock drill during full-face drilling.

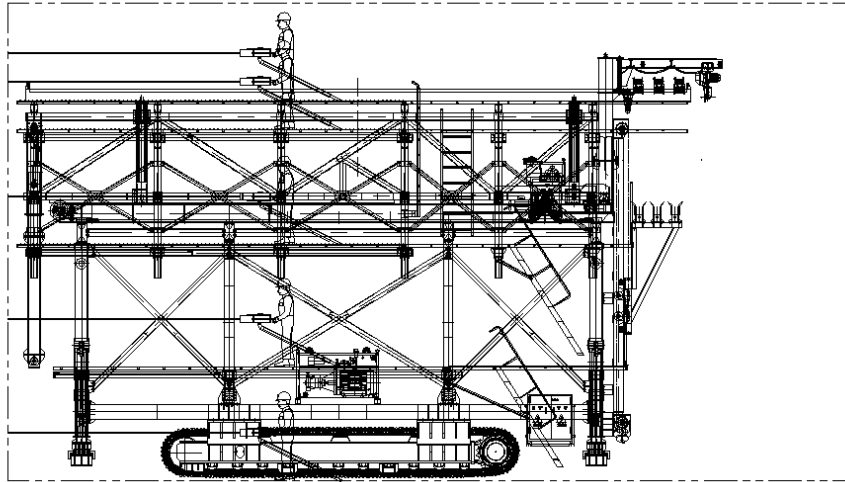


Figure 5. Full-face drilling

4.1.2. Construction using the benching tunneling method

The mobile arch support is extended, with the front leg of the arch supporting the upper bench. Workers use pneumatic rock drills to perform drilling operations on the tunnel face through a working platform on the scaffolding. **Figure 6** shows the diagram of the pneumatic rock drill drilling with the benching method

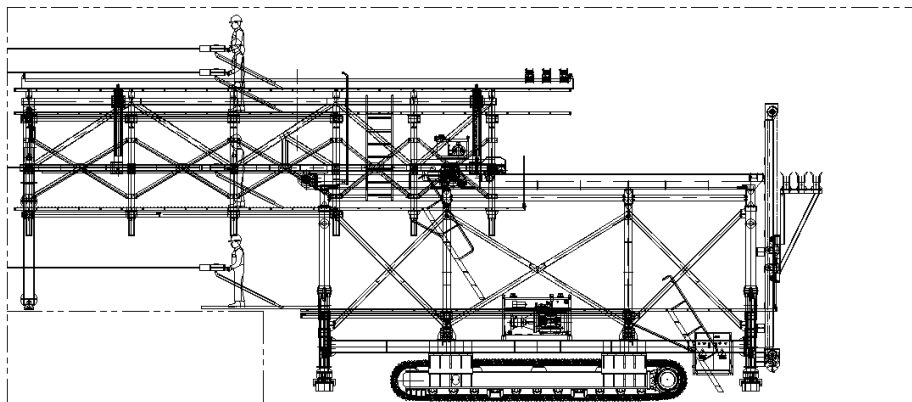


Figure 6. Drilling with the benching method

4.2. Research on arch assembly process

Figure 7 shows the demonstration of the equipment working status.



Figure 7. Demonstration of equipment working status

4.2.1. Full-face tunneling method

- (1) S1: The multi-functional integrated excavation trolley is positioned away from the tunnel face, and the arch is pre-assembled on the ground (reserving the lower part of the arch wall for later assembly) without affecting the passage of construction vehicles at the tunnel face. The arch is then lifted to the arch lifting mechanism using an arch lifting device, which can lift three arches at a time.
- (2) S2: The lifting mechanism raises the arches to the height of the installation trolley. During the lifting process, the mobile arch is extended 1.5m forward, and the cantilever of the arch lifting mechanism rotates to prevent interference between the steel arch, the cantilever of the lifting mechanism, and the track of the installation mechanism during the lifting process.
- (3) S3: The mobile arch is retracted, and workers manually push the arch transfer trolley under the three arches. The lifting mechanism is lowered, allowing the steel arches to rest on the transfer trolley. The steel arches are then locked in place to prevent movement, and the lifting mechanism is further lowered until the steel arches are detached. The arches are then manually pushed to the middle of the trolley.
- (4) S4: The spacing between each arch is adjusted on the trolley according to actual requirements. Steel mesh and connecting bars can be welded between the arches on the trolley ahead of time. When the tunnel face meets the conditions for arch installation, the trolley is moved near the tunnel face, aligned with the center of the tunnel, and the arches are pushed to the installation position using the arch installation mechanism.

4.2.2. Construction using the benching tunneling method

The steps for installing arches using the benching method are basically the same as those for the full-face method. S1: Lift the arches onto the lifting mechanism; S2: Raise the arches to the height of the installation trolley; S3: Lower the steel arches onto the installation trolley and move them forward; S4: Move the entire machine forward, extend the mobile arch, and move the installation trolley forward for arch installation.

5. Conclusion

The multi-functional excavation trolley developed based on the double-track high-speed railway tunnel section has been completed and is currently in the exhibition stage in the factory. Factory trials have shown that the equipment meets the design requirements and can adapt to both full-face and benching tunneling methods, integrating operations such as drilling the tunnel face, assembling arches, and drilling anchor rods. Using lower equipment costs, it improves the level of mechanization and intelligence in tunnel face construction, reduces the number of construction workers, and enhances construction efficiency.

Disclosure statement

The author declares no conflict of interest.

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Research on the Application of Emergency Management of Construction Engineering Enterprises in Flood Season Based on Dual-Control System

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Abstract: The building construction industry, recognized as one of the eight high-risk sectors, also serves as a crucial pillar of the national economy and a key source of employment. Major project advancements typically concentrate between April to June and September to November each year. However, construction progress tends to slow down during July and August due to increased rainfall associated with the flood season. The impact of the flood season on construction projects is primarily reflected in areas such as civil works, machinery and equipment, and temporary power supply. By establishing a dual-control emergency management system for the flood season, construction enterprises can enhance their emergency response capabilities, effectively reduce management challenges, and improve the overall efficiency of emergency handling.

Keywords: Flood season; Emergency management; Dual-control system

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1. Introduction

As one of the eight high-risk industries, the building construction industry is also a crucial part of supporting the national economy and employment. In recent years, China has increased its efforts to manage safety in the construction industry, but the situation of construction safety is still severe, and the safety management of building construction is still facing great challenges^[1]. In addition, the construction industry is prone to extreme weather such as high winds, snowstorms, and floods during the full construction cycle due to its long construction period, which poses new challenges and dilemmas to the traditional safety management model. Usually, safety management focuses on after-the-fact treatment, lacks systematicity and foresight, and is difficult to effectively prevent and control safety risks under extreme conditions.

In China, the annual progress of the project is concentrated in April-June and September-November, and the construction progress is slower in July and August due to more precipitation in the flood season. Risk has always accompanied construction progress. During periods of increased rainfall, the working environment changes significantly where the surfaces become unstable, and hot, humid conditions can affect workers'

awareness and mental state. Therefore, greater attention must be given to safety and emergency management during the flood season to ensure project stability and worker well-being.^[2]

Table 1 presents the number of building construction accidents from 2014 to 2023. The data indicates that both the number of accidents and fatalities increased annually from 2014 to 2017, a period marked by policy relaxation. During this time, China explicitly called for deepening the reform of the construction industry’s “management and service,” improving the regulatory system and mechanisms, and strengthening accountability for quality and safety. These policy initiatives laid a foundation for the industry’s standardized development. The standardized development of the industry provides a policy guarantee. As a result, the accident rate gradually declined following the implementation of stricter regulations. However, a surge in accidents occurred in 2020 due to a nationwide rush to resume construction activities. The downward trend resumed from 2021 to 2023. Overall, the accident rate in the construction sector remains high, and the consequences of such incidents are often severe^[3].

Table 1. Building construction accident statistics from 2014 to 2023

Year	Number of construction accidents in China	Death toll	Year-on-year change rate (number of cases)	Year-on-year rate of change (deaths)	Accident rate
2014	1185	2123	—	—	0.18
2015	1232	2344	4.00%	10.40%	0.2
2016	1336	2749	8.50%	17.30%	0.22
2017	1419	2810	5.50%	2.20%	0.23
2018	1382	2394	-18.80%	-15.50%	0.2
2019	1372	2443	-7.90%	1.90%	0.21
2020	4183	5413	198.40%	121.60%	0.31
2021	4397	5135	5.10%	-5.10%	0.3
2022	4180	4736	-5.00%	-7.80%	0.28
2023	3900	4300	-6.70%	-9.20%	0.26

Table 2 presents the main types of accidents in the construction engineering field. Based on the distribution of accident types, falls from height, being struck by objects, mechanical injuries, and electrocution are the four most frequent types of accidents in the construction industry^[4]. Based on the climatic conditions during the flood season, most types of construction machinery are largely out of service, and work at heights is generally suspended. Therefore, the types of accidents most likely to result in casualties during this period are primarily object strikes, electrocution, structural collapses, and incidents involving poisoning or asphyxiation.

Table 2. Distribution of main types of accidents

Type of accident	Rate	Key reasons
Drop to height	30%	Insufficient edge protection, safety belts not standardized use
Object strikes	25%	Falling objects from heights, inadequate safety precautions
Mechanical damage	20%	Improper operation of machines, inadequate education, and training
Electrocution	15%	Temporary power violations, leakage protection failures
Fire	5%	Improper stacking of flammable materials, electrical short circuits
Collapse	3%	Unstandardized pit support, improper earth stockpiling
Poisoning, asphyxiation	2%	Poor ventilation, toxic gas leakage in confined space operations

In 2021, the Work Safety Law was amended to strengthen the main responsibility of enterprises, and the National Safety Committee explicitly proposed the construction of a dual prevention mechanism ^[5]. All production and operation units are required to strictly comply with work safety laws and regulations, and must establish a comprehensive system of safety risk classification, control, and hidden danger investigation and management. This means that enterprises must not only identify potential safety risks but also categorize and manage these risks and conduct regular hidden danger inspections to ensure that all hidden safety risks are dealt with in a timely manner.

2. The current situation of emergency management in construction enterprises

China has clarified the requirements of the main responsibility of the relevant construction enterprises in recent years by continuing to improve. For example, the laws and regulations on construction safety management, such as the Regulations on the Safe Production Management of Construction Works, have been supervised on this basis. To enable a rapid response in the event of an accident, enhance the speed and coordination of emergency rescue efforts, effectively prevent and control secondary disasters, minimize injuries, protect employee safety, maintain orderly production, and reduce property losses. An emergency management system is developed in accordance with relevant laws, regulations, and corporate policies. At present, it seems that the emergency management of China's construction enterprises mainly covers the formulation of plans, exercises and training, emergency equipment, online monitoring, and coordinated scheduling in several aspects ^[6].

Plan development serves as the foundation of emergency management. In the construction engineering field, a wide range of emergency plans are required, covering incidents such as daily fires, electrocution, and fall-related injuries, as well as emergency responses tailored to special periods. Due to the complexity and diversity of personnel within construction units, these emergency plans are further subdivided into specific implementation programs to ensure clear responsibilities and effective execution. This is especially important during the flood season, when the emergency plan includes a designated flood control team and outlines a specific response process and disposal procedures for emergency events. **Table 3** presents some of the foundational elements used in the development of these emergency plans. However, analysis of inspection data reveals that many current emergency plans in construction projects suffer from excessive duplication and lack adaptation to actual conditions, resulting in insufficient practical effectiveness during real implementation.

Table 3. Basis for the preparation of the emergency plan

Number	Laws, regulations, and institutional norms
1	Work Safety Law of the People's Republic of China
2	Law of the People's Republic of China on Emergency Response
3	Measures for the Management of Emergency Response Plans for Production Safety Accidents
4	Enterprise Production Safety Management System
5	General Provisions of the Emergency Response Plan for Production Safety Accidents in Enterprises

Plan rehearsals are a critical component of effective emergency management. Experience from past accidents shows that early-stage damages are often limited. If personnel consistently follow the content and procedures practiced during regular disaster prevention drills, the severity of accident-related destruction can be significantly reduced. Typically, drills are conducted for the entire project, involving the participation of all staff members. This approach helps to improve the construction personnel's familiarity with emergency response procedures,

enhancing overall preparedness. When work is halted or construction cannot proceed due to adverse weather conditions, it presents an ideal opportunity for personnel training and education. However, many building construction enterprises fall short in this area due to insufficient emergency management awareness and weak risk control consciousness. As a result, some construction workers and even management staff lack clear emergency response procedures, making it difficult for them to respond calmly and effectively during accidents.

Emergency equipment is an important tool for carrying out emergency management and a necessary means to ensure that the emergency plan can be carried out smoothly. Common emergency rescue materials on construction sites mainly include first aid kits, fire extinguishers, safety ropes, protective equipment, search and rescue tools, etc. **Figure 1** shows some of the emergency equipment. Although some units have equipped their sites with an adequate amount of emergency rescue equipment, maintenance and regular servicing are often neglected. This oversight can lead to emergencies, as the effectiveness and safety of the equipment cannot be guaranteed, posing a risk of malfunction or failure. At the same time, daily management should enforce strict control over emergency equipment by establishing a rigorous system for warehouse entry and exit. Corresponding records must be maintained for each piece of emergency equipment, documenting its receipt, deployment, scrapping, and consumption to ensure full accountability and compliance with emergency preparedness requirements.



Figure 1. Emergency equipment

The online monitoring program is an important means of managing the whole process of emergency management, which can not only make real-time forecasts before the occurrence of disasters or accidents, but also monitor the dynamics of accidents after the occurrence of accidents, to ensure that no secondary disasters

occur as well as the safety of rescuers' lives. Online monitoring system in a broad sense consists of two parts, one is the perception layer composed of sensors and transmission equipment, and the other part is the application layer composed of the operation center. At this stage, construction companies primarily rely on online monitoring equipment such as cameras, temperature sensors, wind speed sensors, and dust particulate monitors to track behaviors and meet environmental protection requirements. However, these systems mainly serve to assign responsibility after violations occur, making it difficult to implement effective preventative measures beforehand.

Coordination and scheduling are central to emergency management, requiring the establishment of a command department responsible for emergency response. This department communicates with various departments and functional groups to make timely and effective decisions. Generally, the emergency command consists of an office and a rescue team. The rescue team is further divided into the rescue group, repair group, alert group, and comprehensive protection group. The detailed organizational structure is illustrated in **Figure 2**.

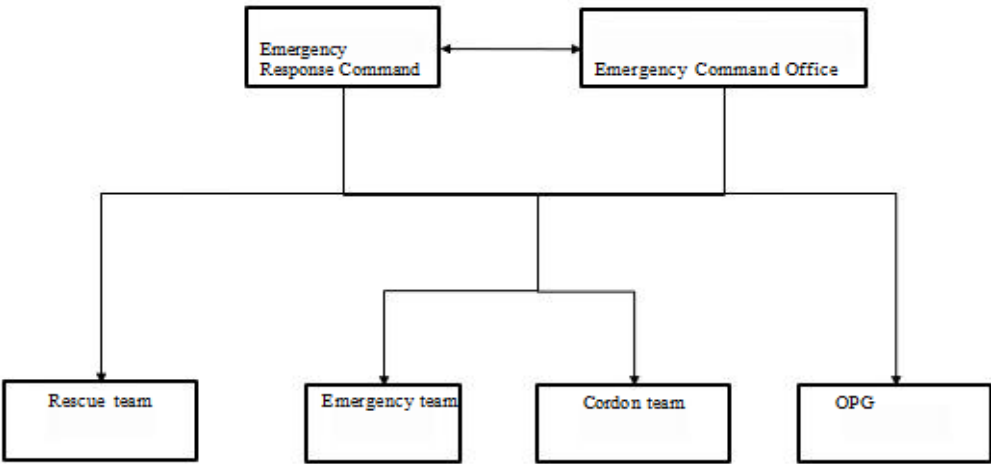


Figure 2. Organizational framework for integrated movement control

The primary functions of coordination and dispatching in emergency management include receiving instructions and mobilization orders from the government, group companies, and higher-level units; organizing and formulating the accident emergency rescue plan; defining and implementing the responsibilities of personnel at all levels during emergency situations; collecting and analyzing issues reported by each rescue team to inform decision-making based on the current situation.

Additionally, coordination and dispatching oversee real-time updates to the command center during critical rescue operations; facilitate collaboration with external rescue forces and manage personnel evacuation; allocate personnel and resources within the operation area; mobilize emergency response teams; designate on-site commanders; coordinate all activities related to the accident site; approve the activation and termination of emergency plans; ensure protection of relevant data following an incident; report accident information; and organize emergency response drills. The efficiency and comprehensiveness of coordination and dispatching directly determine the overall effectiveness of emergency management.

3. Flood season characteristics and main impacts

In China, the annual flood season typically occurs from June to September and is often characterized by heavy and sustained rainfall. The sharp increase in precipitation during this period leads to elevated surface water levels and rising river stages, significantly impacting infrastructure and public safety. For instance, during the

2025 “Dragon Boat Water” period, Shenzhen experienced precipitation that accounted for nearly 20% of its annual total, with some areas recording unprecedented levels reaching 996.4 millimeters. At the same time, the flood season is often accompanied by secondary natural disasters such as flash floods, mudslides, and severe convective weather. While these hazards may have limited direct impact within urban centers, the overall increase in rainfall and prolonged hot, humid conditions can significantly affect workers’ physical and mental well-being. This is particularly true in the southern coastal provinces, where typhoons are more frequent during this period. These environmental stressors not only pose safety risks but also reduce operational efficiency and increase the likelihood of accidents. The following is a brief analysis of how the flood season impacts the construction engineering industry.

3.1. Civil construction

The impact of flood season on civil construction operations mainly exists in the following aspects ^[7]:

(1) Construction progress is affected

Increased rainfall during the flood season leads to water accumulation and muddy conditions at construction sites, resulting in construction site vehicles, personnel, and other mobility difficulties, equipment and materials transportation difficulties. At the same time, for some dangerous projects, such as deep foundation pit, high supporting mold, and other construction operations, need to be completely suspended during the flood season, the rainfall changes the ground soil conditions, increasing the probability of accidents such as collapses and landslides.

(2) Construction quality is affected

During the flood season, even if the corresponding construction materials are sealed and preserved, the high water retention in the air is not conducive to the preservation and utilization of certain materials, such as cement and wood. At the same time, the flood season construction site environment is complex, and the construction process standard is difficult to meet the standard, greatly affecting the quality of the project.

(3) Increase in project cost

During the flood season, construction sites must implement various flood prevention and control measures, such as reinforcing flood barriers with sandbags, ensuring communication equipment is in place, and preparing for the relocation and resettlement of personnel. These preparations are reflected in increased project costs. Additionally, the prices of raw materials often rise during this period, further driving up overall construction expenses.

3.2. Mechanical equipment

The impact of flood season on mechanical equipment is mainly reflected in the two factors of high winds during strong convective weather and water accumulation after precipitation storms. Whenever there is a typhoon, the mechanical equipment and the boarding house at the construction site should be additionally reinforced, which is done to effectively resist the wind load brought by the gusty weather. At the same time, equipment such as tower cranes, mobile cranes, and reinforcement materials are vulnerable to tipping or causing injuries during strong winds. For example, during a typhoon in Shanghai, two tower cranes collapsed at a construction site. Investigations revealed that wind speeds reached 26.5 m/s at the time, 1.72 times the equipment’s design load. The excessive pressure not only caused the collapse but also destroyed the cranes’ safety components ^[8]. Therefore, during the flood season, especially in windy conditions, all mechanical equipment should be stopped, and appropriate protective measures must be taken. These include securing protective covers, fastening steel cables, lowering suspended platforms to the ground, and evacuating personnel from temporary structures such as site dormitories.

3.3. Temporary electricity

Temporary electricity is one of the most frequent safety hazards on construction sites due to its wide distribution and complexity. During the flood season, electrical equipment must be elevated above ground level, as sudden rainfall can cause water to enter power equipment, leading to short circuits or equipment failure. Additionally, water's conductivity increases the risk of electrocution, making proper protection and elevation of electrical systems essential for safety. Additionally, common switch boxes and distribution boxes on construction sites are often of low quality and lack permanent reinforcement. This makes them prone to falling over in strong winds, which can accidentally turn switches on or off. More seriously, falling boxes can pull or damage cables, exposing worn rubber insulation. In humid environments, high voltage combined with damaged insulation increases the risk of non-contact electric shocks, leading to injuries and property damage ^[9]. Therefore, it is essential to strictly control the operating voltage of power and lighting systems, ensuring a safe voltage level of 24V in humid environments.

4. Dual-control system of flood emergency management points

In order to improve the flood emergency management capacity, in the construction project to carry out the establishment of dual-control system can effectively reduce the difficulty of management to improve the efficiency of emergency response. The following analysis will focus on key aspects of construction engineering emergency management based on the dual-control system.

4.1. Hazardous source identification and risky operation type

Based on on-site inspections and research, the primary hazardous sources that may cause harm to personnel on site are mainly classified as first-level hazards, with objects being the most common contributing factors. The sources of danger and types of risky operations on site are listed in **Table 4**.

Table 4. Flood season construction site hazard sources

Number	Risk points	Risk factors or potential events	Inherent risk rating
1	Trench collapse	Accumulated rainfall $\geq 50\text{mm}$, and the slope of the pit top interceptor drainage $< 1\%$ The rate of rise of groundwater level $> 15\text{cm/h}$, resulting in a 30% decrease in soil shear strength.	IV
2	Landslide	Expansion rate of surface cracks $> 2\text{cm/h}$ Cumulative displacement of deep displacement monitoring point $\geq 20\text{mm}$	III
3	Collapse of boarding house	Depth of water on the foundation floor $> 30\text{cm}$, soaking time $\geq 6\text{h}$ The proportion of concrete compressive strength of steel column foundation $< C20 > 10\%$	III
4	Tower crane overthrow	Depth of water in foundation $> 50\text{cm}$ Deviation of verticality of pre-embedded foot bolt $> 3\%$.	IV
5	Temporary Electricity System leakage	Distribution box height from the ground $< 80\text{cm}$ (when the depth of water $\geq 30\text{cm}$) Cable immersion time $> 2\text{h}$ resulting in insulation resistance $< 0.5\text{M}\Omega$	III
6	Material yard landslide	Height of stacking of bagged cement > 10 layers (moisture-proof liner is missing) Slope of stacking of square logs $> 1:1.5$ and no earth blocking facilities	II

4.2. Hierarchical risk control

The higher the risk level, the higher the level of control required ^[10]. Based on the actual situation of the construction enterprise, company-level leaders are responsible for the entire process control of “significant

risks”, department-level leaders are responsible for the entire process control of “general risks”, and team-level leaders are responsible for the entire process control of “low risks”. The entire process should be controlled step by step, with specific measures implemented. There are various measures for risk control, including engineering and technical measures, such as elimination or reduction, substitution, closure, isolation, removal, or redirection etc. In terms of management measures, a range of safety management systems and operating procedures can be established. These include developing a comprehensive and effective emergency rescue plan, implementing self-inspection and internal reporting reward mechanisms for identifying hidden hazards, enforcing strict safety permit requirements for operating procedures, adjusting working hours to reduce exposure based on seasonal factors, and setting up warning signals, among others.

Education and training should begin by introducing employees to the basic risks and their classifications, helping them to correctly understand potential hazards. This foundation is followed by professional safety training aimed at improving employees’ emergency response abilities. Practical exercises should be incorporated to teach methods of self-help and mutual aid, and to train employees to remain calm and effective under stress.

Additionally, employees must be made aware of the specific safety risks associated with their positions and the corresponding prevention and control methods. Strengthening individual protection is crucial—each worker should be provided with protective clothing, ear muffs, safety glasses, insulated gloves and shoes, and convenient respirators. Staff should be trained on the correct use of this equipment both before and during work. Safety management personnel must regularly inspect the effectiveness of personal protective equipment (PPE) and emphasize to employees that PPE is the last line of defense, not a cure-all.

When risks become uncontrollable, emergency response measures should be activated, which include collecting and reporting key site information, implementing emergency plans, coordinating response actions and material supply, and enhancing pre-training to improve the preparedness of all relevant personnel.

4.3. Hidden danger investigation and management

First, focus on high-risk areas by establishing a ledger for key parts. Then, develop an inspection plan to conduct regular hidden danger inspections, documenting findings in inspection records and hidden danger rectification notification forms. Hidden dangers should be classified and graded, with regular public announcements made, and major hazards reported promptly.

Construction sites can use the following methods for hidden danger investigations: (1) Daily inspection; (2) Special inspection; (3) Seasonal inspection; (4) Holiday inspection; (5) Technical monitoring; (6) Employee self-inspection; (7) Expert diagnosis; (8) Double-blind rehearsal inspection; (9) Cross-checking each other; (10) Accident review inspection.

Based on the identified hidden dangers, develop a targeted rectification plan that clearly defines the corrective measures, responsible personnel, and a timeline for completion. Ensure that the rectification process is properly managed and its effectiveness verified. Once the rectification is completed, conduct a timely acceptance inspection and evaluation to confirm that the hazards have been eliminated. The enterprise should document this typical hazard handling process as part of an effective governance experience. Additionally, all hidden dangers should be recorded and maintained in a ledger for regular analysis. Relevant reports and materials should be prepared to support future risk prediction and prevention efforts.

5. Conclusion

The building construction industry faces numerous risks, and the flood season’s climate and hydrological

conditions add further challenges to construction site safety. Safety management personnel in construction enterprises must clearly understand the characteristics of each project and combine this knowledge with flood season features to carry out thorough risk identification and control measures. By effectively applying a comprehensive dual-control system, all potential risk points can be managed, and hidden dangers eliminated to minimize the likelihood of accidents. Continuous improvement in hazard investigation and management is essential to ultimately achieve fundamental safety.

Disclosure statement

The authors declare no conflict of interest.

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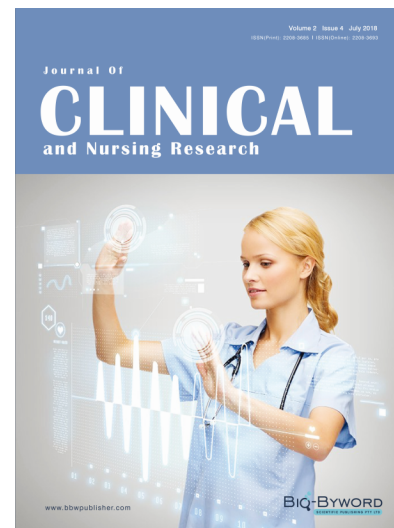
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