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Table of Contents

Journal of World Architecture, 2025, Volume 9, Issue 2
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Design Strategies for Reconstruction and Expansion of Insufficient Clearance Sections in Highway Interchanges

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Abstract: Combining practical engineering projects, this article analyzes the design strategies for the reconstruction and expansion of insufficient clearance sections in highway interchanges. This includes an overview of the project, a comparison of design options for insufficient clearance in interchanges, and the main design strategies for reconstruction and expansion. It is hoped that this analysis can provide a reference for the design of such road reconstruction and expansion projects.

Keywords: Highway; Interchange; Insufficient clearance; Reconstruction and expansion design; Design scheme

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1. Introduction

In the design of highway interchange reconstruction and expansion, insufficient clearance sections are a design challenge. Based on this, designers should combine the actual project overview, compare and select various schemes to determine a reasonable design scheme. Finally, according to the determined design scheme, implement the reconstruction and expansion design with reasonable strategies. This can ensure the rationality of the reconstruction and expansion design and solve the problem of insufficient clearance.

2. Project overview

This study focuses on a highway interchange reconstruction and expansion project. The existing interchange of the project is located on a hill. According to the adjacent line reconstruction and expansion plan, the construction unit needs to build a new interchange on the highway connection line. However, after design analysis, it was found that after the completion of the new interchange, there is insufficient clearance between the two interchanges.

Therefore, before the construction of the new interchange, the construction unit needs to implement reasonable reconstruction and expansion treatment for the project, expanding it from the original three-way interchange form to a four-way interchange form. This article mainly analyzes the design strategy of the reconstruction and expansion of this road section.

3. Comparison and selection of interchange clearance design schemes

3.1. Clearance design supported by signs and markings

According to the current design requirements of this road section, due to the insufficient spacing between the existing interchange and the newly built interchange, all exit preview signs cannot be set, resulting in incomplete road information display. Based on this, designers need to set preview signs at a distance of 500m from the newly established interchange, and all other signs should be set in front of the previous existing interchange to meet the actual prediction and indication requirements. In this case, designers only need to set a preview sign within the insufficient clearance section. When a vehicle enters from the entrance of the previous existing interchange, there will be only one opportunity to read the exit information. If the driver misses it, the vehicle will not be able to reach the exit smoothly and will have to quickly adjust the lane, which can easily cause traffic confusion [1]. To avoid this problem, designers need to reserve a certain distance for drivers to discover and read the exit signs. According to the 3-second theory of determining travel time, when the car speed is 120km/h, the driving distance between seeing the sign and successfully reading it is about 100m. Therefore, if only one exit preview sign is set, the minimum distance between it and the new interchange should be controlled to 600m.

3.2. Clearance design supported by traffic theory

The so-called minimum traffic theory distance refers to the minimum driving distance for the driver of the inner lane vehicle to react and complete relevant operations immediately after reading the exit preview sign. Due to differences in the driver's own state, vehicle performance, and other conditions, different scholars have constructed different models for calculating this clearance. Based on this, the designer assumes a worst-case scenario where a vehicle enters from the ramp entrance. Due to unfamiliar road conditions, the driver may change lanes to the inner lane. When it is found that the exit is located on an adjacent ramp, it is necessary to quickly change lanes to the outer side [2]. In this case, the driving distance during the process of vehicle entry, lane change, re-lane change, and exit can be used as the minimum clearance between adjacent interchanges.

3.3. Clearance design supported by safe lane changing

When vehicles change lanes from the inner lane to the outer lane, designers can introduce traffic flow and probability theory based on a comprehensive consideration of parameters such as the number of lanes and vehicle speed. This can be used as a basis to establish a probabilistic relationship model between vehicle exit distance and safe lane changing [3]. Through this model, it can be concluded that as the clearance of the interchange increases, the safety of lane changing increases linearly, and the threshold for safe lane changing needs to be controlled at 0.95.

3.4. Comparison and determination of clearance design schemes

Through a comparative analysis of the above three clearance design schemes, it is found that the clearance design scheme supported by signs and markings did not fully consider special situations such as lane changing of inner vehicles during the design process. Therefore, the results obtained are relatively conservative and need to be properly adjusted and optimized through other methods. The extreme conditions assumed in the clearance design scheme supported by traffic theory generally do not occur, so the final designed minimum clearance will be much larger than the actual demand. The clearance design scheme supported by safe lane changing, effectively combines relevant theories and probabilities in the process of traffic operation. The various factors considered in the design are compatible with the actual traffic operation of the highway, and various factors such as driving speed, vehicle performance, and driver psychology are also comprehensively considered. Therefore, this scheme is more objective and scientific [4]. Based on this, in this project, the designer decided to design based on the clearance design scheme supported by safe lane changing.

4. Main expansion design strategies for insufficient clearance of interchanges

For the problem of insufficient clearance of interchanges in this project, the designer has determined the following design strategies according to different situations and design requirements during the specific renovation and expansion design.

4.1. Expansion through the addition of auxiliary lanes

Before the auxiliary lane is set up, vehicles will merge into the main line under conditions where the driving speed and lane matching are not ideal, which can easily lead to traffic conflicts. If an auxiliary lane is added at the exit of the interchange to connect two interchanges with insufficient clearance, when the vehicle exits the interchange, it can adjust its driving speed on the auxiliary lane. When there is a safe gap in the inner lane, it can exit in a timely manner, thereby significantly reducing the probability of traffic conflicts [5]. For the auxiliary lane, when setting it up, the designer needs to reasonably determine the length of the auxiliary lane based on various factors such as the actual traffic capacity in the interlaced area, the running time of the split and merge, and the distance of the advance sign.

During specific operation, the main purpose of setting this auxiliary lane is to alleviate or reduce the adverse disturbances caused by the split and merge traffic in the main traffic. If the length of the auxiliary lane is continuously increased, there will be no traffic flow interleaving in the middle, but the two ends will still form a split and merge traffic state. According to the relevant provisions in the "Detailed Rules for the Design of Highway Reconstruction and Expansion" JTG/TL11-2014, if the length of the interlaced area reaches more than 760m, the traffic flow can achieve a complete conversion of split and merge. Under the condition of continuously extending the interlaced area, the adverse effects of this kind of traffic split and merge on straight traffic will continue to weaken [6]. Based on this, the designer initially designed the minimum length of the auxiliary lane in this project as 760m.

According to the relevant provisions in the "Detailed Rules for the Design of Highway Interchanges" JTG T D21-2014, when designing the main line of an interchange in the form of a two-way six-lane, if the number of ramp lanes is increased, the minimum length of the auxiliary lane should also be appropriately adjusted. After comprehensive consideration of various factors, the finally determined minimum length of the auxiliary lane is slightly larger than the initial design value. **Table 1** shows the design parameters of the minimum length of the auxiliary lane based on the designed speed of the main line in this project:

Table 1. Design parameters of the minimum length of the auxiliary lane based on the designed speed of the main line in this project.

Serial number	Main road design speed	General length of auxiliary lane	Minimum length of auxiliary lane
1	80 km/h	1000m	800m
2	100 km/h	1100m	900m
3	120 km/h	1200m	1000m

4.2. Expansion through the setting of collector-distributor roads

When the clear distance of the interchange is insufficient and auxiliary lanes cannot be reasonably set according to the above design requirements, designers can set collector-distributor roads for it. In this type of roadway, there is no straight traffic flow in the interweaving area, and only the traffic flow at the ramp exit and entrance interweaves with it. Typically, such roadways should be designed based on the actual technical requirements of the ramp and the operating speed of the vehicles. Because its design speed is relatively low, the efficiency of vehicle interweaving also needs to be reasonably reduced. Regarding this situation, there is no clear provision for its length design in the "Detailed Rules for the Design of Highway Interchanges." Therefore, in this design, the designer mainly analyzes the minimum length of the collector-distributor road based on road capacity and service level.

Firstly, the length of the interweaving area is reasonably determined. During the specific design, the designer divides the traffic flow interweaving situation into the same-side interweaving area and the opposite-side interweaving area. The interweaving intensity coefficient is estimated based on the vehicle lane-changing rate, thereby making a scientific analysis of vehicle density. Then, the safe operation level of the designed road segment is reasonably evaluated based on vehicle density. In this mode, the distance between the merging and diverging points is the length of the interweaving area. The larger the length value, the longer the lane-changing distance for vehicles in this area, and the smaller the vehicle conflict density. This can effectively improve the traffic capacity of the road segment [7].

Secondly, the length of the interweaving area on the collector-distributor road is reasonably determined. According to the relevant provisions in the "Detailed Rules for the Design of Highway Interchanges", designers can use the standard of variable speed lanes as a basis to make scientific designs for the connection between collector-distributor roads and main roads. Based on the actual situation of the project, the vehicle speed on the collector-distributor road needs to be 20km/h lower than that on the main road. To ensure that vehicles exiting the collector-distributor road can stably enter the ramp, the designer takes the coordination of operating speeds as a basic principle and controls the difference between the driving speed of ramp vehicles and the driving speed of collector-distributor road vehicles to be 20km/h or more.

Based on the above design ideas, the designer performs a trial calculation of the traffic flow in the interweaving area on the collector-distributor road. When the length of the preliminary design value is trial-calculated to be 760m, and if its traffic density reaches 18–25pcu/km/ln, the trial calculation can be terminated. To further simplify the calculation and analysis process, in this design, the designer assumes that the ramp at the exit and entrance of the collector-distributor road has the same design speed. Under this design mode, the designer's trial calculation results for the length of the interweaving area on the collector-distributor road are shown in **Table 2**.

Table 2. Trial calculation results for the length of the interweaving area on the collector-distributor road in this design

Serial number	Design speed of collector-distributor lanes	Design speed of ramps	Length of weaving area on collector-distributor lanes		
			Two-entry and two-exit	Two-entry and one-exit	One-entry and one-exit
1	40 km/h	30 km/h	70m	90m	--
2	40 km/h	40 km/h	--	--	--
3	50 km/h	30 km/h	60m	50m	130m
4	50 km/h	40 km/h	150m	90m	580m
5	50 km/h	50 km/h	--	--	--
6	60 km/h	40 km/h	110m	70m	150m
7	60 km/h	50 km/h	200m	--	410m
8	60 km/h	60 km/h	--	--	730m
9	70 km/h	50 km/h	150m	80m	190m
10	70 km/h	60 km/h	250m	100m	280m
11	70 km/h	70 km/h	--	--	400m
12	80 km/h	60 km/h	200m	85m	180m
13	80 km/h	70 km/h	320m	110m	240m
14	80 km/h	80 km/h	--	130m	320m

The trial calculation results show that as the design speed of the ramp increases, the length of the interweaving area also increases, whereas as the design speed of the collector-distributor road increases, the length of the interweaving area decreases. Under the conditions of a double-entry and double-exit collector-distributor road, the traffic density will reach above 36pcu/km/ln. Therefore, this type of collector-distributor road should be avoided in the design. If the traffic volume is relatively large, a variant form of double-entry and double-exit ramp can be considered in the design of the collector-distributor road. This type of collector-distributor road can reasonably avoid traffic interweaving on the main road and achieve reasonable changes in the merging sections of the entrance and exit. At the same time, in this mode, vehicles will reasonably change lanes to the outermost lane before exiting from the main road, which is completely consistent with China's road traffic habits. **Figure 1** shows a schematic diagram of the variant form of double-entry and double-exit ramp for the design of collector-distributor roads.

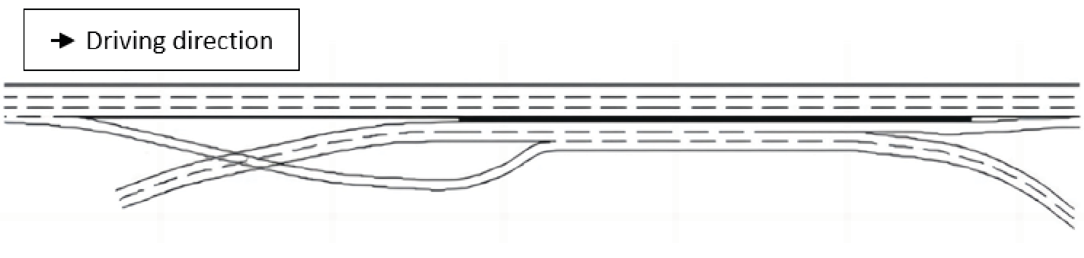

Figure 1. Schematic diagram of double-entry and double-exit ramps in a variant form during the design of collector-distributor lanes

4.3. Expansion through interconnected ramps

If the clear distance between two adjacent interchanges is very small and the length of the weaving area is limited, and the auxiliary lane setting method and the collector-distributor lane setting method cannot meet the actual traffic demand, designers can set up a compound interchange route through interconnected ramps. In this mode, there will be a relatively large number of exits on the designed compound interchange route. To achieve effective merging between exits and entrances, designers can combine actual conditions and adopt several connecting ramps to implement connection processing, thus providing convenience for vehicle merging and diverging on other ramps and effectively reducing the disturbance caused by vehicle merging and diverging to the straight traffic flow in the insufficient clear distance section [8].

4.4. Expansion through multi-way intersection merging

If there is a serious insufficiency of clear distance in the interchange and a new road needs to be connected on this basis, designers can carry out intersection merging design through multi-way intersection merging [9]. Because the overall shape of this kind of interchange is relatively complex and there is no standard form for reference, designers should reasonably select the form of left-turn traffic routes during specific design. For crossroads in the form of dual lanes, designers can design multi-way intersecting routes as annular. This can reasonably simplify the traffic flow pattern and make the layout of the interchange sufficiently compact to meet the actual traffic demand of the project [10].

5. Conclusion

In summary, with the continuous expansion of modern transportation, many existing highways need to be renovated and expanded to meet their actual traffic flow carrying demand. However, when renovating and expanding the main line of existing highways, if there is insufficient clear distance in the interchange, designers need to combine the specific project overview, conduct a comprehensive analysis of various factors, and develop a sufficiently scientific and reasonable renovation and expansion design plan. At the same time, reasonable strategies should be adopted to implement the renovation and expansion design according to the different situations and transportation demands of the insufficient clear distance locations of the highway interchange. Only in this way can the problem of insufficient clear distance be effectively solved, and the renovation and expansion design of the highway can be reasonably optimized to meet the actual vehicle traffic demand.

Disclosure statement

The author declares no conflict of interest.

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The Relationship between Urban Memory and Typology: Utilizing Typology as a Design Tool to Preserve Urban Memory

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Abstract: Urban memory is the soul and vitality of the city, which is created and maintained by people's memory of the living environment. However, urban planning and architecture increasingly lose attention to urban memory, resulting in the loss of uniqueness of urban appearance, and then affect people's sense of identity of the city. Therefore, using the theory of typology for reference, a new design tool - urban memory typology is proposed, which focuses on and introduces historical elements into urban design, and maintains urban memory through the protection of cultural heritage. This method involves clarifying the intrinsic relationship between existing buildings and urban space through typology theory, identifying carriers of urban memory, and, on this basis, proposing strategies and technologies for urban renewal. This study verifies the validity of urban memory typology through case analysis, such as the conservation planning of Qingdao Old city. The results show that using the typology theory can protect the city memory, maintain the stability of the city form, and enhance the local identity of the residents, which is a new method of urban planning and design in line with the concept of humanistic care and sustainable development. This research work provides new theoretical guidance and practical strategies for the protection of urban memory and urban planning and design.

Keywords: Urban memory; Typology; Urban design; Protection of cultural heritage; Urban planning and design

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1. Introduction

As a unique cultural and historical imprint of a city, urban memory plays an irreplaceable role in shaping our cognition and emotions towards the city. With the rapid development of urbanization, modern urban planning and construction often ignore the protection and inheritance of these memories, resulting in the loss of urban personality and residents' sense of local identity, which has a negative impact on social stability. This paper puts forward the application of typology theory in urban design to promote the protection and inheritance of urban memory with its unique advantages. Starting from structure and form, typology provides a new perspective and tool to help us understand and protect urban memory and promote sustainable urban development by revealing internal laws and classifications. The validity and feasibility of this idea are verified by an example analysis. In short, urban memory typology brings a new concept to urban design, aiming to achieve the stable development and preservation of the uniqueness of the city through the protection of historical elements and memories.

2. Concept and importance of urban memory

2.1. Definition of urban memory

Urban memory refers to the collective memory of urban space, architecture, culture, and historical events accumulated through people's cognitive and emotional experience in the process of urban development [1, 2]. It covers not only the material heritage of the city, such as landmarks, historic districts, and cityscapes, but also intangible cultural elements, such as traditional customs, local legends, and social practices. These memories not only carry the historical and cultural value of the city, but also affect the identity and sense of belonging of the residents. The existence of urban memory makes the city unique and continuous, and becomes the core part of the city's soul. In the process of the rapid development of modern cities, urban memory is often neglected or destroyed, which leads to the homogenization of urban appearance and weakens residents' emotional connection and sense of identity to the city. The recognition and preservation of urban memory has become an important issue in urban planning and design, to preserve the character and history of cities, promoting psychological connections and preserving valuable cultural heritage for future generations [3].

2.2. Function and value of urban memory

Urban memory is an important part of urban culture, and its function and value are reflected in many aspects. Urban memory is not only a collection of common living experiences of citizens in a specific space, but also an important factor in shaping the uniqueness of a city. By carrying historical events, cultural practices, and social activities, urban memory promotes emotional cohesion within communities. Its existence enables the city to connect the past with the present in a living way, enhancing the historical continuity of the city. Urban memory enhances residents' sense of local identity and is also a great attraction to outside tourists, enhancing the tourism charm and economic potential of the city. In the context of rapid economic and cultural globalization, urban memory provides a means for cities to resist the trend of homogenization and maintain the diversity and individuality of cities. By preserving important urban memories, cities can not only continue their historical context but also maintain their unique identity in a rapidly evolving modern society.

2.3. Challenges of contemporary urban planning to urban memory

In the process of modernization, urban planning often takes development efficiency and economic growth as priority goals, ignoring the maintenance of urban memory. This trend leads to the increasingly serious homogenization of cities, the simplification of architectural styles, and the gradual forgetting or elimination of traditional neighborhoods and unique cultural elements. In the process of old urban renewal, excessive emphasis on function replacement may cause irreversible damage to historical buildings and original urban texture, and weaken residents' sense of local identity. This neglect of urban memory not only causes cities to lose their individuality but also affects the inheritance of historical and cultural values.

3. Overview of typology theory

3.1. Definition and development of typology

As an analysis tool and design method, typology originates from the development of philosophy and art, and its definition involves the classification and pattern recognition of things [4–6]. Typology is concerned with the similarities and differences between objects by identifying and classifying different types, to reveal the deep structure and law. In architecture and urban design, the use of typology aims to identify and perpetuate the historical and cultural character of a community or city. Its development can be traced back to the taxonomic studies of the 18th century, through the classification of architectural elements and styles, to help designers understand and inherit the traditions of the past. With the progress of The Times and the intensification of urbanization, the application of typology has gradually expanded to the study of the whole urban spatial structure, to meet the dual needs of cultural heritage protection and urban development. Through the study of existing architectural forms and urban space, typology method strengthens the dependence of design on historical context, makes the coexistence of old and new possible, and thus plays a crucial role in the protection of urban memory. This theoretical framework not only promotes academic research but also provides powerful guidance for urban planning practice [7].

3.2. Application of typology in architecture and urban design

As an analytical tool in architecture and urban design, typology provides a framework for designers to identify and interpret urban structures and architectural forms. By examining the type and formal language of architecture, typology helps designers understand the cultural and historical context of the existing environment, to incorporate these elements into the design process to maintain urban memory [8–10]. In urban design, typology promotes the preservation of historic buildings and traditional neighborhoods, supporting the harmonious coexistence of modern design and historical environment. This method emphasizes the continuity of architectural form and advocates following the morphological characteristics of existing urban space in urban renewal, providing theoretical support for urban design to maintain local characteristics and protect urban memory. The application of typology further promotes the sustainable development of urban planning and design.

3.3. Theoretical framework and main contributors of typology

The theoretical framework of typology originates from the systematic study of form and function in architectural and urban design, emphasizing the analysis of recurring design forms to reveal the internal relationship between spatial structure and human activities. In this area, Rossi was a key contributor to the development of the theory of typology, and in his book Typology of Architecture, he saw typology as a unique expression of collective memory based on the history and culture of the city. Krier further enriched the practical orientation of this theory through his research on classical urban forms. The theoretical framework of typology provides designers with an effective tool to maintain urban memory by analyzing and learning from historical forms.

4. The relationship between urban memory and typology

4.1. Typological characteristics of urban memory

As a complex social and cultural phenomenon, urban memory shows its unique characteristics from the perspective of typology. Typology identifies and analyzes the commonality between architecture and urban space to reveal its internal structure and development logic. The typology of urban memory emphasizes the attention to historical form and cultural connotation, which reflects the unique historical evolution and cultural accumulation of the city through the identification and reconstruction of typical elements. This feature is not only reflected in the protection of historical buildings, but also in the inheritance and innovation of urban spatial organization forms. Under the framework of typology, urban memory is seen as a continuum with temporal depth and spatial breadth, which is both dependent on concrete material carriers and perpetuated through human activities and social interactions. The typological characteristics of urban memory not only help to understand the historical context of urban development but also provide important reference and guidance for future urban planning and design, ensure the coexistence of history and modernity, and inject sustainable vitality into the city.

4.2. Analyze the persistence of urban memory by using typology theory

Typology theory plays an important role in analyzing the persistence of urban memory. By identifying and classifying typical elements of architecture and urban form, typology helps to reveal the physical features that sustain the enduring memory of a city. This method can identify the carrier significance of historical blocks, landmark buildings, and traditional spatial layout for urban memory, to ensure that urban memory elements are not ignored in urban renewal and development. The typology theory can be used to analyze the relationship between the existing spatial structure and the historical context of the city, so that designers can maintain these internal connections in the planning and design, to realize the synchronization of functional modernization and cultural inheritance without destroying the urban memory. In this practice, typology not only helps to identify which urban spaces and architectural features are important carriers of urban memory, but also provides techniques and methods for urban design to maintain these features and effectively protect the continuity and stability of urban memory. In this way, urban planning can even enhance residents' sense of local identity, allowing urban memory to coexist harmoniously with modern development.

4.3. Urban memory conservation strategies from the perspective of typology

From the perspective of typology, urban memory can be achieved by identifying and preserving the unique historical forms of the city, including the preservation of representative architectural forms and block textures. Emphasizing the integration of traditional elements with modern design, encouraging the renewal of existing structures to ensure historical coherence and cultural continuity, to enhance urban identity and sustainability.

5. Practical application of urban memory typology

5.1. Construction of urban design tools based on typology

The design tool of urban memory typology builds on the basis of the typology theory, and forms a set of systematic design methods by identifying and analyzing the deep historical elements of the city. At its core lies the identification of representative buildings and urban spaces as carriers of memory that, by combining them with cultural heritage, harmoniously co-exist between historical textures and modern developments [11]. This design tool surveys and classifies the types of buildings in the city, identifying those elements that represent the city's memory and embedding them into new design schemes. The design tools include spatial layout, stylistic features, and material use to ensure a harmonious symbiosis between old and new elements. This design tool has been applied to urban renewal and development projects to preserve and show the unique memory of the city in improving the level of urban modernization [12]. Through the meticulous control of building height, form, and spatial relationships, the tool seeks to maintain the character of the city amid rapid development and to enhance the sense of belonging and identity of the residents.

5.2. Application cases of urban memory typology in urban planning and design

The protection planning of Qingdao old city reflects the concrete application of urban memory typology in urban planning and design. In this case, the plan emphasizes the connection between the existing buildings and the historical context, re-examines the historical district of Qingdao, and explores the typological characteristics of its core landmarks and characteristic buildings through a typological perspective. This approach involves a detailed analysis of the existing building, determining its role in the city's memory, and, based on this, developing a renewal plan. In the planning process, the balance between conservation and development is emphasized to maintain the urban form and historical continuity. Finally, through typological tools, the planning ensures the continuation of the value of historic buildings and cultural landscapes, and enables residents to enhance their sense of identity with the city, thus achieving effective protection of urban memory.

5.3. Analysis of the impact on urban memory protection

As an innovative design tool, urban memory typology has had a profound impact on urban memory protection. By introducing typology theory into urban planning, it is possible to identify and preserve urban Spaces and building types of historical and cultural value. This approach not only helps maintain the continuity of urban form but also enhances residents' sense of identity with the city. According to the case of protection planning of Qingdao old city, the application of typology theory can effectively protect urban memory and maintain the uniqueness and ancient charm of the city. Urban memory typology emphasizes the value of cultural heritage, promotes the balance between development and protection, promotes the comprehensive consideration of urban planning from the material to the spiritual level, and provides a profound and meaningful path of cultural inheritance for modern urban design [13].

6. Summary

6.1. Research conclusions

Research shows that urban memory is a core component of a city's cultural and social fabric, and its preservation is essential for urban identity and sustainable development. With the help of typology theory, it provides a new perspective and method to identify and preserve urban memory. Typology becomes an effective urban design tool by revealing the inherent connections between existing buildings and urban spaces. This study verifies the effectiveness of urban memory typology through the case analysis of Qingdao old city conservation planning, and realizes the stability and enhancement of urban form and local identity. As a design tool, typology can introduce historical elements into urban renewal, ensuring the continuous protection of cultural heritage and thus maintaining the uniqueness of the city. This approach aims to preserve not only the physical form of the city, but also its underlying cultural and historical values. This theoretical and practical innovation provides new guidance for current urban planning and design, and puts forward effective strategies for promoting urban development with social, cultural, and environmental sustainability. This study provides important theoretical basis and methodology support for future urban planning practice [14, 15].

6.2. Inspiration for urban planning and design practice

Urban memory typology is of great significance in urban planning and design practice. Integrating typology theory can provide a structured approach to urban design, emphasizing the compatibility of historical context with modern needs. By identifying and protecting the memory carriers in the city, urban planning is no longer only concerned with spatial layout, but is more concerned with the continuation of culture and emotion. Practice has proved that the typology method can keep the form stable and avoid the homogeneity tendency in urban renewal. The core of its humanistic care emphasizes the local identity of residents and improves the quality of life. Typology also encourages designers to reflect and innovate, and to come up with sustainable solutions based on respect for history. This comprehensive approach provides a solid theoretical basis for creating a unique urban environment [16].

7. Conclusion

By introducing the theoretical framework of typology, this study discusses the importance of urban memory and its relationship with urban design, especially how to use typology as a design tool to protect and strengthen urban memory. The results confirm that the typology of urban memory not only helps to maintain the cultural characteristics and historical continuity of the city, but also enhances the residents' sense of belonging and identity to the city. However, the practical application of urban memory typology also faces some limitations, such as the lack of historical data, conflicts among stakeholders, and existing regulatory and policy frameworks that may hinder the implementation of new approaches. Therefore, future research is needed to find more effective strategies to overcome these barriers and further optimize typology tools to ensure their wider and more effective application in urban planning and design. In addition, interdisciplinary collaboration and deep multi-stakeholder involvement will be key to further promoting the urban memory typology approach. This study not only provides a new perspective and tool for the protection of urban memory, but also provides theoretical and methodological support for the sustainable development of urban planning and design in the future. It is hoped that this study will inspire more scholars and urban planners to pay attention to urban memory conservation and promote more innovative empirical research and practical exploration.

Disclosure statement

The author declares no conflict of interest.

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Design Analysis of Variable-Height Simply Supported Steel Truss Bridge

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Abstract: This article analyzes the design of a variable-height simply supported steel truss bridge based on an actual project. It includes its basic situation, introduction to variable-height simply supported steel truss bridges, key design points of such bridges, and finite element analysis of the design effect. The analysis shows that for such bridges, reasonable main structure design and node design are the keys to determining the overall design idea, and through the reasonable application of the finite element analysis method, the design effect can be scientifically determined, providing a reference for the subsequent structural design of such projects.

Keywords: Bridge; Variable height; Simply supported beam; Steel truss; Finite element analysis

Online publication: April 28, 2025

1. Introduction

In modern bridge construction engineering, steel truss bridges have a smaller structural height, strong spanning ability, and greater structural rigidity, making them more suitable for bridge construction with larger spanning distances and stricter height requirements. In the practical application of such structures, reasonable structural design is crucial [1]. Based on this, designers need to combine various practical situations to reasonably determine their design ideas and implement design optimization through finite element analysis, so as to meet their actual design, construction, and application requirements.

2. Project overview

This study focuses on the reconstruction design project of a river-crossing bridge. The main span of the bridge in this project crosses the Beijing-Hangzhou Grand Canal, and the overall plan is a prestressed concrete continuous steel structure of single-box double-room type, with a specification of 508650 m. The current canal roadway in the area belongs to Grade IV, the planning grade is Grade III, and the planned navigation clearance is 80 × 7 m.

Because the current bridge cannot meet the actual navigation needs of the roadway, and the quality of the existing bridge structure is seriously insufficient, the engineering unit has decided to demolish and rebuild it. The rebuilt main bridge structure is a through-type variable-height simply supported steel truss with a span of 120 m. The main truss of the bridge is a triangular variable-height truss with 10 panels and a total length of 120 m. The height ranges from 9 to 15.915 m. The center-to-center distance between the two main trusses on the main bridge is 18.3 m, the ratio of width to span is 1:6.47, and the bridge deck width is 17.0 m. This article mainly analyzes its structural design based on the project overview.

3. Introduction to variable-height simply supported steel truss bridges

3.1. Basic information

Variable-height simply supported steel truss bridges are a common structure in modern bridge engineering. They have diverse truss forms, variable height designs, and rich rod section shapes. The main force in practical applications is axial force, which can adapt to different loads and has a large mid-span bending moment. Such bridge structures are suitable for modern small and medium-span bridges, urban roads and highways, and scenes with limited construction terrain and space [3].

3.2. Application advantages

Currently, the main advantages of variable-height simply supported steel truss bridges are manifested in the following aspects: Firstly, the structure has a large bending moment and shearing force, strong adaptability to load changes, and can effectively prevent deformation problems. Furthermore, the structure has a lightweight, low infrastructure cost, and the structural size can be reasonably adjusted according to the actual internal force distribution, achieving reasonable savings in materials and costs during construction [2]. Additionally, the structure height can be adjusted according to the actual terrain, and it has a good landscape effect, with strong overall environmental adaptability. Lastly, the structure is in a prefabricated and assembled form, and the components are relatively simple, making construction and operation, and maintenance more convenient.

4. Key design points for variable-height simply supported truss bridge structures

4.1. Main structure design

Based on the actual site conditions and practical application requirements of the bridge structure for this project, the designers have determined the following structural design scheme:

The upper and lower chord sections of the main bridge are designed as box shapes. The former has an inter-node length ranging from 11.84–12.17 m, a top plate, and web thickness between 28–32 mm, an internal width of 800 mm, and a height of 860 mm. The latter has an inter-node length of 11.84 m, an internal width of 800 mm, a height ranging from 1140–1466 mm (forming a cross slope on the bridge deck due to the height difference), and a top plate and web thickness between 20–24 mm.

The end diagonal web member has a box-shaped section, with an inter-node length of 10.77 m, an internal width of 800 mm, a height of 800 mm, and a top plate and web thickness of 36 mm. Other diagonal web members have I-shaped sections, with inter-node lengths ranging from 10.77–16.98 m, a width of 800 mm, heights between 600–800 mm, and flange plate and web thicknesses between 20–32 mm.

The bridge deck system consists of closely spaced crossbeams, and the bridge deck plate is made of orthotropic steel with a top plate thickness of 16 mm. The crossbeams are spaced at 2.96 m intervals, stiffened with U-shaped ribs that are 8 mm thick and spaced 600 mm apart. The longitudinal beams have heights ranging from 1140–1466 mm, a web thickness of 16 mm, a bottom plate thickness of 24 mm, and a width of 600 mm.

The horizontal members of the bridge portal frame and cross members have box-shaped sections, with an internal width of 370 mm, a height of 440 mm, and a top plate and web thickness of 12 mm. The diagonal members have I-shaped sections, with a width of 260 mm, a height of 346 mm, a flange plate thickness of 12 mm, and a web thickness of 10 mm.

4.2. Structural node design

For the variable-height simply supported steel truss structure of this bridge project, the designers have determined the following node design scheme:

Two main trusses are used in the cross-section, with end web members positioned outside the bridge portal frame. Cross members are provided at all other upper chord node locations, and the slopes of the centerlines of the portal frames and cross members align with the web slopes.

The main truss has a one-way transverse slope, and the upper and lower chord nodes are designed as integral units. High-strength bolts are used to connect the members and nodes, as well as to join the web plates, top plates, and bottom plates of adjacent chord members. The end web diagonal members are assembled from four pieces, while other diagonal members are inserted into place [4].

The top plate of the lower chord is welded to the steel bridge deck plate. The main truss web plates are bolted to the crossbeam web plates, and the main truss members are welded to the bottom plate.

A truss-type bridge portal frame, with a height of 3.0 m, is installed at the main truss support location. Truss-type cross members, with a height of 4.5 m, are positioned at other support locations.

5. Finite element analysis of design effects for variable-height simply supported steel truss bridges

5.1. Establishment and settings of the finite element analysis model

To analyze the overall design effects of this variable-height simply supported steel truss bridge, designers utilized MIDAS Civil finite element analysis software. Modeling was completed using beam and plate elements, neglecting participating structural forces, and calculations were performed by applying self-weight loads. According to design standards, all steel plates are bridge-specific Q345QD high-strength low-alloy steel plates, with a tensile and compressive strength of 200MPa and a shear strength of 120MPa. Dead loads include the weight of the truss, pavement, and guardrails; live loads consider the one-way 4-lane highway class I vehicle load with patch load effects, and the impact coefficient is set according to the “General Specifications for Design of Highway Bridges and Culverts” JTG D60-2015 (hereinafter referred to as “Specification 2015”). Temperature loads are taken as the maximum (25°C) and minimum (-38°C) values according to the “Highway Specifications”, and the local temperature gradient for the deck is set at ± 10°C. Wind loads are based on the annual average wind speed (25m/s) at the project site for operational values, while also considering the local 100-year wind load value of 28.6m/s, both in the transverse direction of the bridge. Three load combinations are set according to the “Specifications for Design of Steel Structures of Railway Bridges” TB 10091-2017 (hereinafter referred to as “Railway Specifications”): the first is a combination of dead and live loads, the second is a combination of dead, live, temperature, and operational wind loads, and the third is a combination of dead loads, temperature, and 100-

year wind loads [5].

5.2. Finite element analysis of member design effects

For the strength of the main truss upper and lower chords, web members, cross members, and bridge portal frames in this bridge structural design scheme, designers imported various design and load parameters into the finite element analysis model for verification. Through calculation, it was found that the maximum compressive stress in the standard combination mode is -167MPa for the upper chord, -168MPa for the web members, and -100MPa for the cross members and bridge portal frames. The maximum tensile stress is 152MPa for the lower chord, 134MPa for the web members, and 58MPa for the cross members and bridge portal frames. The maximum compressive and tensile stresses in all locations do not exceed the 200MPa specified in the "Railway Specifications", indicating that the member strength design is qualified [6].

Regarding the overall stability of the main truss upper and lower chords and web members in this bridge structural design scheme, designers considered reduction factors and imported various design and load parameters into the finite element analysis model to verify their combined stresses and judge their stability. **Table 1** presents the finite element analysis verification results for the combined stresses of the main truss upper and lower chords and web members in this variable-height simply supported steel truss bridge design scheme.

Table 1. Finite element analysis verification results for combined stresses of main truss upper and lower chords and web members in the variable-height simply supported steel truss bridge design scheme

Serial Number	Member	Section number	Combined stress limit	Check Value	Qualification
1	Top chord	3#	200MPa	-181MPa	Qualified
2		4#	200MPa	-181MPa	Qualified
3	Bottom chord	--	200MPa	Tension bar	Qualified
4	Web member	5#	200MPa	-107MPa	Qualified
5		6#	200MPa	-124MPa	Qualified
6		7#	200MPa	-154MPa	Qualified
7		8#	200MPa	Tension bar	Qualified
8		9#	200MPa	-141MPa	Qualified

Among them, the tension bar adopts a movable structure, and its state is not affected by combined stress. Through calculation, it can be seen that the combined stress of each member does not exceed the limit, and the overall structure can remain stable, indicating that the overall structural stability of the members is qualified.

Based on this comprehensive judgment, the design effect of the members in the variable-height simply supported steel truss structure of the bridge project is qualified.

5.3. Finite element analysis of bridge deck system design effects

For the deck system of the variable-height simply supported steel truss structure in this bridge project, designers first verified the tensile and compressive stresses by importing the design parameters and load parameters of the crossbeam into the finite element analysis model. The maximum tensile stress calculated was 104MPa, and the maximum compressive stress was -158MPa, both within the prescribed limit of 200MPa. This demonstrates that the design of the crossbeam is satisfactory.

Next, designers imported the design parameters and load parameters of the bridge deck panel into the finite element analysis model, using element modeling to verify the tensile and compressive stress values of the transverse and longitudinal bridges [7]. The maximum transverse tensile stress was found to be 27MPa, with a maximum compressive stress of -79MPa. For the longitudinal direction, the maximum tensile stress was 93MPa, and the maximum compressive stress was -8MPa. All these values are within the specified limit of 200MPa, indicating that the design of the bridge deck panel is satisfactory.

Based on this comprehensive evaluation, it can be concluded that the design effects of the deck system in the variable-height simply supported steel truss structure of this bridge project are qualified.

5.4. Finite element analysis of steel truss design effect

Regarding the design effect of the steel truss in the variable-height simply supported steel truss structure of this bridge project, designers first imported the steel truss design parameters and load parameters into a finite element analysis model to check its deflection. According to the relevant regulations in the "Highway Specifications", without considering impact stress, when the lane vehicle load is at the frequent value, the deflection of the steel truss of the bridge structure should be L/500 (L represents the total length of the steel truss bridge) or less, which is considered qualified. After this calculation, it is concluded that under the above conditions, the maximum deflection of the steel truss is 30 mm, which is less than L/500 (240 mm), indicating that the design effect of the steel truss deflection is qualified.

On this basis, the designer used the first-order elastic buckling calculation method in the finite element analysis software to perform a first-order buckling calculation on the steel truss. The calculation shows that the critical value of its buckling coefficient is 7.4. Further finite element analysis reveals that the buckling coefficient of the steel truss will only reach the critical value in the case of web member instability. However, according to the above finite element analysis and calculation results, there is no risk of instability in the structural web members, so there will be no instability issues in the steel truss, indicating that the design effect of the first-order buckling of the steel truss is qualified.

Therefore, it can be comprehensively judged that the design effect of the steel truss in the variable-height simply supported steel truss structure of this bridge project is qualified.

5.5. Finite element analysis of pre-camber design effect

According to the relevant regulations in the "Highway Specifications", for steel bridge structures in bridge engineering, pre-camber settings should be properly made during design. Under normal circumstances, the pre-camber should be taken according to the deflection formed under the condition of dead load plus 1/2 of the frequent live load value, and the frequent value coefficient is taken as 1. For the variable-height simply supported steel truss structure of this bridge project, based on its basic design conditions and the actual situation of the construction site, the designer set the camber method as not changing the length of the lower chord and web members, but only by lengthening or shortening the length of the upper chord, so that the steel beam structure is cambered upwards, and its camber value is close to the theoretical pre-camber [8]. To verify the design effect of its pre-camber, the designer imported the overall bridge structure design parameters and corresponding loads into the finite element analysis model to analyze the design effect of its pre-camber.

Table 2 shows the finite element analysis and calculation results of the pre-camber of the entire bridge structure in the design scheme of the variable-height simply supported steel truss bridge.

Table 2. Finite element analysis and calculation results of the pre-camber of the entire bridge structure in the design scheme

Serial number	Member number	Node number	Extension of top chord	Theoretical pre-camber	Actual pre-camber	Pre-camber deviation
1	A1A2	1#	8 mm	85 mm	84 mm	-1 mm
2	A2A3	2#	8 mm	186 mm	185 mm	-1 mm
3	A3A4	3#	13 mm	235 mm	238 mm	3 mm
4	A4A5	4#	13 mm	286 mm	283 mm	-3 mm
5	A5A6	5#	18 mm	290 mm	292 mm	2 mm
6	A6A7	6#	14 mm	274 mm	275 mm	1 mm
7	A7A8	7#	14 mm	221 mm	221 mm	0 mm
8	A8A9	8#	9 mm	163 mm	160 mm	-3 mm
9	A9A10	9#	8 mm	49 mm	51 mm	2 mm

After calculation, the maximum difference between the actual pre-camber and the theoretical pre-camber of the bridge is 3 mm, which does not exceed the standard deviation limit of 5 mm. This indicates that the design value of the upper chord extension is completely reasonable, and the design effect of the pre-camber of the overall bridge structure is qualified.

6. Conclusion

In summary, for the variable-height simply supported steel truss structure in bridge engineering, during specific design, designers should first complete various structural parameter designs based on actual conditions and needs, and then verify the design effect through finite element analysis. After the finite element calculation of the bridge design scheme in this project, the designer confirms that the design effect is completely qualified and can be put into practical application.

Disclosure statement

The author declares no conflict of interest.

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Research on Key Stages and Control Strategies of Whole-Process Cost Management in Agency-Built Projects

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Abstract: Against the backdrop of the increasingly complex construction market environment, the whole-process cost management of agency-built projects faces issues such as cost overruns and insufficient management efficiency due to the numerous stages and high technical requirements involved. This paper focuses on the key stages of whole-process cost management in agency-built projects, including project initiation, design, construction, and completion. It proposes strategies to optimize the cost management process and enhance management efficiency, providing theoretical support and practical guidance for the whole-process cost management under the agency-built model.

Keywords: Agency-built projects; Whole-process cost management; Cost control; Dynamic management; Completion settlement

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1. Introduction

Agency-built projects are widely applied in complex construction projects due to their high degree of specialization and strong management efficiency. However, with the changes in the construction market environment and the expansion of project scale, the whole-process cost management of agency-built projects is facing practical problems such as an imperfect management system and increased difficulty in cost control. Based on the practical needs of agency-built projects, this paper starts from the key stages of whole-process cost management, combines actual cases, and explores optimized management models and control strategies, providing a scientific basis for reference and practical guidance in relevant fields.

2. The basic concept and framework of whole-process cost management in agency-built projects

The whole-process cost management of agency-built projects refers to a management approach that systematically manages and dynamically controls the cost of construction projects from project initiation to completion and delivery under the agency-built model [1]. Its purpose is to optimize resource allocation and enhance investment efficiency by employing scientific methods and effective technical means, thereby ensuring the achievement of project objectives. The basic framework of whole-process cost management consists of four core stages: First, during the project initiation stage, cost estimation and investment control are carried out through feasibility studies, economic analysis, and preliminary estimation to determine a reasonable scale of investment. Second, during the design stage, cost optimization is achieved through limited design, alternative scheme selection, and value engineering to coordinate the design outcomes with cost targets. Third, during the construction stage, dynamic cost management is implemented with contract management as the core, and real-time cost control is realized through quantity surveying, change review, and phased settlement. Fourth, during the completion stage, settlement and cost evaluation are conducted through completion account audit, cost indicator analysis, and post-evaluation to improve the management mechanism. This is specifically illustrated in **Figure 1**.

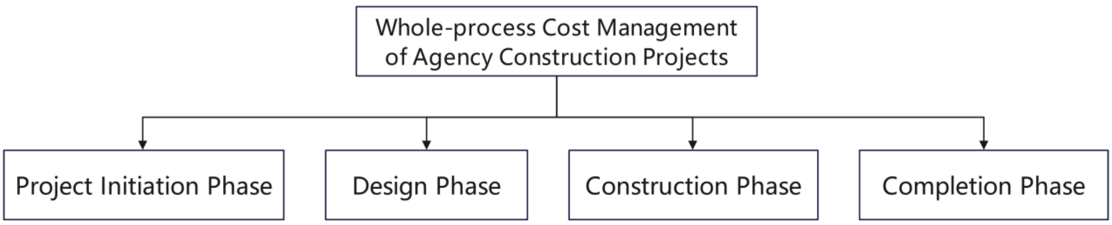

Figure 1. Technical roadmap for whole-process cost management of agency-built projects

3. Key stages

3.1. Cost management during project initiation and design stages

During the project initiation stage, cost management centers on a scientific and rational investment estimation, taking into account factors such as technical feasibility, market demand, policy environment, and funding sources to formulate an investment plan that meets the overall project objectives [2]. In the design stage, a combination of limited design, scheme optimization, and value engineering is employed to achieve a coordinated unity between cost targets and design depth. The management process emphasizes the full utilization of technical tools and data models, integrating project functional requirements and cost indicators for comprehensive evaluation, and adopting multi-scheme comparison to optimize design outcomes [3].

3.2. Cost control and dynamic management during construction stage

Cost control and dynamic management during the construction stage involve real-time supervision and dynamic adjustment of the project implementation process to achieve cost control objectives. The focus of management is on the basis of contract terms and construction organization design, employing methods such as quantity surveying, contract execution, and phased settlement to implement refined cost control. Dynamic management relies on real-time data analysis, integrating construction progress, resource allocation, and quality requirements organically [4]. It involves optimizing construction organization, adjusting resource allocation, and monitoring budget execution to ensure that costs are effectively controlled within the set limits.

3.3. Settlement review and cost evaluation during completion stage

The core of settlement review and cost evaluation during the completion stage is to ensure the authenticity and reliability of project costs and to provide a comprehensive summary of management work. The settlement review is based on contract terms and actual completed work quantities, conducting a systematic review of completion documents, settlement files, and bill of quantities. During the review process, construction records, design changes, and actual on-site completion are comprehensively compared, with a focus on verifying the accuracy of work quantities and costs to avoid overestimation or omission. Cost evaluation focuses on analyzing the implementation effectiveness of whole-process cost management, assessing the deviation between actual and budgeted costs, and summarizing the strengths and weaknesses of management measures and their implementation effects to provide experience accumulation and improvement suggestions for subsequent projects [5].

4. Project overview

The Phase III Infrastructure Construction of the Airside Economic Industrial Park Surrounding the Phase III Expansion Project of Baiyun International Airport (Fangshi, Fenghe, Yahu, Heruilu, and Zhusan plots) is located in Renhe Town and Zhongluotan Town, Baiyun District, Guangzhou City [6]. The construction content of the project includes resettlement housing, supporting commercial and public buildings, as well as municipal road facilities within the land use red line, with a planned total construction area of approximately 851,638.55 square meters, including 624,020.8 square meters above ground and 227,617.75 square meters underground. The project is planned to resettle 1,906 residential units, with a resettlement housing area of 533,643 square meters, a public supporting facilities area of 70,326.8 square meters, and an underground area of 227,617.75 square meters. The engineering content includes excavation support, karst cavity treatment, soft foundation treatment, earth and stone work, architectural decoration, civil air defense, heating, ventilation, intelligent systems, landscape engineering, etc., and is guided by green building standards to promote sustainable development [7]. The project has a planned total duration of 1,080 days, and upon completion, it will enhance the level of infrastructure in the region and provide strong support for regional economic development [8].

5. Control strategies for whole-process cost management in agency-built projects

5.1. Improving the accuracy of cost forecasting in the project decision-making stage

In the project decision-making stage, this project has formulated a scientific preliminary planning and detailed cost forecasting strategy to ensure the rationality and feasibility of the budget plan. Specific measures include strictly implementing geological survey procedures, organizing a professional team to conduct thorough surveys and analyses based on the special geological conditions and climatic characteristics of the project area, and forming a complete set of basic data covering geological types, groundwater conditions, and construction risks. Meanwhile, following the relevant requirements of the “Code for Quantity-based Pricing of Construction Projects (GB50500-2013),” detailed calculations are conducted for each individual project, clarifying the cost composition of each sub-item in the bill of quantities, and a precise budget allocation plan is formulated by comprehensively analyzing factors such as material supply, construction techniques, and technical parameters [9]. In addition, the project employs a dynamic estimation model to track key cost elements such as material price fluctuations, labor cost adjustments, and machinery rental fees in real time, and sets aside a reasonable contingency of 10%–15% to ensure sufficient financial flexibility to cope with policy adjustments, market price fluctuations, and unexpected events. This is specifically illustrated in **Figure 2**.

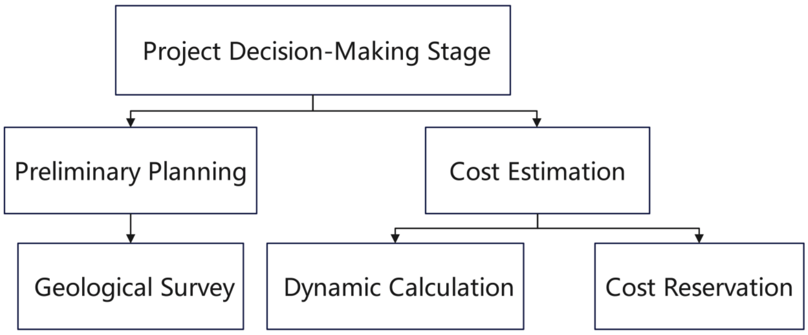

Figure 2. Cost management technical roadmap for the project decision-making stage

To enhance the precision of cost forecasting and the scientific basis for decision-making, the project established a regional construction cost database [10]. By employing big data technology to integrate historical cost data from similar projects and calibrating the cost baseline in accordance with current market dynamics, the project conducted a sensitivity analysis to assess potential cost fluctuations caused by different design schemes. To ensure the comprehensiveness and accuracy of cost estimation, the project implemented an expert review and an interdepartmental joint review mechanism. A joint evaluation team, composed of cost experts, design units, construction management teams, and third-party consulting firms, was organized to conduct multiple rounds of review and optimization of the preliminary budget plan. Consensus was reached on the rationality of key cost indicators and the feasibility of construction. Additionally, digital budget management tools were introduced to update estimation parameters in real-time and generate visual reports, ensuring transparency and traceability of budget data. Regular cross-departmental coordination meetings were held to review and revise the technical approach and cost model of budget preparation. Ultimately, a precise cost control system covering the entire project life cycle was constructed, laying a solid foundation for cost management in subsequent implementation stages [11].

5.2. Strengthening cost control in the design stage

In the design stage, the design unit fully implemented the requirements of the "Regulations on the Depth of Architectural Engineering Design Documents (2016 Edition)," clarifying the design depth and delivery standards for each specialty. Combining the technical demands of green building and prefabricated construction, BIM technology was employed throughout the entire design process. Specific measures included establishing a 3D model of the entire project using BIM technology to dynamically simulate the building volume, structural layout, and installation of equipment and pipelines [12]. Multiple design schemes were optimized and compared to achieve a balance between technical feasibility and economic viability. Comprehensive analysis was conducted on material usage, construction techniques, and technical parameters of building components, with real-time cost estimation of optimized schemes to ensure that the final design outcome met regulatory requirements and minimized cost risks during the construction phase.

Furthermore, the project strengthened the integrated management of design and cost control by establishing a linkage mechanism among the design unit, cost consulting unit, and construction unit. Before the submission of design results, a comprehensive review and optimization were conducted on errors in quantity calculation, unreasonable material selection, and structural redundancy in the construction drawings. To address potential cost fluctuations caused by design changes, a dynamic cost early warning system was adopted to track cost changes in real-time and intervene promptly. In the design stage, the dynamic management capability of cost data was enhanced by introducing quantitative analysis tools and cost management software to dynamically update material market price fluctuations, supply chain conditions, and costs of design changes, ensuring timely and accurate cost control information. The project also strictly regulated the design briefing and drawing review process, adopting refined drawing review and briefing meetings to clarify construction technical requirements and cost control priorities [13]. This ensured that construction units accurately understood the design intent, minimizing construction changes and material waste caused by drawing issues, thereby achieving optimized cost management throughout the life cycle.

5.3. Strict cost monitoring and management in the construction stage

In the construction stage, the project established a comprehensive dynamic cost management system to precisely align the budget with actual expenditures, ensuring strict control over project costs throughout the process. Specific measures included establishing a dynamic monitoring system supported by a digital management platform to achieve real-time tracking and analysis of project progress, resource consumption, and fund flow. By comparing dynamic data with the construction schedule, potential cost deviations were quickly identified and corrected. For change requests submitted by construction units, a rigorous multi-party review mechanism was implemented. The supervising unit first verified the actual completed work volume on-site, followed by detailed estimation and re-calculation of the change content by the cost consulting unit. Finally, the contracting party decided whether to approve the change costs based on the review results, ensuring that the calculation basis for change costs was sufficient and that fund usage complied with contractual requirements [14].

In terms of material and equipment procurement management, the project strictly implemented a material supply management system for the contracting party. Clear regulations were set for procurement standards, supply channels, and quality acceptance procedures. Market dynamic monitoring was employed to analyze material price fluctuations in real-time, and procurement price limits and risk contingency plans were established for key materials to avoid cost overruns caused by abnormal market price fluctuations or material quality issues. Meanwhile, on-site construction implemented refined cost accounting management, with dedicated cost personnel calculating daily work volume completion, resource consumption, and material utilization. Detailed cost accounting reports were regularly submitted to the contracting party and supervising unit for review. Additionally, regular multi-party coordination meetings were held to compare budget and actual expenditure data, analyze cost risks in construction progress, and take corrective measures in a timely manner to ensure that fund usage during the entire construction stage was scientific, rational, and controllable. The specific management process is shown in **Figure 3**.

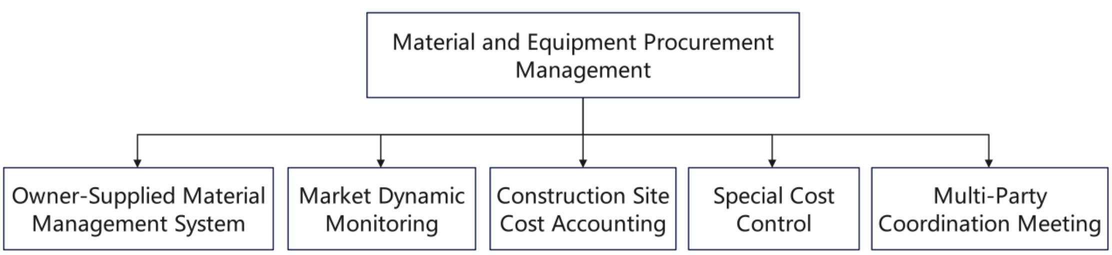

Figure 3. Technical roadmap for material and equipment procurement management

5.4. Rational settlement and audit during the completion and acceptance stage

Before completion and acceptance, the construction unit must submit a complete set of completion documents in accordance with the contract requirements. These documents include verified completion drawings, change records, on-site approval forms, and various types of acceptance documents. Based on these documents, the construction unit is required to prepare a detailed completion settlement file. The cost management department will conduct a thorough review of the settlement documents submitted by the construction unit, strictly checking the bill of quantities, change approval contents, and the actual completed work volume to ensure that the settlement data is consistent with the construction contract and the actual project situation. Any issues identified during the review will be immediately fed back to the construction unit for timely rectification. The review will focus on verifying the consistency between the bill of quantities items and the completion drawings, with particular attention to high-risk items and the compliance of costs outside the contract. In addition, a dynamic settlement progress management mechanism has been established, enabling the cost management department to control and accept the settlement process in stages. This mechanism effectively shortens the completion settlement review cycle and prevents delays in settlement from affecting the overall financial plan of the project [15].

During the audit phase, this project introduces an independent third-party auditing institution to conduct a comprehensive review of the completion settlement. Special emphasis is placed on auditing items that are prone to discrepancies or disputes, such as change orders, key material usage, and costs outside the contract. This ensures that all costs are supported by sufficient evidence and reasonable calculation standards. Regarding the payment and refund of the quality guarantee deposit, the project adopts a tiered review mechanism, with the supervising unit, cost consulting unit, and contracting party jointly reviewing and signing off on the payment approval opinions. This ensures that the payment of the guarantee deposit complies with the contract terms and acceptance standards. In addition, for matters involving settlement disputes, the project has established a detailed dispute resolution process. Expert reviews or arbitration procedures are organized to ensure fair handling of disputes and to avoid delays in project acceptance and fund management, thereby achieving standardized and closed-loop management of completion settlement.

6. Conclusion

Whole-process cost management in agency-built projects is a crucial component in achieving project economic benefits, efficient resource utilization, and quality control. The management process spans the entire life cycle of the project, from initiation to design, construction, and completion. Scientific and rational cost management can effectively improve resource utilization, reduce the risk of cost overruns, and promote dual enhancements in engineering quality and economic benefits. This paper has conducted a systematic review of key stages and in-depth research on control strategies, proposing specific measures to optimize whole-process cost management. These measures provide a comprehensive scientific basis and optimization path for cost management under the agency-built model.

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Study on Safety Management Measures for Municipal Infrastructure Demolition Project

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Abstract: With the continuous advancement of the country's urbanization process, many cities are simultaneously carrying out the renovation of old urban areas while building new urban areas, which involves the demolition of many buildings and municipal infrastructures. To ensure the smooth progress of demolition projects, related safety management work is crucial. This article will discuss the safety management measures for demolition projects based on the basic principles of safety management for municipal infrastructure demolition projects, taking the demolition of gas storage tanks as an example.

Keywords: Municipal; Infrastructure; Demolition engineering; Safety management

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1. Basic principles of safety management for demolition projects of housing construction and municipal infrastructure

Demolition enterprises should have the corresponding qualifications. The demolition operations undertaken should be in line with the grade regulations, and they cannot be subcontracted or leapfrogged. Before the demolition project is carried out, the preparation of the construction organization design should be completed. The construction organization design should be scientific, specific, and operable, and at the same time, have strong safety technical measures. If it is necessary to change the construction method and adjust the construction sequence, the construction organization design should be supplemented and the written documents should be revised. In terms of demolition methods, mechanical demolition should be the main method as much as possible to reduce the manpower and material resources consumed by demolition, to ensure the safety of the operation. If large dust is generated during the demolition stage, the wet operation method should be the main one. If the scaffold needs to be used, the scaffold erection needs to be carried out by a professional unit, and a special project construction plan can be prepared, and it can only be used normally after passing the acceptance. In the stage of the demolition process, the scaffold can be removed simultaneously. After the demolition construction is completed, the personnel should fully clean up the site and avoid affecting the safety of the surrounding pipelines and buildings [1].

2. Safety management of infrastructure demolition projects - take the removal of gas storage tanks as an example

2.1. Preparation work

Before dismantling the storage tank, relevant documents should be drawn up, and the demolition plan and construction organization design approval should be applied to the relevant departments. Before construction, relevant personnel should fully read and understand relevant regulations and documents as well as do a good job of technical disclosure. Technicians should take into account the actual situation to increase the effective protection of the site. In terms of site preparation, the power supply and circuit required for demolition construction need to meet national and industry standards. The same is true for the supply and drainage system. The construction site should have a drainage system to avoid a large amount of water accumulation on site. The site should be flat to avoid water accumulation affecting the safety of the foundation. At the same time, various construction facilities used for on-site demolition should be strengthened to strengthen the exemplary management of lifting tools. On-site fire protection facilities also need to be fully implemented, such as warning signs, safety warning signs, etc. [2].

2.2. Tank removal

Before cutting the baseplate, in order to ensure the thoroughness of the baseplate removal, the floor concrete part should be completely removed by a hydraulic hammer, and the tank baseplate should be fully exposed to avoid a large amount of dust during concrete removal. If there is a lot of dust on site, water can be sprayed by a high-pressure water gun, and mist water can be sprayed to achieve the purpose of dust reduction. Through the infrared level scribing, the tank wall is cut along the scribing direction, which can generally be completed by a water knife of an ultra-high pressure water jet cutting machine.

The outer tank wall can be cut by hydraulic hawkbill pliers. When scribing and cutting, it should be avoided to touch the tank column to prevent the column from being disconnected without interruption. Since the shearing is a physical reaction, coupled with the high temperature caused by the metal collision, the shearing position is sprayed by the high-pressure water gun to achieve the cooling effect. Before the shearing of the tank is completed, the site can be divided by a crane, and different parts can be laid down by a crane [3]. Before laying down, the on-site personnel need to hang the sling utensils and traction ropes, etc., and then cut them off by hydraulic shears. All lifting work needs to comply with safety precautions. After the steel plate is removed, the materials should be stacked at the designated location according to the requirements of the construction unit and the actual situation on site. The tank water tower layer should meet the construction requirements of the outer tank layer.

All operations should comply with the demolition construction requirements, and the site environment should be isolated, and special personnel should be arranged for monitoring. During construction, the removal of tank wall panels and tank edge panels is a key process in the demolition project. Circular cutting can be carried out by an automatic high-pressure water cutting machine, and the tank body can be cut by large hydraulic pliers. This removal method does not generate open flame operations, and the safety risk is low. The workload of building scaffolding can be omitted, and cost control can be done well [4].

2.3. Safety management

2.3.1 Safety education

For personnel entering the site construction, the safety person in charge of the project department shall do a good job of safety education and establish a safety education file in a targeted manner. After the personnel receive education, the project department shall conduct an assessment and complete the application of the admission certificate before they can enter the site for operation. Education belongs to the third-level education. The enterprise, the project department and the team are the main bodies of education respectively. All education processes ultimately need to be signed and written records formed.

For personnel engaged in special work, while doing a good job of safety education, a special operation personnel registration form should be established in a targeted manner, and various types of information of personnel, including the issuing authority, the operation certificate number, the operation project and the operation of machinery and equipment, should be recorded in detail. Safety education should comply with the requirements of the actual situation on site, as well as the post responsibility system and technical operation procedures. The content of safety education includes safety management system, fire prevention and fire protection knowledge, equipment use requirements, safety production overview, emergency treatment measures, etc., and strives to be detailed [5]. If there is a requirement for transfer or resumption of work, the safety education for new positions or new construction requirements should be re-organized, and the personnel will be tested. After passing the assessment, the personnel can be re-employed. During the period when the personnel are on duty, if there is an illegal operation situation, the project department should re-organize the safety education of the personnel, and it also needs to go through the assessment before allowing the personnel to return to work.

During the demolition project stage, the project department also needs to conduct safety education of personnel from time to time, and carry out safety education activities through safety activity days, safety regular meetings, etc. In case of special climate conditions or construction site conditions, additional safety education is required. All learning situations need to form a safety ledger. Personnel need to master the safety rules and regulations, and consciously abide by them. If any operation with hidden risks is found, it should be rejected in a timely manner. Once an accident occurs, it should be reported to the person in charge in a timely manner.

2.3.2. Safety and technical disclosure

Before the start of the tank removal project, technical disclosure should be carried out. The content of the disclosure should be as detailed as possible. Both the disclosure and the person to be disclosed need to sign. On-site construction personnel should sign the bottom and urge the personnel to implement the specific operations. The person in charge of the site should organize random inspections of the safety situation from time to time, and order corrections if it does not meet the requirements.

2.3.3. Safety inspection

The safety officer should strengthen the inspection of the site during the tank removal stage to reduce the unsafe behavior of people and the unsafe state of things. For the safety defects found, the safety officer should supervise the on-site construction personnel and complete the rectification within the specified time limit. The relevant situation of the inspection should be clearly recorded [6]. The content of the inspection is specific, including the implementation of the system, the thinking of personnel, the use of machinery and equipment, the safety of equipment, the implementation of education and training, the use of labor insurance, and the handling of accidents.

For the problems found in the safety inspection, the project department should summarize the solution to the problem through a meeting, and formulate a follow-up rectification tracking plan. The power supply and water source at the demolition site need to be handled by a special person. Safety warning signs should be set up in dangerous locations (additional red lights should be installed at night to serve as a reminder) to strengthen the safety awareness of personnel. If a fire needs to be started, a fire prevention responsibility system should be established specifically, and an approval system should be used for fire use. A fire prevention management system should be set up on site, and a person should be responsible for the fire approval system. The smoothness and cleanliness of the road on site should meet the requirements.

There should be good drainage conditions in the field, no water accumulation, and garbage should not be piled up at will. Instead, it should be dealt with in a timely manner. The responsibility system for safe production should be implemented on an individual basis, and the implementation of personnel should be supervised. For the machinery and equipment used in the demolition construction, the switch should be equipped with a leakage protector, the rotation position should be equipped with All construction personnel are required to wear a badge, and the badge information should include the name, title and contact number of the personnel [7].

2.3.4. Safety signs and announcements

Switch boxes, distribution boxes, etc. used on site should be carefully inspected. If maintenance is required, the power supply should be disconnected in advance, and the power outage sign should be hung in a conspicuous position. If the construction site work utensils and mechanical equipment do not meet the demolition construction requirements, they cannot enter the construction site and hang the signs on the mechanical equipment. If there is a large noise at the construction site, or there is a painting operation, the on-site personnel should be reminded to wear anti-noise devices. Safety passage positions should prevent signs such as fire hydrants or fire extinguishers. Once personnel encounter a fire, they can organize fire extinguishing as soon as possible.

2.4. Protection of personnel

The personal protection of personnel is of paramount importance. Personnel entering the site for construction should wear safety helmets and puncture-proof safety shoes. If it is necessary to dispose of materials that may harm hands, such as irritating, flammable, corrosive and relatively sharp materials, gloves should be worn. When engaged in crushing, burning and welding, etc., welding masks and protective glasses should be worn to prevent strong light or sparks from harming the eyes [8].

2.5. Mechanical management

Safety protection devices should be set up at the transmission position of construction machinery and equipment. The supervisor should take protective measures and ensure that relevant operations are in place. The safety protection of mechanical protection facilities needs to be implemented by special personnel. If conditions permit, protective facilities should be fixed on the machine, and sharp corners should be replaced by barrier protection facilities.

During the demolition stage, if abnormal phenomena such as heat and noise are found in the construction machinery and equipment, or other faults are found, it should be stopped in time, and the power supply should be cut off for comprehensive maintenance. During the construction stage of machinery and equipment, operators cannot eat on site. At the same time, they should complete the cleaning of waste and garbage as soon as possible, and fulfill the requirements of safe construction and civilized construction.

The construction of machinery and equipment should be guaranteed to be standardized, and no illegal command or construction can be carried out. Night construction should be equipped with adequate lighting, and electricians should have professional qualification certificates. In order to avoid leakage of electricity, a rain shelter should be set up on the site, and various types of machinery and equipment should be scientifically arranged to prevent the occupation of a large number of work sites. After the demolition is completed, it should be recycled as soon as possible [9].

2.6. Electricity management

Cables should ensure good insulation, correct wiring, and All the dismantling and maintenance of power supply lines need to be completed by electricians. On-site power distribution cabinet doors should be locked, and fire extinguishing equipment and protective supplies should be placed near the site for easy access at any time. Temporary power equipment set up should be well grounded protection. All kinds of portable equipment should also be well protected against leakage. The rated current should not be greater than 30mA, and the response time should not exceed 0.1s [10].

3. Conclusion

To sum up, the safety management of municipal infrastructure demolition projects needs to do a good job in technical management, on-site management and personnel management, etc., and do a good job in safety education for personnel, as well as safety inspection of the site, and establish a strong sense of safety production among personnel, so as to improve the safety of demolition projects and ensure the smooth progress of related work.

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Application Strategy of BIM Technology in Bridge Design

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Abstract: BIM technology has become an important tool in road and bridge design. Through the application of BIM technology, the entire bridge process can be modeled to form a virtual bridge form. Through the simulation of bridge construction materials, construction techniques, and construction processes, a comprehensive analysis can be conducted to achieve visualization of the design and improve the efficiency of bridge design. This article mainly analyzes the advantages of BIM technology in bridge design, explores the application forms in bridge design, and proposes strategies to optimize bridge design, providing a certain reference for the improvement and optimization of bridge design work.

Keywords: Bridge design; BIM technology; Advantages

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1. Introduction

In the process of bridge design, various factors such as construction procedures, construction sites, and construction materials need to be fully considered. Therefore, traditional bridge design is difficult, has a long design cycle, and is prone to changes in the later stages of design. The application of BIM technology in bridge design allows for the direct input of construction requirements and measurement data into the system. The system can automatically analyze the design data to form a bridge design model, making the bridge design data more accurate [1]. Furthermore, through the model, potential construction issues can be visually identified and addressed during the design phase, avoiding rework later on, which can lead to wasted construction materials and increased costs. BIM technology has numerous advantages in bridge design, making it the primary tool system for bridge design. However, the current application and development are not yet perfect, and further optimization is possible in subsequent applications.

2. Advantages of BIM technology in bridge design

2.1. Formation of visual structure diagrams

The application of BIM technology in bridge design allows for the creation of three-dimensional, visual design structure diagrams through data input. Designers can preview the design drawings, view the feasibility of the design drawings from different angles of the bridge structure, which is conducive to discovering design problems in a timely manner and optimizing the design results [2]. Additionally, the visual design drawings formed by BIM technology can simulate real-world scenarios, including the application of advanced materials and various pipeline collision tests. This allows for the resolution of design deficiencies from the early stages of design, effectively controlling design costs.

2.2. Achieving intensive construction management

BIM technology expresses advanced design concepts and can accurately analyze models. If design issues are discovered during the design phase, these two functions can be utilized to form clearer and more intuitive inspections, provide corresponding feedback, and demonstrate the application of the design scheme [3]. BIM technology can use simulation systems to present various components in the design. Using auxiliary custom parameters to solve various problems in bridge design improves the quality of bridge design, achieves intensive management of bridge design, provides effective guidance for subsequent design and construction work, ensures construction efficiency, and prevents rework issues later on.

2.3. Improving design efficiency

Bridge construction is susceptible to various forces. To ensure construction quality, the accuracy of design calculations must be guaranteed. However, traditional bridge design primarily relies on manual design methods without utilizing digital technology, which can easily lead to various errors in the design [4]. The application of BIM technology is beneficial for improving the accuracy of bridge design. It can use simulation technology to analyze potential problems that may exist in the design, reducing design errors. Additionally, all design modifications in traditional design require manual adjustments, which can be time-consuming and difficult. BIM technology can revise the design scheme by adjusting parameters, shortening the design cycle and improving design efficiency.

3. Application forms of BIM technology in bridge design

3.1. Assisting in feasibility analysis

In bridge design, it is necessary to fully consider various factors such as the climate and geology of the construction site, which involves a relatively complex analytical process. The application of BIM technology can create a visual design form, coordinate and simulate bridge engineering projects, digitize complex data, and provide designers with more standardized reference solutions [5]. Simultaneously, BIM technology can also be applied to the surveying and mapping process, enabling advance simulation analysis to avoid significant changes during construction and providing necessary supplements for subsequent design work. BIM technology can further utilize 4D technical means to simulate the construction process during the design phase, locate construction equipment, retrieve relevant control routes and information, and break traditional management modes. Therefore, in the construction of BIM models, it is essential to ensure the accuracy and authenticity of the data.

3.2. Batch output of design outcome documents

Design drawings are the primary basis for subsequent construction in bridge design. By adopting BIM technology, detailed inspections of bridge design elements can be conducted using software systems, design drawings can be verified, defects and insufficiencies can be identified in a timely manner, and rectifications can be made to address these issues, enabling drawing verification and review. During the operation of BIM technology, directly inputting component parameters can facilitate the updating of design drawings [6]. Additionally, in the initial design of drawings, data associations can be established between components, allowing for information changes to occur automatically when one data point is modified. This enables batch modifications in drawing design, improves drawing design efficiency, and ensures the quality of drawing design.

3.3. Engineering quantity statistics application

In bridge engineering design, engineering quantity statistics is a crucial aspect. Traditional engineering quantity statistics primarily rely on two-dimensional plan design drawings, where information between various components is independent and requires sequential analysis. If design requirements change, the engineering quantities of each component need to be updated promptly, and all related data must be modified, increasing the workload in bridge design. The application of BIM technology in bridge design effectively addresses these issues. BIM technology allows for the creation of virtual bridge models through parameter input and enables precise statistics on cost information and materials related to various components based on the model. By utilizing this data, custom formulas for calculating various engineering quantities can be constructed, enabling automatic statistics and calculations even when data changes.

Additionally, Revit software can be employed to generate detailed information commands for various parameters during drawing design, which are used for engineering quantity statistics. Furthermore, in bridge construction, large amounts of steel bars, concrete, and other construction materials are used, with variations in material specifications and shapes depending on the location. Traditional manual calculations require multiple statistics based on material classification [7]. Moreover, it is necessary to add various information such as material type and specifications to the statistical and calculation details, increasing the computational workload of the project. With BIM technology, data input directly follows pre-designed commands to complete various engineering calculations.

3.4. Construction process simulation application

The primary purpose of bridge design is to provide a reference for subsequent construction, ensuring the safety and efficiency of later construction work. Therefore, bridge engineering design must be reasonable to avoid design changes and rework due to issues discovered during later construction, which can affect construction progress and increase costs. Traditional bridge design primarily relies on drawings and written proposals. This two-dimensional design approach is less effective for presenting complex processes, making it difficult to fully exhibit all design details. The lack of intuitive design drawings can hinder designers' comprehensive consideration of the design scheme [8]. The application of BIM technology enables the creation of three-dimensional visual models during the design phase, allowing for the simulation of the entire bridge construction process.

Especially for concealed construction content or structurally complex locations, software simulation ensures the rationality of construction procedures and achieves better construction results. In simulation applications, BIM technology can disassemble the bridge model into multiple small units through coding, ensuring that each unit's procedures meet construction principles and generate procedure codes. Subsequent construction plans strictly follow the division of procedures, and the allocated procedure content is imported into the workbench to simulate the construction process. This allows for adjustments and optimizations of the construction scheme based on the arrangement of construction procedures. Additionally, BIM simulation technology can simulate the craftsmanship in bridge construction, ensuring the rationality of construction procedures. For example, in the construction process of prestressed tendon formwork, BIM technology models can be utilized during the design phase to establish standard controls for construction workload and quality control points, improving operational efficiency.

3.5. Bridge design conflict testing

BIM technology is widely used in bridge collision conflict experiments. Through BIM collision conflict testing, the rationality of the position of all components in bridge design can be ensured, avoiding problems of component crossover and collision in subsequent construction and guaranteeing the safety of the bridge construction structure. Most collision conflict detections require breaking the two-dimensional spatial layout mode and coordinating from three-dimensional space to ensure that all constructions do not form obstacles in the three-dimensional distribution [9]. Firstly, in the preparation stage of design, the application of BIM technology can integrate and consolidate all information, incorporating various design elements into one environment. Simultaneously, the accuracy of various parameters is tested to ensure they meet the granularity requirements of the detection.

Secondly, it can be used for model building. After the BIM model is constructed, collision conflict detection is directly performed on the virtual platform, automatically scanning and finely distinguishing various potential conflict areas in the design, especially the large number of pipelines involved in the bridge, which can be displayed in a timely manner once there is a conflict collision. Finally, the collision detection software can visualize the locations of conflicts and generate reports to reflect the problems between components and make timely adjustments. In BIM technology-assisted bridge design detection, potential problems in construction can be investigated during the design phase, reducing the probability of workload changes later and ensuring the safety of bridge construction.

4. Application strategies of BIM technology in bridge design

4.1. Improving BIM design models

The application of BIM technology in bridge design allows for the integration of main structural information of the bridge. However, bridge design is difficult to achieve in one step, and there are many areas that require optimization later. Overall, the application of BIM technology in bridge design demonstrates strong design interactivity. Designers can use BIM technology to more intuitively view the three-dimensional drawings of the bridge and adjust the drawings according to design needs. Simultaneously, adjustments to the data in the model can be made to update the overall structural design. In the application of technology, the uniformity and standardization of all data must be ensured. BIM technology can standardize various data and improve the accuracy of the model. Especially with the improvement of BIM technology's computing power, the control over the accuracy calculation of the design model will be stronger, and the design of bridge components will be more refined. This requires that the model constructed by BIM technology must handle the details of each location, breaking the single structural model. Attempts can be made to combine it with models such as pipelines and electromechanical components in the bridge structure to form a more complete design scheme and make the bridge design model collaborative.

4.2. Optimizing bridge design schemes

Before starting bridge design, it is necessary to determine the bridge structure and construction scheme, which serve as references for the design drawings. The design also needs to be preset in advance based on the design scheme. However, due to factors such as early surveys and design ideas, there will inevitably be some defects, making it impossible to achieve a one-time design. Additionally, traditional CAD software uses a two-dimensional image design method, which is not conducive to reflecting bridge features. If errors occur in the referenced design during bridge construction, there will inevitably be problems of rework or stoppage in later construction, which will have a huge impact on bridge construction [10]. The application of BIM technology in bridge design projects is conducive to optimizing and improving bridge design projects and promoting the smooth progress of construction projects. BIM technology's prediction and simulation functions can also be utilized to input corresponding data into the bridge model, form data analysis, and construct a three-dimensional model. This enables comprehensive inspection of the design project, avoiding leftover issues, and preventing situations such as non-compliance or lagging progress in later construction.

4.3. Enhancing designer capabilities

BIM technology is still emerging for bridge design work. Although it has many advantages in design applications, there are still a large number of potential functions that have not been effectively developed. To ensure the effectiveness of BIM technology in bridge design, it is necessary to strengthen technical training for designers. All designers need to participate in theoretical and operational training on BIM technology concepts, principles, and more, to ensure that everyone is proficient in BIM technology and understands the application methods of the system. Advanced training should be regularly conducted so that designers can receive higher-level training after having a certain foundation in BIM design. For example, collaborative design, data analysis, and other methods can be adopted to enhance designers' skills and improve their BIM technology application abilities. To enhance designers' practical abilities, it is necessary to strengthen practical exercises in BIM technology, simulate bridge design environments, and improve designers' problem-solving abilities. Additionally, a BIM technology exchange group can be established within the enterprise, where designers can exchange design experiences, raise design questions, and discuss them together, creating a good learning atmosphere. Furthermore, regular BIM technology exchange meetings can be held to showcase BIM design achievements and share design insights. Technical evaluation and incentive levels can also be set up to stimulate employees' enthusiasm for BIM technology.

5. Conclusion

In summary, the application of BIM technology in the design phase of bridge engineering can create a visual design model for the design project. By inputting parameters, a three-dimensional design scheme can be completed, which is beneficial for designers to discover problems in bridge design and make timely rectifications, reducing later engineering changes. At the same time, it can also combine design needs to obtain new design models through parameter changes, shortening design time and ensuring design efficiency. It can also be applied to work such as engineering quantity calculation and design collision contradiction experiments, minimizing mistakes made in the initial design stage and providing more accurate references for subsequent bridge construction. Therefore, in the application of BIM technology, it is necessary to strengthen the optimization of design models, improve design schemes, and enhance designer training to promote the effective use of BIM technology functions.

Disclosure statement

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Reflections on the Integration of Folk Pattern Elements into the Design of Architectural Art

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Abstract: In the production and life of ancient Chinese folk artists, through the abstract and geometric arrangement of things, they formed many meaningful patterns. These patterns are widely used in a variety of decorations, reflecting the most simple artistic ideas in the life of the working people, and are also an important embodiment of folk art aesthetics. Many elements of folk patterns have been preserved to this day, and they have an important role in inspiring and guiding today's art design. This paper mainly analyzes the folk pattern elements and their artistic value, and elaborates on the application of folk pattern elements in architectural design and the specific design methods, to provide certain references for the combination of modern architectural design and traditional folk patterns.

Keywords: Folk pattern elements; Architectural design; Value

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1. Introduction

Folk art patterns are mainly derived from the extraction of elements in life. Different ethnic groups and cultures have different living habits and customs, which form a richer folk art pattern. During the thousands of years of cultural development, China has gone through many dynasties and changes in the ruling system and has formed a richer level of thinking and spirituality. However, no matter which dynasty or ethnic group, the desire for a better life is the ultimate ideal pursuit. Therefore, the main emotion reflected in folk patterns is the desire for a better life, with auspicious symbols. Traditional folk art is more varied and beautifully modeled, reflecting the ideals of the people and the symbolism of traditional culture. The application of these patterns in modern architectural design can reflect the beauty of architectural design, enrich the cultural connotation of the design and form a better artistic effect. Therefore, it is necessary to strengthen the importance of folk pattern elements to lay the foundation for the development of modern architectural design.

2. Overview of folk pattern elements

Folk pattern elements taken from the people's life. Different ethnic groups, different cultural backgrounds make different regions and ethnic groups to form different customs and concepts, the formation of folk art style there will also be some differences. Over thousands of years of development, the working people have experienced the changes of the times, struggled with the hardships of life, and yearned for a better life more strongly. Therefore, people's wish for a better life is also expressed in folk patterns. Traditional folk art has many kinds, simple modeling, and has a close connection with life, which can reflect the rich cultural connotation [1]. At the same time, these patterns have been inherited in the development of history, and have been widely used in the decoration of homes, costumes, houses and various major ceremonies. The different forms of plants and animals, geometric and natural landscapes in folk pattern elements contain the fantasies and inner will of the creators, and can also convey good wishes in application.

3. The value of folk patterns integrated into architectural design

The integration of folk patterns into architectural art design can reflect relatively strong regional and national characteristics. At the same time, folk patterns contain the meaning of auspiciousness and wealth, and integrating folk patterns into modern architectural art design can enhance the cultural connotation of architectural design. For example, the architectural design of the tiled pattern, in which the Azure Dragon, White Tiger, Vermilion Bird and Black Tortoise, and other beasts, carved in the building with the meaning of home protection, has a very good meaning. At the same time, these auspicious animals are also an important part of traditional culture, and their application in architectural decoration is conducive to enhancing the momentum of architectural space and better spreading the national spirit. Especially with the development of industrialization, people's pursuit of spiritual life continues to improve, the integration of traditional folk patterns in architectural design can express the aspirations of modern people for a better life, provide better spiritual solace for the public, show the profundity of traditional culture, and enhance cultural self-confidence.

At the same time, the problem of homogenization in the current architectural art design is more obvious, and there is a lack of breakthrough in artistic design innovation. Traditional folk pattern is a decorative pattern with deep cultural connotation inherited for thousands of years, extracted from life, which contains traditional Chinese aesthetic elements. Although part of the pattern is no longer in line with the current aesthetic characteristics, it can be extracted and reorganized through the elements of these patterns, and the current architectural art design fusion, the formation of modern and classical aesthetic collision, can still enhance the aesthetic level of architectural art, to solve the problem of homogenization of architectural art design [2].

In addition, every nation has a characteristic culture, these cultural contents will be passed down through various ways. Folk pattern elements is an important traditional cultural heritage carrier, has a very strong national characteristics, carrying the spirit of China's culture of thousands of years, and has an important role in promoting the development of contemporary social spirit and culture. Folk pattern itself has a relatively unique artistic expression ability, can show a good national character. After the development of several dynasties, the cultural connotation of folk pattern is richer, and the integration with modern culture is the inheritance of traditional culture. The application in architectural art design can, along with the development of the construction industry, let people around the world understand the development process of Chinese culture and history. In the great collision of Chinese and Western culture, the symbolic development of folk patterns can preserve the essence and heritage of traditional Chinese culture, promote the inheritance of traditional culture, and show the charm of local culture.

4. The application of folk pattern elements in architectural art design

4.1. Application of wall design

The wall is an important decorative content in architectural design, and it is also the main application location of folk pattern elements. Modern wall space design more common decorations include wallpaper, decorative paintings, wall paintings, wood carvings and other components. All of these decorations can be decorated with traditional patterns, following the overall decoration style and preferences to form a complicated or simple pattern decoration form. The choice of pattern should be combined with the spatial properties of the wall as well as the location of the area and the material decoration basis, etc., to ensure that the pattern fits the space. For example, if the wall's skirting line is selected as a wooden material, the pattern can be made of simple patterns such as corrugated and geometric patterns, which will not be too complicated and can match most of the decoration styles.

4.2. Ceiling design application

There is a big difference between the ceiling in modern architecture and the ceiling in ancient architecture. The structure of the ceiling in traditional architecture is mainly wooden, while the decoration and structure are more complicated. Some higher-level buildings will set up algae wells, birdbaths, and other complicated structural decorations, and a large number of patterns will be applied, among which the more commonly used patterns include fish, peony or geometric patterns. These patterns are colorful and rich in form [3]. The ceiling design of modern buildings is generally more simple, and the top of a single color, will not use a large number of complex color decorations. Therefore, the application of folk patterns in modern architectural decoration will be innovative based on the original, such as pattern decoration around the lamps or ceilings (**Figure 1**). The pattern decoration around the ceiling is generally simple, using geometric patterns such as a back-word pattern and swastika pattern, or simple plant and flower pattern, which can be combined with the specific decoration style to determine the pattern form. Most of the patterns around the lamps are based on plant patterns, which are relatively more complex.

Figure 1. Peony-patterned ceiling

4.3. Ground design application

Modern building floor decoration materials are mainly wood flooring, ceramic tiles, natural stone and carpets, etc. These materials can be processed through the later formation of patterns, adding artistic flavor. Different architectural functions can be combined to design different patterned structures. For example, for large buildings such as hotels, restaurants, and shopping malls, they can be spliced into various patterns through the collage process. A single piece of pattern can be used to form the pavement of the pattern sequence structure after splicing. Generally, for a large range of paving, you can choose a large and simple pattern structure, and for a small range of paving, you can choose a small pattern. Through the choice of floor pattern structure, a unique aesthetic characteristics can be formed.

4.4. Soft decoration design application

The soft decoration in the building can enhance the sense of space hierarchy, divide the functional areas inside the building, and form a more artistic and aesthetic architectural space structure. Common architectural soft decorations include screens, partitions, and so on. The material of the screen can be made of different material structures such as brocade, glass, metal, wood, etc., and the screen is usually set up with decorations such as openwork carvings or relief carvings (**Figure 2**). In the architectural design, the material and pattern selection of the screen need to be based on the overall space and meet the spatial function. There are more choices of patterns for screens, and any patterns with auspicious symbols can be applied to screen decoration. In addition to the screen partition, furniture is also an important part of the building's interior soft decoration. Traditional folk patterns are widely used in modern furniture, such as simple patterns in Ming furniture, paper-cut patterns, and facial elements. The setting of the pattern should be matched with the overall style of the furniture, and to ensure the appropriateness, avoid the area and shape of the pattern is too complex, resulting in the furniture structure is too fancy or cumbersome, and it is difficult to maintain coordination with the internal space of the building.

Figure 2. Folk geometric patterns of screen

4.5. Application of display design

Chinese folk pattern elements are currently widely used in the decoration art design of architectural interior space, in addition to furniture, tables and chairs, etc., can also be applied to other decorations, such as curtains, lamps, hanging pictures, vases and so on. These exhibits themselves have artistic design characteristics, so there are more choices in the application of folk pattern elements, including auspicious meaning of dragon and phoenix pattern, plant pattern and momofuku pattern, etc. Some exhibits will also integrate calligraphy text pattern, such as curtains, pillows, and so on. The selection of these exhibits needs to conform to the overall style of the building interior, and can also be used to create the atmosphere of the building in the form of mixing and matching, according to the owner's personal preference to choose the corresponding pattern.

5. The method of integrating folk pattern elements into architectural art design

5.1. Direct application of folk pattern elements

The application of folk pattern elements in architectural design can enhance the humanistic atmosphere of the building, and through the combination of patterns and appropriate changes, the decorative pattern can be formed in line with modern aesthetic. However, in some architectural designs, in order to emphasize the traditional cultural characteristics and create a retro style, folk pattern elements are usually applied directly. For example, the most common "Reversal pattern" is widely used in the architectural design of new Chinese style, which is used in the TV background wall, screen, furniture, and wall decoration of the tea room (**Figure 3**) [4]. At the same time, the application of patterns with auspicious symbols such as plant patterns, fish patterns, and dragon and phoenix patterns is also relatively wide and can be applied to the decoration of various spaces inside the building without strict application requirements.

Figure 3. The decoration of the TV background wall

5.2. Integration and application of folk pattern elements

Some of the folk patterns are quite old, their structure is cumbersome and does not conform to the current aesthetic, so they are not suitable for direct application in architectural art design. In the application of this pattern, it is necessary to reintegrate the pattern, simplify the pattern, and conform to the current aesthetic characteristics. There are several common ways: First, the traditional folk patterns are simplified and deformed. Simplified and deformed patterns are more in line with the current concept of minimalist architectural design. The deformation of the pattern generally retains a part of the pattern with a moral meaning, the elements of which are refined and summarized to achieve the pattern of the reconstruction. Second, the elements of the traditional folk patterns are disrupted and reorganized. The traditional folk patterns are divided and then recombined. Different recombination methods such as overlapping, rotating, and juxtaposing of pattern elements can be used to make the structure of pattern have the rhythmic beauty of change and unity from a visual point of view. It not only makes the pattern more in line with modern aesthetics, but also gives the pattern a richer meaning.

5.3. Abstract application of folk pattern elements

The most common folk pattern in architectural design is the geometric pattern, which is also more in line with the modern aesthetic pattern form. In architectural art design, the traditional folk patterns can be abstracted by combining the construction process and the overall architectural style, and some more concise structures can be formed. For example, large patterns can be abstracted into simple geometric patterns, or further simplified into the pattern form of point, line, and surface structure. The modeling changes of traditional folk patterns have a strong logic, which is in line with the modern design features, and can better reflect the imagery and structural beauty of patterns.

6. The strategy of integrating folk pattern elements into architectural art design

6.1. Understanding the connotation of folk pattern elements

When folk pattern elements are integrated into architectural art design, first of all, designers should fully understand the connotation of folk pattern elements in order to ensure the rationality of pattern application. The elements of folk patterns are relatively rich, among which the most traditional pattern is mainly the lucky symbol such as the character for happiness, longevity and plant patterns, for example, plum, orchid, bamboo and chrysanthemum, or regional and ethnic patterns, such as Shaanxi paper cutting. In the study of traditional folk patterns, it is necessary to have a comprehensive understanding of the symbolism, color characteristics, and stylistic features of patterns. Many patterns in architectural art design cannot be applied directly, but have to be abstracted and deformed before being applied to the design. If the characteristics of folk patterns are not understood, the subsequent secondary creation will be affected, leading to unreasonable problems in the application of patterns in architectural design [5].

6.2. Innovate the application of folk patterns

The application of folk pattern elements to architectural design work needs to be combined with the design needs and architectural style of the pattern for innovative combinations. Designers should make a comprehensive analysis from the concept of modern design and the connotation of traditional patterns, and then extract and optimize the patterns to meet the aesthetic needs of modern architectural art. They should also try to combine folk pattern elements with other arts to enhance the humanistic flavor and aesthetic level of modern architecture. For example, it can integrate the relief craft with folk patterns or integrate traditional patterns in decorative murals, etc., so as to create an architectural art style with an ancient Chinese style.

6.3. Rational planning pattern space layout

The design of spatial layout is an important element in modern architectural design, which can divide the building into different functional areas and can also create a hierarchical space within the building. The application of traditional folk pattern in the space layout should be combined with different functional areas and the characteristics of the building to form a fusion of elements to build a harmonious and unified space structure system, ao as to ensure that the folk pattern elements are skillfully applied and form a subtle connection relationship in the space. For example, the entrance of the building can be designed with folk pattern decorations, and then with the extension of the wall to form the link of patterns, connecting the divided space with patterns of the same elements to form a whole, forming a more ethnic and characteristic architectural space.

6.4. Emphasis on integration with modern elements

In modern architectural design, the design and application of folk pattern elements need to meet the requirements and aesthetics of modern architectural design, so they must be effectively integrated with modern elements. In the application of folk pattern elements, according to the symbolism of the pattern, as well as the structure, color and other effective integration with modern architecture, designers should avoid the application of pattern is too abrupt. For example, in the application of patterns in the study, you can try to use Chinese characters and plant patterns, which can enhance the humanistic atmosphere of the study. For the living room, auspicious characters such as the character for good fortune and longevity can be used, which has good implications. For the elevator room, stairs, and other positions, geometric patterns can be used as the main design content, which looks more simple and the process is simple.

7. Conclusion

In conclusion, the integration of folk pattern elements into architectural design is conducive to enriching architectural design elements, promoting the inheritance and development of traditional culture, and better displaying local culture on the world stage. The design and application of folk pattern elements can be combined with the requirements of architectural design, using direct application, reintegration, and abstraction to integrate the elements to meet the current aesthetic characteristics and form a diversified aesthetic form. At the same time, it is also necessary to choose patterns reasonably according to different positions of architectural design, meet the aesthetic needs of different functional areas, and ensure the rationality of the application of folk patterns.

Disclosure statement

The author declares no conflict of interest.

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Fire Protection Design and Case Analysis of Renovated and Expanded Student Apartments in Universities

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Abstract: With the continuous enrollment expansion of universities and the increase in the number of international students, student apartments are becoming increasingly in short supply, inevitably leading to renovation and expansion projects of apartments. New requirements have emerged for fire protection design in the renovation of student apartments. This case mainly involves new approaches and methods of fire protection design in the renovation of old buildings. An indoor fire hydrant system is newly added to the water supply part of the apartment building, and the main measures include drawing water from a nearby source and establishing a fire protection linkage control system.

Keywords: Renovation and expansion; Universities; Student apartments; Fire protection design

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1. Introduction

In recent years, with the expansion of the enrollment scale in universities, the construction of student apartments cannot meet the enrollment demand. As a result, the existing student apartments generally accommodate 8 or 10 people per room, which does not meet the construction standards specified in the "Guiding Opinions of the National Development and Reform Commission and Other Departments on Strengthening the Construction of Student Dormitories in Universities": 4 undergraduate students per room, 2 postgraduate students per room, and 1 doctoral student per room. With a large population density, in case of a fire, the consequences would be disastrous. Therefore, the fire protection construction of student apartments in universities is of utmost importance for ensuring the safety of the campus. Many universities are gradually renovating and expanding their existing apartments. The original buildings did not meet the area requirements for the mandatory configuration of fire hydrants, and after the expansion, the construction of the fire protection system needs to be added [1].

2. Existing problems

Firstly, the issues of fire protection water sources and power supplies need to be considered. When the old apartments in universities were initially designed, the building volume was not so large, so there was no corresponding quota for the system water source. Correspondingly, the electrical load will also increase. Therefore, it is necessary to consider providing a normal water supply and electrical capacity expansion projects to meet the daily needs of the renovated and expanded apartments.

Furthermore, the risks of cross operations during the construction process need to be considered. During the renovation of old buildings, problems such as pipeline conflicts and the collapse of old pipelines are inevitable. It is necessary to consider the damage to the original fire protection system in the building or the system caused unintentionally.

In addition, there are issues such as whether the fire protection design of student apartments should be carried out according to the standards for residential buildings or public buildings. The student apartments in universities can be designed and constructed according to the two standards of civil buildings and public buildings. Judging from the nature of the building itself, the student apartment buildings in universities should be determined as public buildings. According to relevant codes and laws, "buildings exceeding 24 meters should be classified as high-rise buildings, and apartment buildings exceeding 50 meters or with an area of more than 1,500 square meters per floor should be classified as first-class high-rise buildings". Although currently in the fire protection design of universities, both standards are legally valid. Only by strictly classifying the student apartment buildings in universities and then carrying out the design and construction of the overall fire protection layout, fire protection water supply, automatic fire protection facilities, fire protection power supply, etc. according to the provisions of the current "Code for Fire Protection Design of Buildings" and "Code for Fire Protection Design of High-rise Civil Buildings" can the congenital fire hazards be minimized to the greatest extent [2].

3. Design ideas

On the premise of fully meeting the fire protection requirements, the characteristics of fire protection for the special building group of the renovation and expansion of student apartments in universities are reflected, that is, drawing the fire protection water source nearby and connecting to the existing fire protection linkage system.

3.1. Drawing the fire protection water source nearby

According to the provisions of the "Code for Fire Protection Design of Buildings" (GB50016-2006) in China, "For other civil buildings such as office buildings, teaching buildings, and non-residential buildings that exceed 5 floors or have a volume greater than 10,000 m^3, indoor fire hydrants with a diameter of DN65 should be installed.". In this case, after the completion of the third-phase project of Building No. 14, the building volume has exceeded 10,000 m^3, so indoor fire hydrants need to be installed. However, the outdoor water source in the design is far away, and it is difficult to directly connect to the municipal pipeline network. To save resources and meet the requirements of the indoor fire hydrant system, that is, to ensure that the indoor fire hydrant system has sufficient water quantity and water pressure, the water source of the nearby high-rise apartment is selected to meet the fire protection requirements.

3.2. Fire protection linkage system

The fire protection linkage system is widely used in newly built buildings currently. That is, the changes in environmental parameters such as smoke, light, and temperature during a fire are detected by corresponding detectors and then transmitted to the central processing host. Through the rapid analysis of the computer, it is determined whether there is a fire, and the fire situation is quickly reported. At the same time, the automatic fire extinguishing system is activated to suppress the fire; the emergency broadcast and crowd evacuation guidance systems are triggered to assist occupants in evacuating swiftly; the fireproof rolling shutter doors close to isolate the affected area; and the smoke exhaust system starts operating to remove toxic gases. These coordinated actions aim to control the fire, minimize casualties, and reduce property damage. In this case, the connected high-rise apartment is a newly built building equipped with automatic fire control and alarm devices. At the same time, the automatic control system can also start the outdoor fire hydrant water supply system to meet the requirements of water quantity and water pressure for fire protection. The outdoor fire hydrant water supply system is composed of the outdoor pipeline network, fire hydrants, fire pools, and water pumps, etc., ensuring water safety [3].

4. Case analysis

4.1. Project overview

Building No. 14 of a certain university's student apartment was completed in three phases. The building floor height is 3.2 meters, the number of floors is 5, the building height is 17.2 meters, and the fire resistance rating is Class II. The first phase was completed and put into use in the 1990s, with a usable area of approximately 2,900 m^2, which did not meet the area requirements for the mandatory configuration of fire hydrants at that time. A few years later, the second-phase project was constructed, and the project plan for the third-phase project was preliminarily formulated. However, the total area of the first and second phases still did not meet the area requirements for the mandatory configuration of fire hydrants.

At the beginning of the 21st century, to achieve teaching goals such as enrollment expansion and academic exchanges with foreign countries, the school decided to build the third-phase project of Building No. 14, which was built as an international student apartment and could meet the usage requirements of most international students in the school. Among them, a total of 84 rooms were put into use, including 76 international student dormitories, 1 duty room on the first floor, 1 hot water room on each of the second and fourth floors, 1 laundry room on each of the third and fifth floors, and 3 other equipment rooms. The original exterior windows, entrance doors, heating system, and radiators were all retained. This building is equipped with an access control system, an intercom system for the building, a telephone system, a wired and wireless network system, and the pipelines for the television and air conditioning systems are reserved. A solar energy system was newly added to the entire Building No. 14, and a one-card charging system is used for the hot water used by students.

After the completion of the third-phase project, the overall structure of Building No. 14 has met the configuration requirements of fire hydrants. According to the provisions of the "Code for Fire Protection Design of Buildings", except as specified in Article 8.3.4 of this code, the following buildings should be equipped with indoor fire hydrants with a diameter of DN65: For other civil buildings such as office buildings, teaching buildings, and non-residential buildings that exceed 5 floors or have a volume greater than 10,000 m^3; For residential buildings exceeding 7 floors, an indoor fire hydrant system should be installed. When it is really difficult, only a dry fire standpipe and an indoor fire hydrant with a diameter of DN65 without a fire hydrant box can be installed. The diameter of the fire standpipe should not be less than DN65. Therefore, in this design, a fire hydrant system was added, and a fire protection linkage control system was also equipped.

4.2. Fire protection water source

(1) Fire Pool: In order to meet the fire protection water quantity requirements in the initial stage of a fire, a fire pool for storage was set up. This fire pool stores the fire protection water quantity for 10 minutes to ensure the water pressure of the pipeline network and the water consumption in the initial stage of a fire.

(2) Ring pipeline network of the high-rise apartment: The water source is drawn from the ring pipeline network on the second underground floor of the nearby high-rise apartment. Both of the two access points meet the water quantity and water pressure requirements of Building No. 14. Inside Building No. 14, the requirement of simultaneous water supply also needs to be met, forming a loop water supply.

4.3. Fire protection water supply system

As a supplement to the water supply pipeline network, the fire protection water supply system can meet the requirements of water quantity and water pressure for fire protection. Both the water pressure and flow rate need to meet the fire extinguishing requirements at the most unfavorable point. There are fire pumps in the pump room. When a fire alarm is received, the fire protection water supply system is started, so that the pressure in the pipeline network quickly reaches the pressure requirements of the high-pressure water supply pipeline. The full water column of the water gun should not be less than 10 m to ensure that after the firefighters arrive at the fire scene, they can directly connect the water belt and water gun from the fire hydrant to ensure the safe and effective extinguishing of the fire.

(1) Fire protection water quantity

According to the specification requirements, outdoor fire hydrants should be installed in civil buildings, and the fire resistance rating is Class II, so a fire protection water supply should be set up. According to the specification, the number of fire incidents at the same time is set to 2 times. Regarding the indoor fire hydrant water consumption for one fire extinguishing, according to the characteristics of this building, since the maximum building volume is greater than 10,000 m^3, it is taken as 15 L/s. The fire duration for civil buildings is calculated as 2 hours, and the fire protection water consumption is taken as 15 L/s. The fire pool should be set to 108 m^3, and the data of the municipal water supply is 60 m^3/h, which can be replenished within 2 hours, meeting the requirements.

(2) Fire protection water pressure

The fire protection water pressure here mainly refers to the water pressure situation that the pump can provide to the system. According to the indoor water supply design specification, that is, the minimum effective head of the pump needs to meet:

$$H = Hxh + z + \Sigma h$$

H refers to the water pressure that the pump can provide to the system; *Hxh* refers to the water pressure at the most unfavorable fire hydrant outlet; *z* refers to the elevation difference from the water intake to the axis of the pump; *Σh* refers to the total head loss in the pipeline.

(3) Pipeline laying

New fire protection pipelines are rearranged to make the overall fire protection water supply pipeline form a system with the original fire protection pipeline of the high-rise apartment. Since the fire protection water quantity is 15 L/S, the fire protection pipeline is arranged in a branched shape, and the pipeline burial depth is 1.00 meter. At the same time, the following requirements are met:

$$S1 \leq 2$$

$$R = C \cdot Ld + h$$

S1 refers to the distance between fire hydrants, in m; *R* refers to the protection radius of the fire hydrant, in m; *C* refers to the bending reduction coefficient when the water belt is deployed, generally taken as 0.8–0.9; *Ld* refers to the length of the water belt, and the length of each water belt should not be greater than 25 m, in m; *h* refers to the horizontal projection length of the full water column of the water gun when it is inclined at 45°, in m, *h* = 0.71Hm, generally taken as h = 3 m; *Hm* refers to the length of the full water column of the water gun, in m; *b* refers to the maximum protection width of the fire hydrant, in m.

(4) Control of the fire protection water supply system

The control of the fire situation in the initial stage of a fire mainly lies in the start and control of the fire pump, which is also the most reliable guarantee for the operation of the water fire extinguishing system [3–5]. Therefore, in the control of the fire protection water supply system, the linkage control of the system fire pump is a crucial part. For the fire hydrant system, the start of the fire pump in the temporary high-pressure system is generally controlled by the fire control center and the button in the fire hydrant box. In this case, the start of the fire pump mainly relies on the cooperation of the linkage system. After receiving the alarm, the main machine of Building No. 14 starts first, and within 5 seconds, the control cabinet in the connected high-rise apartment starts the corresponding program to control the operation of the water pump, to achieve automatic control. In addition to setting up a fire pump, a standby fire pump should also be set up, and it should meet the requirements of automatic control and water quantity, and water pressure.

(5) Others

After research by the design institute and the owner, the fire protection water source was determined. It was determined that the fire protection water source is drawn from the fire pump room of the nearby high-rise apartment. After on-site investigation and consultation of relevant drawings, the following specific suggestions are made:

(1) The water source is drawn from the ring pipeline network on the second underground floor of the nearby high-rise apartment. The two access points are located in the corridor on the west side of the second underground floor (**Figure 1**). It is connected to the ceiling of the storage room on the first underground floor through the storage room and goes out of the wall. The elevation of going out of the wall is -1.25 meters, and the practice refers to the construction requirements of the high-rise apartment.

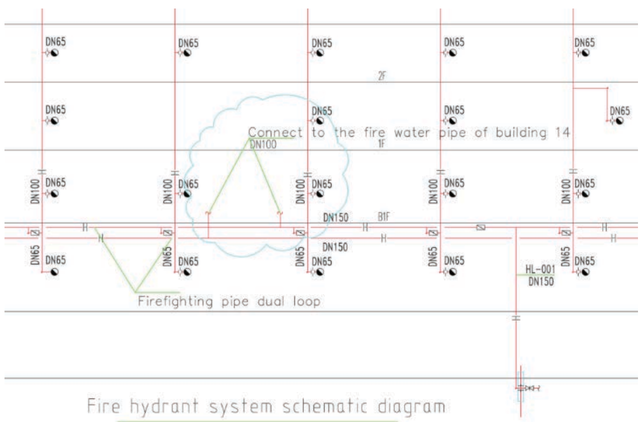

Figure 1. Schematic diagram of the access points

(2) The outdoor route must be surveyed clearly to check whether there are conflicts with other pipelines.

(3) The original designed fire hydrants in Building No. 14 need to select pressure-reducing and pressure-

stabilizing fire hydrants according to the pressure at the hydrant outlet.

(4) Requirements for weak current construction. The fire pump starting line of the fire hydrant is laid through a SC40 steel pipe along the outdoor fire water pipe (the horizontal clear distance between the fire pump starting line pipe and the fire water pipe is ≥ 0.5 m) to the first underground floor of the high-rise apartment building, and then connected to the fire pump starting line of the nearby fire hydrant button in the corridor. Waterproof treatment should be done at the place where the steel pipe enters the building. The steel pipes laid openly on the first underground floor of the high-rise apartment building should be painted with fireproof paint.

(5) In addition to meeting the requirements of relevant codes and regulations, the above construction also needs to meet the relevant requirements of the Party A, such as the settings of water meters and water wells.

(6) For the fire protection linkage control system, when a fire occurs in the building, the alarm device should first detect the fire signal, quickly transmit it to the main machine, start the alarm bell according to the set program, and quickly cut off all kinds of non-fire protection power supplies [4].

5. Conclusion

Due to the limitations of the existing scale of universities, there are many problems in the selection of water sources and the design of the linkage control of building fire protection facilities for renovation and expansion projects. This article only starts from the universities themselves and proposes several solutions to common situations from the perspective of energy conservation and full utilization of resources. When designing and constructing the selection of water sources and the linkage control of building fire protection facilities, it is necessary to comply with the relevant requirements of the current fire protection codes and also meet the principles of economy and practicality. These solutions are also important links in realizing the construction of a modern building system in universities [5].

Disclosure statement

The author declares no conflict of interest.

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Research and Application of Verticality Detection Method for Circular Pier with Equal Section

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Abstract: This article presents four techniques for assessing verticality: the plumb line approach, the total station distance technique, the three-point centering method, and the centroid method. Given the significant error associated with the total station horizontal distance technique when measuring circular piers, this paper proposes the centroid method. This method calculates verticality by determining the coordinates of the center points at both ends of the pier. Experimental findings indicate that the centroid method achieves accuracy in measuring the verticality of circular piers comparable to the three-point centering method, while offering a faster inspection process. Furthermore, the paper explores the concept of composite verticality and validates the effectiveness of the centroid method in measuring composite verticality and its practical applications through comparative experiments.

Keywords: Verticality; Centrality method; Synthetic verticality

Online publication: April 28, 2025

1. Introduction

During the construction and acceptance of bridges, the verticality of pier columns serves as a critical parameter for both process control and final evaluation. For tall piers, various methods have been developed to assess verticality [1–3]. This study focuses on the measurement of verticality, particularly examining the detection techniques and practical applications for circular piers with constant cross-sections. Throughout the experimental process, multiple measuring instruments and approaches were employed, and an in-depth analysis was conducted on the various factors influencing the accuracy of verticality measurements. Among these methods, the horizontal distance technique has gained widespread adoption in bridge pier verticality assessments due to its straightforward principle and clear outcomes. However, when applied to cylindrical piers, the curvature of the surface introduces complexities, as the inclination of the bridge can directly impact the measured tilt values [4]. To address this specific challenge, this paper proposes an innovative verticality detection method designed to enhance the precision of measurements for circular piers.

2. Verticality specification requirements

The verticality of the pier serves as a critical indicator for assessing construction quality during both construction control and acceptance testing. It is also a key measured element, designated as item 11. The permissible deviation for pier verticality, as outlined in relevant specifications [5], can be found in **Table 1**.

Table 1. The specified value or allowable deviation of pier verticality.

Check items		Specify values or allowable deviations
Full height verticality (mm)	$H \leq 5m$	≤ 5
	$5m < H \leq 60m$	$< H/1000$, and ≤ 20
	$H > 60m$	$\leq H/3000$, and < 30

3. Method for measuring the verticality

3.1. Plumb line method for measuring verticality

The plumb line technique is a procedure for assessing verticality using a suspended weight attached to a line [6]. During the assessment, the vertical line is secured at the top of the pier, and the horizontal distance between this line and the concrete edge of the pier column is measured with a steel rule at the base of the pier. The ratio of the difference in readings between the upper and lower steel rules to the length of the vertical line represents the verticality of the detection surface [7]. Compared to other methods, the plumb line approach is more visually straightforward; however, it imposes stricter on-site requirements, such as needing auxiliary equipment to lift the line and weight. Additionally, the detection outcomes are highly sensitive to wind speed [8].

3.2. Vertical measurement by total station flat distance method

Figure 1 shows the schematic diagram of the total station flat distance method. The horizontal distance method involves positioning the measurement point as close as possible to both the top and bottom ends of the pier column. Based on the alignment direction, establish the vertical and transverse axes of the structure. Set up a total station at both the vertical and horizontal testing fronts of the structure. Measure the horizontal distance HD_1 from the upper surface to the instrument and the height difference VD_1 between the instrument's horizontal plane and the upper surface. Additionally, measure the horizontal distance HD_2 and height difference VD_2 from the instrument's level to the upper surface [9]. Once data collection is complete, use the formula $\Delta D = HD_1\text{-}HD_2$ to calculate the slope of the structure within the tested height range, which represents the tilt value. Finally, apply the formula $B=\Delta D/(VD_1\text{-}VD_2)\times 100$ to determine the verticality of the structure within the tested height range [10, 11].

Upon measuring the circular pier, it was discovered that the results contained significant errors. The line of sight for the circular pier does not lie in the same plane when measured using the horizontal distance method, which leads to considerable inaccuracies in the verticality data. Consequently, alternative measurement approaches have been further considered [12, 13].

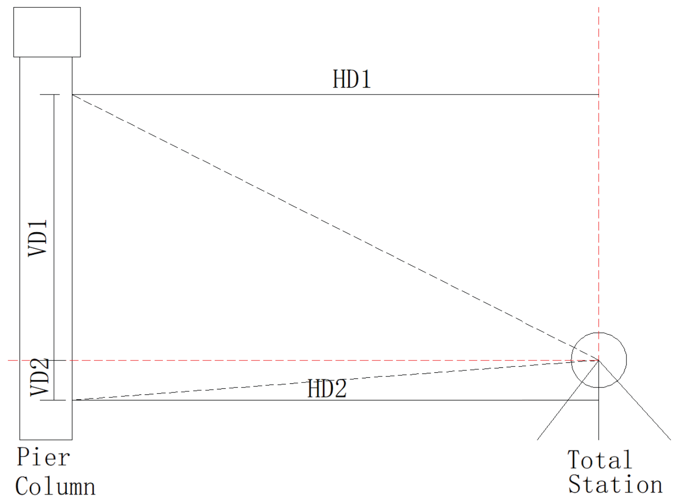

Figure 1. Schematic diagram of total station flat distance method

3.3. Measuring the verticality of round pier by three-point circle method

Figure 2 shows a diagram of the three-point circle fixing method.To measure the verticality of the round pier, at an arbitrary location on the top surface of the pier at the same height, measure three points. Their three-dimensional coordinates are $A_1(X_1,Y_1,Z_1)$, $A_2(X_2,Y_2,Z_2)$, and $A3(X_3,Y_3,Z_3)$, where $Z_1=Z_2=Z_3$. Next, at the same height on the bottom of the pier, measure another three points at any position. The three-dimensional coordinates for these points are $B_1(x_1,y_1,z_1)$, $B_2(x_2,y_2,z_2)$, and $B_3(x_3,y_3,z_3)$, with $z_1=z_2=z_3$. Using the general equation of a circle, the center coordinates of the circles can be determined as $O(X,Y,Z)$ and $P(x,y,z)$. Based on the center coordinates of circles *O* and *P*, the offsets in the *x*-direction $Dx=X–x$, the *y*-direction $Dy=Y–y$, and the height difference in the *Z*-direction $H=Z–z$ can be calculated. At this point, the longitudinal alignment deviation of the bridge is given by Dx/H , while the transverse alignment deviation is represented by Dy/H [14, 15].

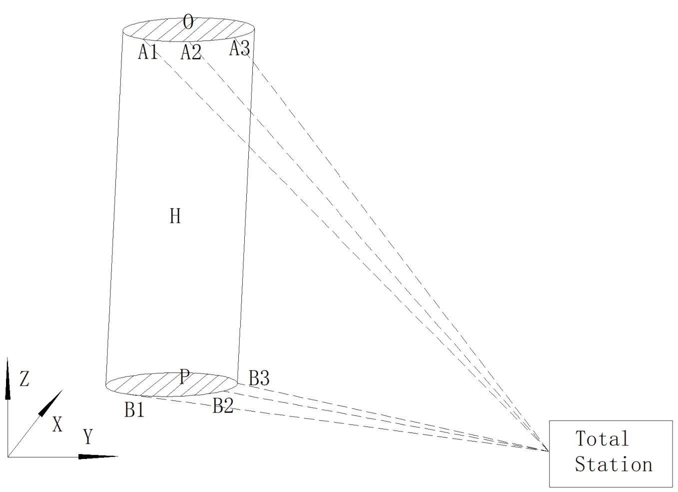

Figure 2. Schematic diagram of three-point circle fixing method

3.4. Centroid method for measuring the verticality of circular pier

Using the centroid method shown in **Figure 3**, the total station is set up on the test front of the longitudinal and transverse structures respectively. Aim at one edge of the upper surface of the pier and record the horizontal Angle HL1. Then keep the vertical brake of the instrument and turn the instrument to the other edge of the pier and record the horizontal Angle HL2. After the horizontal data is obtained, the horizontal angle of the center point is calculated. Keeping the instrument upright, measure the coordinates of the center point on the upper surface *(X1, Y1, Z1)*. Similarly, measure the coordinates of the center point of the lower surface *(X2, Y2, Z2)*, and calculate the verticality (%), $B = \sqrt{(X_1-X_2)^2+(Y_1-Y_2)^2}/(Z_1-Z_2) \times 100$ of the structure within the test height range according to the following formula. Through the above steps and calculation methods, the slope and verticality of the structure can be accurately measured and calculated. Compared with the three-point circle method, the centroid method only needs to measure two points in the same plane, which is more convenient and fast.

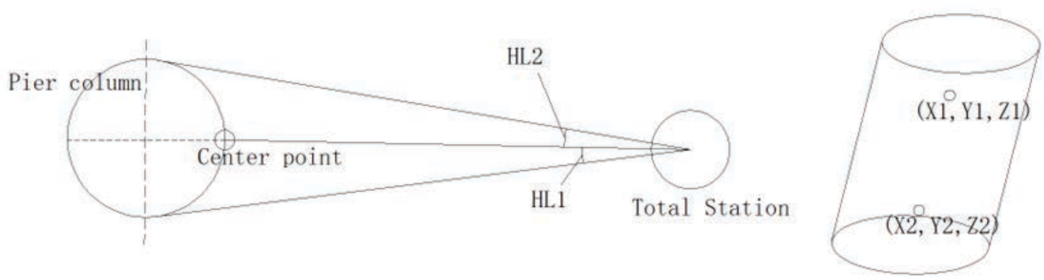

Figure 3. Line of sight diagram of centroid method

4. A specific study of synthetic verticality

By conducting research on specific projects, it has been observed that bridge piers do not only tilt in a single direction but also integrate two sets of data in the vertical plane using the principle of force synthesis. To ensure the accuracy of these findings, two distinct measurement techniques were employed. Initially, the pier was stabilized and then tilted at a specific angle in a particular direction. The plumb line method was used to assess verticality while maintaining the tilt angle constant as shown in **Figure 4**.

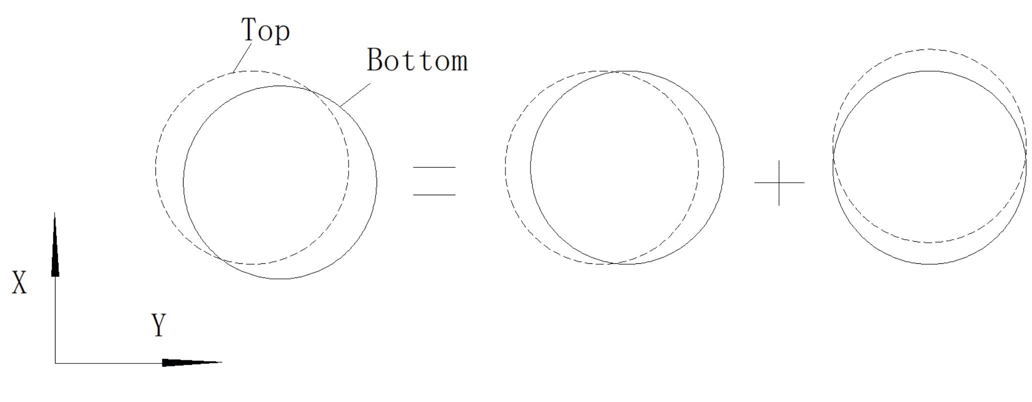

Figure 4. Schematic diagram of the mutual influence of the tilt of cylindrical piers along and across the bridge

Meanwhile, the centroid method was applied to measure the X and Y coordinates. Subsequently, the results from the three-point circle fixation method and the plumb line method were compared, as shown in **Table 2**.

Table 2. Comparison data table of centroid method

Inclined bearing	Point position	Verticality measured by the three-point circle method	ΔHD Horizontal distance (m)	ΔVD height difference (m)	Verticality measured by centroid method (%)	Resultant verticality (mm) by centroid method	Vertical method (mm)
South west	West	-4.6	-0.0545	1.2077	-4.5	5.6	5.9
South west	South	-3.8	-0.0438	1.1526	-3.8		
North west	South	15.0	0.1833	1.2208	15.0	17	17
North west	West	-8.2	-0.0962	1.1798	-8.2		
North east	South	5.8	0.0728	1.2398	5.8	11	11
North east	West	9.5	0.1169	1.2368	9.5		
South east	West	9.7	0.1126	1.2362	9.9	14	13.8
South east	South	-9.7	-0.1146	1.9200	-9.6		

Based on the data, it is evident that the centroid method can efficiently evaluate the resultant verticality and minimize the impact of the offset angle on the deviation. Experimental results indicate that the centroid method demonstrates higher accuracy than the horizontal distance method when measuring round piers. Through engineering application, a comparison with the measured data from the three-point circle fixing method shows good consistency between the two methods, indicating they possess significant practical value in engineering applications.

5. Conclusions

By comparing the two measurement approaches, it is evident that the centroid method offers greater accuracy compared to the horizontal distance method. Additionally, it is also quicker and more practical than both the three-point circle fixing method and the plumb line method. Furthermore, upon conducting a detailed examination of the deviation outcomes, it becomes evident that this approach possesses certain constraints in providing precise ratings when critical components such as piers and abutments sustain significant damage. Similarly, limitations arise when a single component is in an exceedingly deteriorated state.

Disclosure statement

The authors declare no conflict of interest.

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Exploring Therapeutic Design of Outdoor Landscape for Medical Buildings Enabled by Wisdom: A Case Study of the Fifth People's Hospital of Chongqing

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Abstract: The outdoor landscape design of medical buildings affects the healthcare experience of patients and the work environment of medical staff. Therapeutic landscapes contribute to the recovery of patients and provide a comfortable, convenient, and safe outdoor space for both patients and healthcare professionals. This article analyzes the concept, classification, design necessity, and smart enhancement methods of therapeutic landscapes. By combining the case study of the wellness landscape design of the Fifth People's Hospital of Chongqing, it derives insights into therapeutic landscape design, such as the rational use of natural elements, the construction of pedestrian space systems, the arrangement of specialized botanical gardens, the integration of multiple therapies, and the application of smart technologies. The aim is to promote the development of therapeutic outdoor landscape design for medical buildings.

Keywords: Medical buildings; Smart empowerment; Outdoor landscapes; Therapeutic

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1. Concept of therapeutic landscapes

The healing aspect of landscapes refers to the positive impact that landscape design and environmental creation have on people's physical, psychological, and spiritual well-being. It helps people relieve stress, relax, and promote overall health. This healing landscape is particularly important in the medical building environment, as it provides a better healing space for patients. The concept of healing landscapes originated in the early 1980s [1]. Ulrish, an American environmental psychologist, studied the relationship between natural landscapes and patients' recovery. Later, Gesler, an American geographer, formally introduced the concept of healing landscapes at the 1990 Norwegian International Medical Geography Forum [2]. Healing landscapes, a type of landscape, aim to restore patients' physical and mental health through plant configuration, landscape sketch design, and cultural symbol expression [3]. Healing landscapes, also known as healing gardens or recuperative gardens, are natural and cultural landscapes in outdoor activity spaces designed based on users' psychological and physiological needs. By integrating with the surrounding natural environment, they create an ecological, recuperative, and natural outdoor space, providing a safe, comfortable, and beautiful recuperative medical environment that restores bodily functions.

2. Classification of therapeutic landscapes

Therapeutic landscapes are generally classified into medical gardens, experience gardens, meditation gardens, rehabilitation gardens, and horticultural gardens [4]. Medical gardens focus on patients' physical, psychological, and spiritual needs, providing an outdoor space for restoring bodily functions and regaining health. Experience gardens emphasize creating an outdoor activity space for patients. Meditation gardens prioritize patients' psychological needs, offering a serene garden for contemplation and rest, reducing mental and psychological stress. Rehabilitation gardens are equipped with facilities that help patients restore motor functions, aiding in their recovery through daily exercise. Horticultural gardens allow patients to participate in gardening, alleviating irritability and psychological pressure through work and enabling them to feel positive energy in the growth and changes of plants.

3. Importance of outdoor therapeutic landscapes in medical buildings

As specialized buildings, medical facilities are primarily used by patients, healthcare workers, and visitors. Patients, as the main users of the environment, are often physically weak and emotionally sensitive, prone to anxiety and unease. They have a significant need for healing landscapes that can alleviate emotional stress and contribute to their recovery. Healthcare workers, facing high work pressure and intense mental stress, also require a relaxing and stress-relieving space amidst their noisy medical work. Visitors, such as family members, need an environment that eases their minds and provides a venue for communication. Therefore, recuperative landscapes become the optimal choice for outdoor medical building landscapes. With the primary task of treating patients, the outdoor landscapes of medical buildings, as an extension of indoor spaces, should also aim to assist in patient treatment. By evoking positive emotions and reducing negative ones through natural environments and cultural features, these landscapes provide an outdoor healing space for users' physical and mental recovery.

4. Healing properties of landscapes enabled by smart technology

With the continuous deepening of China's intelligent development and the national focus on sub-health, landscape design has gradually shifted its focus to the integration of digital landscapes and spaces, emphasizing the restoration of mental health and highlighting the functionality of landscapes [5]. As an outdoor extension of treatment and healing spaces, it is particularly important to utilize smart technology to enhance the healing effects of medical building outdoor landscapes on patients and their families. The healing properties of landscapes enabled by smart technology are primarily reflected in the following aspects:

(1) Smart environmental monitoring and control

Smart technology can monitor the temperature, humidity, light intensity, and air quality of the outdoor environment of medical buildings in real-time, and adjust them through intelligent systems to optimize the ecological functions of the landscape space and enhance its comfort. By creating a comfortable natural environment through intelligent environmental control, the healing properties of the landscape are improved.

(2) Multi-sensory stimulation in landscape design

Smart technology, combined with the natural environment, provides patients with a multi-sensory healing experience. For example, intelligent devices can adjust the sound of water features, lighting colors, and regulate plant fragrances to enhance the healing effects of the landscape. Additionally, interactive landscape installations such as smart seating and biofeedback equipment can monitor users' physical states in real-time, provide personalized healing solutions, and improve the rehabilitative effects of the environment.

(3) Smart interaction and rehabilitation support

Outdoor smart interactive devices offer users an immersive rehabilitation experience. For instance, intelligent rehabilitation equipment that can automatically adjust its difficulty based on patients' health data is installed, and it can also provide real-time feedback on users' health data to medical staff. Virtual horticultural activities utilizing VR technology are set up to distract patients from their pain.

(4) Smart enhancement of barrier-free design

Smart technology can enhance the accessibility and adaptability of landscapes for elderly and disabled patients, providing them with more humanized healing spaces. For example, intelligent navigation systems can help patients quickly find their destinations. Smart seating can offer patients personalized resting spaces.

5. Analysis of the landscape design of the Fifth People's Hospital of Chongqing

5.1. Project overview

The project is located in the Danzishi area of Nan'an District, Chongqing. The site is bordered by residential land on the west, a residential community on the south, and a natural mountainous area with rich vegetation but a steep slope on the east. The mountainous terrain is relatively complex. On the west side lies a natural river, Dashaxi, which has poor water quality and vegetation, as well as a weak riverbank. The main users of the site are hospital patients and their families, surrounding residents, hospital staff, and a small number of tourists.

5.2. Outdoor spatial layout

The project design is guided by the ideology of ecological civilization construction and adopts the design concept of "looking at the mountains, managing water, leaving space, integrating, and being pleasant." The goal is to create a high-quality medical environment and build a landscape environment that combines medical care with a love for nature and mountains. By integrating three functional blocks: an ecological wetland park, a hospital in a garden, and a mountain health park, the design aims to create an ecological demonstration zone for health and wellness featuring "one mountain, one river, and one park", as shown **Figures 1** and **2**.

Figure 1. General plan (Image source: project design text materials)

Figure 2. Overall layout (Image source: project design text materials)

(1) One mountain: Embrace the scenery at the foot of Panlong Mountain and wander through the ecological health park. With ecology and nature as the main theme, integrate health culture to create a regional park with rich activities and comprehensive facilities that serve urban residents.

(2) One river: Build a wetland art greenway and play the harmony of ecological music. Focus on water management, ecological construction, and outdoor experiences to create a modern and leisure-oriented ecological riverside landscape area.

(3) One park: Gather humanistic care, beautiful environment, and health culture to build an international,

modern, smart, and garden-style hospital.

5.3. Features of landscape design

The project takes ecology and nature as the main theme, integrating health and wellness culture to create an ecological space full of natural experiences. It allows people to fully engage with nature, achieving harmony between heaven and humanity, and promoting harmonious coexistence with nature. Combining the operational model of "commerce driving the park, and the park supporting the hospital", it fully embodies an ecological scene where the hospital is within the park, and the park is within the hospital. Together, they create a landscape environment that integrates medical care with health and wellness.

(1) Forest therapy

Forest therapy relies on rich forest landscapes, forest air environments, ecological cultures, and other primary resources. It purifies the air, reduces noise, generates negative oxygen ions, and has other functions that affect human physiological health, as well as regulatory effects on human psychology. It is complemented by corresponding health and wellness, as well as medical and recreational facilities, to carry out forest recreation aimed at self-cultivation, nourishing the mind, and delaying aging.

(2) Ecological health and wellness

Relying on a good ecological system and natural environment, projects such as forest bathing, fitness trails, healing gardens, healthy diets, forest tea houses, and sports health are carried out. These achieve the five healing effects of nourishing the body, mind, nature, wisdom, and morality, thereby having a therapeutic effect on physical, psychological, temperamental, intellectual, and moral aspects.

(3) Cultural health and wellness

Combining the cultural characteristics of Chongqing's Bayu culture with the hospital's historical and cultural heritage, unique cultural venues are established to provide cultural experiences and learning exchange spaces for the health and wellness community. This aims to achieve spiritual healing, enhance happiness, and establish a positive and optimistic mindset.

(4) Sports health and wellness

Relying on the forest environment and ecological advantages, sports health and wellness fitness trails, fitness areas, basketball, table tennis, and badminton courts are constructed. Yoga, leisure Tai Chi, forest exploration, and other activities are carried out to cultivate the body and mind, allowing the spirit to unite with the body, thus realizing the healing properties of the landscape.

5.4. Smart applications

The project adopts a three-dimensional landscape design, introducing a green environment into the hospital through forms such as rooftop gardens, terraced green spaces, and corridor spaces. By utilizing smart technologies like intelligent irrigation systems and environmental monitoring equipment, the ecological functions of the environment are optimized in real-time, ensuring an ecologically healthy and healing environment for patients. Smart interactive spaces are set up, providing personalized rehabilitation support for patients in real-time through intelligent interactive devices such as biofeedback equipment and smart rehabilitation appliances. Additionally, interactive sensor-based signage is installed, featuring diverse functions and interesting designs, to meet the accessible navigation needs of patients.

6. Insights into therapeutic design of outdoor landscapes for medical buildings enabled by smart technologies

6.1. Valuing the therapeutic benefits of natural elements

The natural environment can alleviate patients' anxiety and stress, improve their emotions, and promote physical recovery. Natural elements in landscapes include plants, water bodies, and lighting and shadows. Through photosynthesis, plants release oxygen, enhancing air quality and beautifying the environment. The graceful forms and flowing sounds of water bodies create a serene landscape space, helping patients relax and unwind. Natural changes in lighting and shadows bring warmth and vitality to patients. As natural elements exhibit different landscape effects with seasonal changes, they offer varying experiences to patients, stimulating their perception and interest in nature and enhancing their psychological identification with the recuperative environment. Outdoor landscapes of medical buildings should actively incorporate surrounding natural elements, emphasizing natural features while minimizing the impact of artificial facilities. The ecological and social values arising from the design of natural and artificial elements should be recognized. By fully tapping into the therapeutic functions of natural elements and cleverly integrating them into outdoor landscapes, a comfortable, serene, and vibrant healing space can be created for patients and their families, promoting physical and mental recuperation.

6.2. Constructing a reasonable walking space system

The walking system in the outdoor space of medical buildings serves as the primary outdoor activity path for patients. Its reasonable planning and design can guide patients to engage in moderate activities, helping them better integrate into the natural environment during their recovery process, promoting physical recovery, relieving psychological pressure, and improving emotional states. A reasonable walking space system should fully consider the diverse and humane needs of patients. In the design process, attention should be paid to seamless indoor-outdoor connectivity, ensuring easy access to the outdoors and enhancing the utilization of outdoor spaces. Furthermore, road widths and slopes should meet barrier-free design requirements, accommodating easy passage for wheelchairs or those with mobility issues. Paths should extend into natural landscapes, enabling patients to fully immerse themselves in nature during walks, promoting interaction with the natural environment and experiencing its therapeutic power. Additionally, rest nodes, such as benches and pavilions, should be set up along the paths, providing patients with leisure spaces where they can take breaks, admire beautiful scenery, breathe fresh air, and enjoy the tranquility of nature, thereby relieving psychological pressure and improving emotional states. By carefully designing the walking space system, patients are provided with a safe and convenient activity space, aiding them in regaining health and vitality in a natural environment.

6.3. Arranging specialized botanical gardens

Plants emit scents that can enter the human body through the lungs and skin, exerting beneficial effects on disease prevention, physical strengthening, and longevity. For instance, the fragrance of camphor trees can dispel rheumatism and relieve pain. Specialized botanical gardens feature a single plant or a specific type of plant, such as a medicinal herb garden, an aromatic garden, a rose garden, or a meadow dotted with flowers [6]. Medicinal herb gardens cultivate plants with medicinal properties. Herbs like rosemary and lavender can soothe nerves and reduce anxiety, while plants like honeysuckle and mint have detoxifying effects that help enhance patients' immunity. Signs introduce the medicinal effects of these plants, allowing patients to learn about traditional Chinese medicine while admiring the plants.

Aromatic gardens utilize olfactory stimulation for therapeutic benefits. The fragrance of plants can soothe nerves, reduce anxiety, improve sleep quality, and even alleviate pain to some extent, promoting patients' physical and psychological recovery. Rose gardens are filled with the scent of roses, relaxing tense nerves and unwinding the mind. Patients can stroll through the flower paths, immersing themselves in the space of roses, releasing inner fatigue, and rejuvenating their minds with the healing power of roses. Meadows dotted with flowers often feature a colorful natural tapestry of native wildflowers and weeds, blooming with different flowers throughout the seasons, creating a serene and vivid natural atmosphere. Botanical gardens, with their natural and wild landscapes and diverse plant species, become an ecological space with tremendous healing functions [7].

6.4. Integrating multiple therapies

In the outdoor landscape design of medical buildings, various healing therapies can be cleverly integrated to create a multifunctional physical and mental healing space. By comprehensively applying horticultural therapy, aromatherapy, traditional Chinese medicine's five-element therapy, naturopathy, color therapy, and more, the ornamental, functional, and healing aspects of the landscape are enhanced. By setting up a horticultural area, patients can participate in planting and caring for plants, promoting communication among patients, and allowing them to relax and engage in physical activities while experiencing plant growth. Planting fragrant and non-toxic plants can stimulate patients' olfactory systems to varying degrees, utilizing their scents to soothe emotions and reduce stress, achieving the effects of aromatherapy. Incorporating areas for experiencing traditional Chinese medicine external therapies such as massage, scraping, and moxibustion in the landscape helps patients relieve physical discomfort and promote physical health. Rational utilization of natural elements like sunlight, air, and water in the landscape allows for the design of open lawns, clear water bodies, and comfortable lounges, unleashing the relaxing effects of naturopathy. Different colors of plants are arranged in the landscape design, and plant colors are reasonably matched to create a healing visual experience by leveraging the varying impacts of plant colors on human emotions. For instance, red plants can stimulate the respiratory system and promote blood circulation, green plants help relax nerves and alleviate stress, while white plants are beneficial for lowering blood pressure and soothing emotions.

6.5. Integration of smart technology with healing landscapes

With the emergence of new technologies and concepts such as artificial intelligence, cloud computing, big data, and virtual reality, the technical means of landscape design have undergone corresponding changes. Smart landscapes represent the soul of modern landscapes, and the healing aspect of hospital landscapes can also be achieved through intelligent technology [8]. For example, virtual reality technology can provide patients with specific healing virtual spaces tailored to different psychological issues, not only utilizing the positive guiding role of the natural environment but also enhancing the immersive and personalized experience with smart technology. By introducing the Internet of Things and artificial intelligence technology, a rainwater collection and water circulation system can be established, along with various interactive devices, enabling people to perceive changes in the natural environment and rebuild an intimate connection between humans and nature. Technologies like the Internet of Things, big data, and artificial intelligence allow for real-time monitoring and analysis of environmental data, optimizing landscape design and better meeting patients' health needs.

7. Conclusion

The healing design of outdoor landscapes for medical buildings not only satisfies patients' physiological needs but also focuses on their psychological and social demands. By rationally utilizing natural elements, constructing a walking space system, arranging specialized botanical gardens, integrating multiple therapies, and adopting smart technologies, a healthy, comfortable, and therapeutically beneficial healing space environment can be created, providing patients with a sanctuary for their physical and mental recuperation and fully unleashing the therapeutic functions of medical buildings.

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Research on the Protection and Transformation of Traditional Architecture

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Abstract: Traditional architecture, as a crucial component of human cultural heritage, conveys significant historical context and cultural significance while reflecting regional traits and national identity. Nevertheless, in the face of rapid modernization, traditional architecture is encountering challenges on an unprecedented scale. This study focuses on examining the strategies for preserving and transforming traditional architecture. By evaluating the importance, issues, and obstacles associated with safeguarding traditional architecture, this paper seeks to propose effective and rational conservation approaches and transformation techniques, ultimately aiming to ensure the sustainable development and cultural continuity of traditional architecture.

Keywords: Traditional architecture; Protection; Transformation; Cultural inheritance

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1. The importance and necessity of protecting and transforming traditional architecture

1.1. Historical and cultural inheritance

The architectural styles, decorative elements, and spatial arrangements of traditional structures serve as reflections of the social culture and aesthetic values from specific historical periods. These aspects contribute to the uniqueness and diversity of regional cultures. For instance, ancient Chinese architecture emphasizes the philosophical concept of harmony between humans and nature. Through skillful design layouts and intricate decorations, it conveys the ancients' respect for the natural world and their wisdom in achieving coexistence. In contrast, European structures such as medieval castles and churches, with their grand exteriors and exquisite interior embellishments, embody the religious beliefs, noble traditions, and artistic accomplishments of European societies since the Middle Ages. These buildings act not only as historical witnesses but also as cultural custodians and educators. They narrate the tales of the past in a silent yet powerful manner, sparking people's curiosity and contemplation regarding history and culture [1].

Moreover, safeguarding traditional structures plays a crucial role in sustaining cultural diversity and fostering intercultural interactions. In an era of globalization, the movement toward cultural uniformity is growing more pronounced, placing numerous local traits and cultural customs at risk of being sidelined or even lost altogether. As emblematic representations of regional culture, preserving historic architecture signifies not only a commitment to local traditions but also an offering to global cultural richness. Consequently, it is essential to uphold and safeguard traditional buildings. Through their preservation, a dynamic space for interaction and dialogue can be created between diverse cultures, encouraging mutual appreciation and respect, while collaboratively establishing the cultural groundwork for a shared human destiny [2].

1.2. Urban landscape

Traditional buildings frequently exhibit a strong connection to the natural surroundings, cultural scenery, and historical backdrop of a city. Together, these elements create the distinctive skyline, street views, and public spaces that define an urban area. Through their individual architectural designs, material choices, and attention to detail, such structures reveal the evolutionary path and cultural traits of the city across various historical eras. The significance of preserving traditional architecture is further highlighted in its role in defining urban spatial patterns and visual environments, as well as fostering social frameworks and community unity within cities. Safeguarding traditional architecture means upholding the identity, uniqueness, and cultural legacy of a city while establishing a robust basis for its sustainable progress and cultural continuity [3].

The adaptation of traditional architecture involves more than just the physical renewal and functional enhancement of structures; it also signifies utilizing innovative design and technological integration to ensure that these architectural elements align with urban development requirements. This process fosters a balanced coexistence between historical significance and contemporary needs. Revitalizing historic buildings contributes to elevating the overall appearance and quality of a city. By reconfiguring the spatial arrangements and upgrading the functionalities of these structures, they can be made more compatible with modern urban lifestyles, as referenced in [4].

1.3. Ecological, environmental protection and sustainable development

The preservation and restoration of traditional structures can contribute to minimizing environmental harm. Numerous historic buildings were originally designed with eco-friendly principles, such as natural ventilation systems, efficient use of daylight, and sustainable materials, all of which play a role in decreasing energy usage and pollution levels. By maintaining and upgrading these structures, we can preserve and promote these environmentally conscious ideas while advancing the growth of sustainable architecture. Additionally, it is essential to minimize demolition and reconstruction waste to mitigate any adverse effects on the environment.

The preservation and revitalization of traditional structures can play a crucial role in driving urban regeneration and fostering community progress. As urbanization continues to accelerate, numerous historic buildings face the threat of demolition. Nevertheless, these architectural landmarks represent more than just cultural legacies; they also serve as vital components of their respective communities. By restoring and repurposing them, new vitality and utility are introduced into these structures, transforming them into focal points that connect and engage community members, thereby encouraging interaction among residents. Such efforts not only sustain the unity and identity of the community but also support the long-term ecological and economic sustainability of urban environments [5].

2. Challenges and dilemmas faced by traditional architecture

2.1. The impact of modernization

The swift advancement of modernization has significantly influenced traditional architecture. As urbanization proceeds at an accelerated pace, numerous traditional structures have been torn down to make way for contemporary skyscrapers and infrastructure. This cycle of destruction and rebuilding not only results in the erosion of historical and cultural heritage but also contributes to the fading of community memories and the sense of belonging embedded in these traditional buildings. Many historic structures have been overlooked or pushed to the periphery during the push for modernization, with their historical importance and cultural contributions remaining underappreciated and undervalued [6].

The push for modernization has also led to transformations in people's lifestyles. Contemporary living emphasizes functionality, ease, and comfort, whereas traditional structures frequently fail to align with these requirements. For instance, the interior features of older buildings might not accommodate the lifestyle preferences of today's individuals and may be lacking in modern amenities and technology. As a result, numerous individuals have come to prefer modern residences and constructions in their quest for a higher quality of life, causing traditional buildings to become increasingly obsolete or neglected.

2.2. Disrepair and potential safety hazards

Deterioration stands as one of the primary challenges confronting traditional structures. Owing to historical contexts, numerous traditional buildings were constructed without the benefit of contemporary materials and technological advancements, leading to comparatively weaker structural integrity and limited durability. As years go by, these constructions have increasingly encountered issues like cracked walls, leaking roofs, and deteriorated wooden elements. Should these concerns remain unaddressed, they could pose significant risks to the buildings' structural stability. Additionally, neglect can cause the building's internal systems to become outdated, failing to accommodate modern living requirements and ultimately accelerating the disuse and desertion of traditional architecture [7].

Another significant challenge for traditional buildings lies in their concealed safety risks. Due to their unique structural and material properties, these buildings are often more susceptible to both natural calamities and human-induced damage. For instance, timber-framed structures are especially prone to fire hazards, and in the event of a fire, it can spread rapidly, leading to substantial loss of life and property. Additionally, traditional buildings exhibit weaknesses in terms of earthquake resistance, which may result in building failures and casualties during seismic events [8].

2.3. Lack of cultural awareness and weak protection awareness

The deficiency in cultural awareness is primarily manifested through the undervaluation and misinterpretation of traditional architecture's significance. Influenced by modernization, individuals often favor contemporary and innovative architectural designs, perceiving traditional structures as "antiquated" or "traditionalist." This mindset results in the underappreciation of the historical, cultural, and artistic worth of traditional buildings, sometimes even questioning their necessity. Consequently, there is a diminished sense of responsibility regarding the preservation of traditional architecture [9]. On one hand, many people lack fundamental knowledge and accountability for safeguarding these structures, treating them as expendable cultural emblems while disregarding their role as invaluable heritage. On the other hand, governmental bodies and related organizations exhibit shortcomings in preserving traditional buildings. In certain regions, the absence of comprehensive conservation plans and efficient oversight systems has created numerous obstacles in protecting these structures. The shortfall in cultural understanding and the weakened commitment to preservation not only jeopardize the safety and completeness of traditional architecture but also risk losing the historical and cultural data embedded within them. This loss, in turn, hinders the continuation and evolution of national culture [10].

3. Strategies and methods for the protection and transformation of traditional architecture

3.1. Strengthening laws and regulations

The government has issued the Law of the People's Republic of China on the Protection of Cultural Relics, along with other relevant laws and regulations, which classify traditional buildings as immovable cultural relics under legal safeguarding. These legislative measures establish a fundamental legal structure and foundation for preserving traditional buildings. Furthermore, locally-focused normative documents can also be developed, allowing for more tailored approaches that align with regional circumstances, thereby enhancing the regulatory protection of traditional buildings[11].

The government ought to reinforce legal enforcement in safeguarding traditional structures, suppress any unlawful destruction of these buildings, and uphold the seriousness and authority of relevant laws. Furthermore, it is essential for the government to enhance the training and supervision of legal enforcement officers to elevate their professional skills and enforcement capabilities. Additionally, through diverse methods and channels, there should be increased promotion and dissemination of regulations concerning the protection of traditional buildings. This will contribute to raising public awareness and comprehension of these laws, fostering a stronger legal consciousness among citizens, and encouraging the development of a positive environment where society collectively participates in preserving traditional architecture [12].

3.2. Raise the awareness of protection and strengthen publicity and education

To enhance the consciousness of preservation, it is crucial to begin with children by integrating traditional architecture protection knowledge into the educational system. By utilizing classroom instruction, extracurricular activities, and other methods, children can be exposed to and comprehend the historical, cultural, and artistic significance of traditional structures at an early stage, fostering their sense of belonging and pride in traditional culture.

To reinforce outreach and education, modern media platforms should be utilized. By constructing a comprehensive and multi-dimensional promotional network through television, radio, the Internet, and social media, the grace and allure of traditional buildings can be engagingly showcased. Through the creation of specialized documentaries, online tutorials, WeChat official account articles, live interactions, and other formats, the narratives and significance behind these structures are shared, drawing greater public interest and encouraging participation in preservation efforts [13].

Hosting vibrant public engagement activities serves as a practical method to enhance awareness regarding preservation. For instance, events such as traditional architecture photography contests, hand-drawn map competitions, and cultural festivals can be organized to inspire the public to document and convey their appreciation for traditional structures through diverse means. Concurrently, it is essential to develop a volunteer service framework that enlists individuals passionate about traditional culture to partake in the routine upkeep, interpretation, and tours of historical buildings. This enables conservation efforts to function as a crucial avenue for community members to contribute to social welfare and achieve personal fulfillment.

3.3. Establish a list and archives for the protection of traditional buildings

Creating an inventory of traditional buildings for preservation involves officially recognizing and documenting structures that possess historical, artistic, and scientific significance. This inventory typically includes details such as the name, location, age, architectural style, and historical-cultural importance of each building. By identifying structures that meet specific criteria and including them in the register of Notable Historic Buildings, these sites can receive the recognition and safeguarding they require. Such criteria encompass representing local history, showcasing architectural artistry, and embodying the historical and cultural traits of regional architecture. Once a building is added to this register, it cannot be modified without approval and is subject to stringent protective measures [14].

Simultaneously, creating archives for traditional structures is a crucial aspect of preservation efforts. The content of these archives should encompass comprehensive details about the building, including its historical context, architectural features, artistic embellishments, and maintenance history, among others. Such information can be documented and preserved in diverse formats, such as written descriptions, diagrams, photographs, and visual recordings. Establishing these archives not only aids in comprehending the historical evolution and present condition of the structure but also furnishes a reliable foundation for future preservation and restoration endeavors. For instance, prior to restoring ancient edifices, it is essential to document their original appearance, gather restoration data meticulously, and prepare necessary materials, thereby ensuring a solid foundation for the restoration initiative. Additionally, monitoring and archiving records generated during the upkeep of historical buildings—such as restoration strategies, design blueprints, and implemented measures—are integral components of archive preservation.

3.4 Reconstruction methods and case analysis

3.4.1. Preliminary assessment and planning

Prior to transforming a conventional structure, a comprehensive evaluation and strategic planning are essential. This involves a detailed examination of the building's historical context, cultural significance, architectural integrity, and possible functional requirements. Through this analysis, it becomes feasible to identify which components should be conserved and which areas require renovation or modernization. Additionally, during the planning phase, consideration must also be given to how the refurbished structure will harmonize with its surroundings and promote sustainable development. For instance, in the restoration of an old cottage on Gaoyou Road in Shanghai, the designers preserved the prominent chimneys and weathered walls while incorporating materials and hues in the new sections that complement the original building. As a result, the renovated structure maintains its historical allure while seamlessly integrating with the surrounding landscape [15].

3.4.2. Structural reinforcement and restoration

The reinforcement and restoration of traditional structures represent a critical stage in the renovation process. This involves employing contemporary materials and techniques to strengthen essential elements like walls, beams, columns, and foundations, thereby ensuring the building's overall stability. Additionally, damaged or deteriorated components must be meticulously repaired or replaced to restore their original functionality and aesthetic appeal.

For instance, during the renovation of Fujian Province's tulou, designers utilized modern resources and methods to fortify walls, beams, and columns due to their intricate construction and historical age. Simultaneously, damaged elements such as tiles, doors, and windows were carefully restored or substituted. In another case, the design team for the Shenshanling Comprehensive Service Center proposed integrating the building into ecological restoration efforts by addressing a 15-meter-high exposed slope. Through a stepped-back design approach, they connected the structure with the natural mountain terrain, creating open outdoor spaces while transforming the building into an extension of the natural landscape.

3.4.3. Function update and space optimization

Traditional structures frequently embody a wealth of historical and cultural significance; however, in contemporary settings, their functional demands may evolve. Consequently, during restoration projects, it is essential to modernize and enhance the building's functionality based on practical requirements while optimizing its spatial layout. For instance, the Qianyang Farmer's Market, initially comprising two dilapidated old residences, has been reimagined as a cutting-edge rural public service complex. This facility now incorporates functions such as promotional exhibitions, an e-commerce hub, agricultural education programs, online and offline trading of local goods, and immersive agritourism experiences. Through the creation of new walkways and small pavilions, the designers successfully linked the two residential units, thereby crafting a harmonious blend of indoor and outdoor spaces that interweave old and new elements, offering diverse vistas.

4. Conclusion

The preservation and adaptation of traditional architecture serve as crucial approaches for achieving cultural heritage and sustainable development. By implementing thoughtful conservation strategies and adaptive reuse techniques, it is possible to maintain the historical essence and cultural identity of these structures while endowing them with contemporary functions and renewed relevance. Moving forward, there should be an ongoing emphasis on researching the preservation and adaptation of traditional buildings to foster the continuation and evolution of architectural culture. In this endeavor, focus should extend beyond physical preservation to uncover and perpetuate the underlying cultural significance, ensuring that traditional architecture acts as a link between history and modernity, providing invaluable legacy for future generations.

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Application of Energy Saving and Green Environmental Protection Building Materials in Building Engineering

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Abstract: Construction engineering plays a vital role in urban development, especially as the pace of modern progress continues to accelerate. The widespread use of energy-saving and green environmental protection building materials in this field not only brings convenience to daily life but also promotes the scientific, sustainable, and stable development of construction projects. These materials significantly extend the service life of buildings while supporting environmental protection efforts. This paper explores the practical application value of energy-saving and environmentally friendly building materials in construction engineering, outlines the key application principles, and analyzes their specific types and usage requirements. The aim is to provide a valuable reference for future research and practical implementation.

Keywords: Energy saving and green environmental protection; Building materials; Building engineering; Application path

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1. Introduction

In the global push towards sustainable development, the construction industry, being a major area for resource consumption and carbon emissions, is experiencing unparalleled pressure to undergo transformation. Energy-efficient and eco-friendly building materials have emerged as a crucial driving force behind the sustainable advancement of this sector [1]. With their attributes of low energy consumption, minimal pollution, and recyclability, these materials can significantly mitigate environmental harm throughout a building's lifecycle while also enhancing its performance and comfort. From cutting energy usage during production to lowering operational costs in use, green materials are revolutionizing all facets of construction endeavors. Whether addressing climate change or fulfilling the public's demand for high-quality living spaces, the extensive adoption of energy-saving, green, and environmentally friendly building materials in construction carries profound implications, ushering in a new era of green growth within the industry [2].

2. The application value of energy-saving green environmental protection building materials in construction projects

2.1. Green environmental protection and pollution-free

As a new type of material, energy-saving green building materials differ significantly from conventional building materials. These differences are mainly reflected in the fact that harmful substances are not added during their production and processing. Additionally, they possess notable characteristics such as environmental friendliness and energy efficiency. At the same time, its recyclable characteristics, such as the recycling and reprocessing of scrap steel and waste concrete, save natural resources and reduce production costs. In addition, some green environmental protection materials also have antibacterial, air purification, and other functions, which is conducive to improving indoor environmental quality and protecting human health. Therefore, the use of energy-saving green environmental protection building materials in construction projects can avoid causing pollution to the surrounding environment [3].

2.2. Energy consumption is relatively small

In general, the construction process involves building materials that tend to consume a significant amount of energy. This is because their production processes are still evolving, leading to inevitable environmental and ecological pollution during the extraction, processing, and utilization of raw materials. From an environmental protection perspective, these materials produce fewer pollutants during production, and some are biodegradable, which helps minimize contamination of soil and water resources. Energy-saving, green, and environmentally friendly building materials can be efficiently recycled, thus preventing excessive resource depletion. Additionally, these materials typically have lower costs, making them better suited to meet the demands of today's ecologically focused society [4].

2.3. Functional diversity

In contemporary building construction, energy-efficient, green, and environmentally friendly materials exhibit functional versatility. Typically, these materials are composed of multiple components and are formed through a specific manufacturing process. The significant composite properties of such materials allow for the full utilization of the advantages of various substances while minimizing the drawbacks of conventional building materials in construction projects [5].

3. Principles followed by energy-saving, green, and environmentally friendly building materials in construction projects

3.1. The principle of no harm and energy conservation

In construction projects, the selection of green environmental protection materials is guided by the principles of harm prevention and energy efficiency. These materials must ensure they pose no threat to human health, avoid emitting harmful volatile substances like formaldehyde or benzene, maintain indoor air quality at its source, and provide occupants with a safe and comfortable environment. Additionally, enhancing energy savings remains crucial. For instance, utilizing high-performance insulation materials such as polystyrene boards or rock wool boards can significantly minimize building heat transfer. This reduces the energy required for winter heating and summer cooling, thereby improving energy efficiency. Such practices assist buildings in achieving energy conservation and emission reduction targets, decrease reliance on conventional energy sources, and align with the modern concept of low-carbon development [6].

3.2. Conform to the principle of ecological development

Adhering to the principle of ecological development demands that green building materials exhibit eco-friendliness throughout their entire life cycle, from production to disposal. During the manufacturing phase, emphasis should be placed on selecting renewable and recyclable raw materials, such as recycled aggregates derived from waste concrete. This approach can help decrease the over-extraction of natural sand and gravel while safeguarding natural resources. Additionally, the manufacturing process should incorporate low-energy and low-pollution technologies to minimize carbon emissions and waste generation. Once these materials are no longer in use, they should either be reusable or biodegradable, allowing for easy reclamation or natural decomposition. This ensures minimal environmental impact, preserves ecological balance and stability, and fosters a harmonious relationship between architecture and nature [7].

3.3. The principle of economy and aesthetics

The concepts of cost-effectiveness and visual appeal must not be overlooked. Green, environmentally friendly materials, while ensuring optimal performance, should also exhibit strong economic advantages. Although their initial costs might be somewhat higher, in the long term, due to energy-saving benefits and reduced maintenance expenses, they can lead to an overall decrease in costs, providing significant financial advantages for construction projects [8]. Additionally, these materials must align with architectural aesthetic requirements. Modern green materials are continually evolving in design innovation. For instance, eco-friendly paints offer diverse colors and textures, while energy-efficient doors and windows come in various styles. These elements not only enhance the visual attractiveness of buildings but also emphasize the distinct character of contemporary architecture. Thus, while promoting sustainable development, such structures also possess artistic allure, fulfilling people's aspirations for high-quality buildings.

4. The specific application of energy-saving green environmental protection building materials in construction projects

4.1. The application of energy-saving and green environmental protection building materials in the wall

The wall serves as a crucial component of a building, and the use of energy-efficient, green, and environmentally friendly materials in its construction plays a significant role in enhancing the overall performance of the structure.

4.1.1. New wall materials

For example, aerated concrete blocks are produced primarily from siliceous materials (such as sand or fly ash) and calcareous materials (like cement or lime) through a series of processes, including batching, mixing, casting, aeration, cutting, and autoclave curing. These blocks are known for their lightweight properties, with densities typically only one-third that of traditional clay bricks. This significantly reduces the overall weight of buildings and decreases foundation engineering costs [9]. Furthermore, they exhibit exceptional thermal insulation due to their low thermal conductivity, effectively minimizing heat transfer and reducing energy consumption in buildings. Additionally, aerated concrete blocks offer superior soundproofing capabilities, efficiently blocking external noise and enhancing indoor tranquility and comfort [10].

4.1.2. Composite wall material

Wall materials constructed from composite materials with varying characteristics are extensively utilized in construction projects. For instance, a commonly used material in external wall insulation systems is the composite wall made from polystyrene boards and cement mortar. Polystyrene boards exhibit superior thermal insulation capabilities due to their extremely low thermal conductivity, effectively maintaining heat retention and insulation. Meanwhile, cement mortar contributes excellent strength and durability, safeguarding the polystyrene board against environmental damage. This type of composite wall not only fulfills the thermal insulation needs of walls but also guarantees their structural integrity and stability. Additionally, it enhances the energy efficiency and longevity of buildings [11].

4.2. The application of energy-saving green environmental protection building materials in waterproof sealing

Ensuring that building structures remain unaffected by water and maintaining indoor dryness and comfort largely depend on the effectiveness of waterproof sealing. In this context, energy-efficient and eco-friendly waterproof sealing materials are crucial. They contribute significantly to preventing water infiltration while supporting sustainable construction practices.

4.2.1. Polymer waterproof coil material

Polymer-based waterproof membranes utilize synthetic rubber, synthetic resin, or a combination of both as primary materials. These are supplemented with suitable quantities of chemical additives and fillers, processed through various techniques to form rollable sheet materials. For instance, EPDM rubber waterproof membranes exhibit superior resistance to weathering, ozone, and chemical corrosion, along with excellent elasticity and tensile strength. They boast an extended lifespan and can maintain effective waterproofing capabilities even under severe environmental conditions. In contrast to traditional asphalt-based waterproof membranes, polymer alternatives offer easier installation via cold adhesive or self-adhesive methods, thereby minimizing environmental impact and energy usage during construction [12].

4.2.2. Sealant

In the various components of a building, such as doors, windows, and curtain walls, sealants are applied to fill gaps and provide functions like waterproofing, sealing, and sound insulation. Among these, silicone sealant is widely utilized as an environmentally friendly option. It demonstrates excellent resistance to weather conditions, water, and strong adhesive properties. This sealant adheres effectively to most construction materials, creating a robust sealing layer that efficiently prevents rain leakage and air infiltration. Additionally, its stable chemical composition ensures no environmental pollution, aligning well with green standards.

4.3. The application of energy-saving green environmental protection building materials in thermal insulation

Thermal insulation materials play a crucial role in decreasing building energy consumption and keeping the indoor temperature stable. Energy-efficient and environmentally friendly thermal insulation materials have become prevalent in construction projects.

4.3.1. Rock wool board

Rock wool board is an inorganic fiber material primarily produced from natural rocks such as basalt and diabase, through processes of high-temperature melting and fibrosis. This material exhibits exceptional thermal insulation capabilities due to its low thermal conductivity, effectively minimizing heat transfer. Additionally, rock wool board is non-combustible, offering superior fire resistance that enhances the fire safety of buildings. Its sound absorption and noise reduction properties are also noteworthy, significantly diminishing external noise interference within indoor environments. Furthermore, as an inorganic substance, rock wool board possesses stable chemical characteristics, resisting degradation over time and ensuring a long service life. The production process generates minimal environmental pollution, making it an eco-friendly option.

4.3.2. Foam glass

Foam glass is a porous glass material produced by utilizing recycled glass, foaming agents, modifying additives, and foaming accelerators, processed through grinding, mixing, shaping, and heat treatment. This material exhibits exceptionally low thermal conductivity and outstanding thermal insulation capabilities. Its closed-cell structure provides excellent waterproofing properties, effectively resisting moisture penetration. Foam glass is non-flammable, corrosion-resistant, nontoxic, and demonstrates strong chemical stability, making it an ideal eco-friendly thermal insulation material. In construction applications, foam glass can be employed for exterior wall insulation, roof insulation, and other components, significantly enhancing the energy efficiency of buildings.

4.4. The application of energy-saving green environmental protection building materials in the prevention of fire

Fire presents a significant risk to the safety of both structures and people, thus making the use of energy-efficient, eco-friendly building materials with good fire resistance essential in construction endeavors.

4.4.1. Fireproof paint

Fire-resistant paint is a specialized coating applied to building surfaces to inhibit fire propagation and prolong the substrate's resistance to burning during a fire. Among these, water-based fireproof coatings represent an eco-friendly option. They utilize water as a solvent, eliminating the need for organic solvents and preventing the release of volatile organic compounds during both production and application. This makes them safe for both the environment and human health. Water-based fireproof coatings exhibit excellent fire-retardant properties; when exposed to fire, they quickly expand to create an insulating barrier that prevents heat from transferring to the underlying material, thereby safeguarding the structural integrity of the building. Additionally, these coatings offer superior aesthetic qualities, allowing for customization in terms of color and gloss to meet architectural design requirements.

4.4.2. Non-combustible materials

For example, inorganic fiber-reinforced cement boards use cement as the base material and inorganic fibers (such as glass or carbon fibers) as reinforcing materials. These boards are manufactured through processes like molding and maintenance. Inorganic fiber-reinforced cement boards are non-flammable, meaning they will not catch fire or produce toxic gases when exposed to flames. This makes them effective in preventing the spread of fire. Additionally, they possess high strength and excellent weather resistance, making them suitable for applications such as building firewalls or fire-resistant ceilings, thereby enhancing the fire safety of structures [13].

5. Requirements for the application of energy-saving green environmental protection building materials in building projects

5.1. Focus on environmental and ecological pollution issues

In the process of selecting and utilizing energy-efficient and eco-friendly construction materials, it is crucial to thoroughly evaluate their environmental and ecological consequences. Initially, the manufacturing procedures for these materials should aim to reduce the depletion of natural resources and minimize ecological harm. For instance, preference can be given to materials derived from industrial by-products or agricultural residues, promoting resource reutilization. Furthermore, during their application, these materials must not emit hazardous substances like formaldehyde or benzene, which could lead to volatile organic compound pollution and compromise both indoor and outdoor air quality, ultimately affecting human health. Additionally, proper consideration must be given to material disposal methods to guarantee that they can either be sustainably recycled or disposed of in an environmentally responsible manner upon reaching the end of their useful life, thereby mitigating any adverse environmental effects [14].

5.2. Pay attention to environmental protection and energy conservation

The construction sector must steadfastly advance towards the goals of environmental protection and energy conservation. This involves consistently encouraging the adoption and implementation of energy-efficient, green building materials in various projects. Firstly, greater emphasis should be placed on investing in the research and development of such eco-friendly materials. By fostering technological innovation among research institutions and enterprises, it is possible to enhance material performance and quality while simultaneously cutting production expenses, thereby increasing market competitiveness. Furthermore, architectural design firms and construction entities should proactively integrate these sustainable materials into their projects. They can refine both design strategies and construction techniques to fully leverage the benefits of energy-saving and environmentally friendly materials. Through boosting building energy efficiency, minimizing energy usage, and curbing greenhouse gas emissions, the industry can play a pivotal role in addressing global climate change.

5.3. Pay attention to the publicity and promotion of energy-saving and green building materials

To enhance the market recognition and usage rate of energy-efficient green building materials, it is crucial to intensify promotional efforts. Government departments can develop relevant policies and regulations that offer specific incentives and support for construction projects utilizing these materials, thereby encouraging the industry to adopt them more actively. Simultaneously, diverse media platforms—including television, newspapers, and the internet—can be leveraged to extensively promote the benefits and successful applications of energy-efficient green building materials, increasing public understanding and acceptance. Furthermore, organizing specialized training sessions and technical exchange events can help disseminate knowledge and application techniques to professionals in architectural design, construction, and supervision. This will not only elevate their expertise but also foster the broader integration of energy-saving and environmentally friendly materials in construction projects [15].

6. Conclusion

In conclusion, the integration of energy-efficient and green building materials in construction has yielded significant outcomes, transitioning steadily from theoretical promotion to practical implementation. This approach not only enhances the ecological and environmental attributes of structures but also drives technological advancements and upgrades within associated industries. Nevertheless, achieving a thorough green transformation in the construction sector demands ongoing commitment from all stakeholders. Researchers must persist in boosting investment in research and development, refining material characteristics, cutting expenses, and broadening their applications. Simultaneously, governmental bodies should enhance policies and regulations, reinforce market oversight, and incentivize the adoption of green materials in more construction endeavors. Moreover, raising public awareness and acceptance of green buildings remains vital. As technology evolves, policies are reinforced, and societal consensus is established, energy-saving and green building materials will undoubtedly play a leading role in future construction initiatives, providing a robust foundation for creating an ecologically sustainable and livable environment.

Disclosure statement

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Discussion on the Design of Compound Interchange Interweaving Section of Expressway

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Abstract: The purpose of this article is to explore the design of compound interchange interweaving sections on expressways. During the research phase, based on the support of the literature research method, the classification and development of the interchange system, as well as the design forms of the compound interchange interweaving section, were analyzed. Subsequently, based on the case method, the design of the compound interchange interweaving section of the ShiWu and ShiBai expressways in Shiyan, Hubei Province, was discussed, and a design scheme and scheme comparison were proposed. It is hoped that this article can provide technical reference and ideas for China's road and bridge engineering teams, ensuring that the design results can not only guarantee the normal passage of traffic on the North Intersection Expressway but also ensure the straight-line traffic capacity of the main highway under the background of dislocation intersection, achieving smooth and safe transitions between different expressways.

Keywords: Expressway; Compound traffic interweaving section; Collector-distributor road; Auxiliary lane

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1. Introduction

The construction of the expressway interchange system aims to ensure smooth and unobstructed road traffic on expressways. In the context of continuous growth in traffic volume and accelerating urbanization in China, expressways are facing escalating pressure and challenges [1]. As a new design concept, the compound interchange interweaving system can effectively reduce the investment level of construction and the land occupation of highway construction while ensuring the smoothness and safety of expressways. It plays a more important role in alleviating congestion and improving expressway traffic capacity. Therefore, researching the design of compound interchange interweaving sections on expressways is a high-value research behavior that further leverages the advantages of this design form and promotes continuous improvement in China's expressway construction and service levels [2].

2. Classification and development of expressway interchange systems

2.1. Classification of expressway interchange systems

2.1.1. Interchange type

The principle of the interchange type system is to achieve non-interference of traffic flow between different roads through the interchange combination of bridges, tunnels, and other three-dimensional structures, promoting rapid vehicle passage on the roads. It is suitable for areas with high traffic volumes, such as important transportation hubs. This system can effectively avoid congestion and traffic accidents caused by plane intersections, but its design and construction costs are high, and the construction period is long [3].

2.1.2. Ramp-type interchange

Ramp-type interchanges achieve turning and switching between different roads by setting a series of curves and ramps. This system is characterized by its relatively simple design, lower construction difficulty, and larger land occupation. Typically, this system is mostly applied to highway entrances and exits and areas with lower traffic density. However, ramp-type interchanges may experience traffic convergence and congestion under high traffic volume conditions [4].

2.1.3. Hybrid interchange

The hybrid interchange system combines the characteristics of both the interchange and ramp types, creating a more flexible traffic flow conversion system through a combination of multi-level interchanges and ramps. This form is characterized by flexible design, diverse functions, and strong adaptability, allowing effective traffic diversion while also enabling adjustments and optimizations based on specific needs. Hybrid interchanges are suitable for large integrated transportation hubs with complex terrains and diversified transportation demands, balancing construction costs and traffic efficiency to some extent.

2.1.4. Compound interchange

The compound interchange system integrates various interchange modes, such as interchanges, ramps, and roundabouts, to form a complex traffic network structure, enabling the highway interchange system to have extremely high traffic capacity and diversified traffic conversion methods. The compound interchange system is highly suitable for areas with extremely high traffic volumes, such as the periphery of large cities and hub zones where multiple highways intersect [5].

2.2. Development history of expressway interchange systems

Currently, expressway interchange systems have undergone multiple generations of development. Early expressway interchange systems focused on simple ramp designs. In the 80s and 90s, as traffic volumes continued to expand globally, the interchange-type became the mainstream construction mode for interchange systems. This form ensured improved separation and safety at intersections while overcoming traffic volume and terrain limitations. With the development of road and bridge engineering technology, the hybrid interchange system emerged to effectively overcome the high construction costs and large land occupation constraints faced by the interchange-type system. This system not only achieved a good transition between highways and city roads but also integrated the advantages of interchange and ramp systems [6]. However, as time progressed, it was found that this system limited drivers' visibility, and the separation effect at intersections was not ideal. Based on the above background and considering the advantages and disadvantages of different systems, the compound interchange system was born. Compared to the hybrid interchange system, the compound interchange system is more flexible in spatial utilization, provides a broader field of vision for vehicle drivers, and can ensure traffic safety. Simultaneously, this system can further enhance the traffic capacity of expressways through improved ramp designs.

3. Design forms of compound interchange interweaving sections on expressways

When there is a need for traffic conversion between newly built and existing expressways, establishing a single intersection point cross full-hub interchange is the most ideal form. However, during the actual design phase, there are often limitations due to existing features, topography, or narrow available corridors. When planning and design stages do not allow for the establishment of a single intersection point cross full-hub interchange, displaced intersection often becomes the most economical and reasonable design form. In this context, compound interchange interweaving sections can be designed in three forms based on differentiated compound methods: auxiliary lanes connecting to form an integrated road segment, collector-distributor roads connecting to form a separated road segment, and interweaving separation lanes connecting to form a completely separated road segment [7].

3.1. Auxiliary lanes connecting to form an integrated road segment

In this design form, when the length of the shared road segment is greater than 3km, or the volume of interweaving traffic and turning traffic is less than the connection between adjacent interchanges, the existing main expressway line can be widened and expanded, and auxiliary lanes can be constructed to meet the needs of turning and straight traffic on the shared road.

3.2. Collector-distributor roads connecting to form a separated road segment

In this design form, when the length of the shared road segment is less than or equal to 3km, or even if auxiliary lanes are set up in the integrated road segment mode, but the traffic demand cannot be met, independent collector-distributor roads can be set up outside the straight lanes of the main expressway line to directly connect the main entrance and exit. This design can reduce the difficulty of adjacent exits on the main expressway line, maintain the continuity of two straight lanes, and effectively transfer the interweaving traffic volume on the main expressway line to the collector-distributor roads.

3.3. Interweaving separation lanes connecting to form a completely separated road segment

This design form is suitable for situations where the length of the shared road segment is too short. Even if the form of collector-distributor roads connecting to form a separated road segment is adopted, it still cannot meet the length requirement of the interweaving section. This design involves adding interweaving separation lanes for each turn, using connecting ramps to directly separate the interweaving traffic flows of different directions, fundamentally avoiding conflict points caused by interweaving traffic flows and reducing the negative impact on straight traffic safety [8].

4. Research on the design of complex interchange interweaving sections of expressways

4.1. Overview of the expressway

This article takes the complex interchange project of Shiwu Middle Expressway in Shiyan City, Hubei Province as an example to explore the design process of the complex interchange interweaving section. During the operation of this section of the highway, the Shiwu Middle Expressway and the Shiwu North Expressway both need to interconnect with the Shitian Expressway in Baoxia Town. Due to the constraints brought by the terrain of this node, the distribution of large-scale structures such as bridges and tunnels on the Shitian Expressway, and the corridor of the main highway, there is a displaced intersecting common section between the Shiwu North Expressway and the Shiwu Middle Expressway in Baoxia Town. In the design phase of the complex interchange interweaving section, it is required to ensure that the main direction of the two highways is always in normal operation, minimize the construction volume of the complex interchange interweaving section, save economic costs, and form a safe, reasonable, and economical interconnection method. Based on traffic volume predictions, the distribution of traffic volume in different directions at this engineering node is obtained, as shown in **Figure 1**.

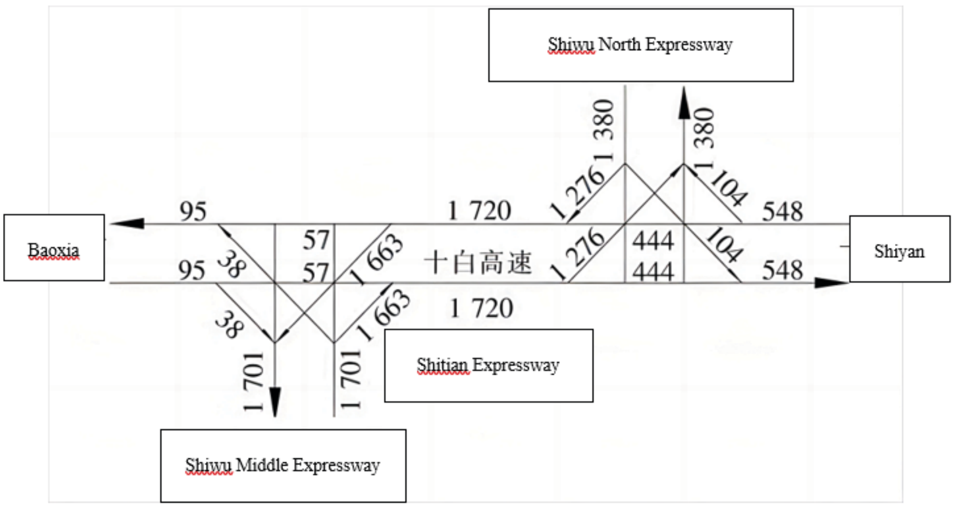

Figure 1. Distribution of traffic volume in different directions at the engineering node

As shown in **Figure 1**, the main traffic volume at this node is concentrated in the direction of Shiwu North Expressway → Baoxia, with a traffic volume of 1276 pcu/h calculated based on the long-term traffic forecast for 2042. The secondary traffic volume is focused on the direction of Shiwu North Expressway → Shiyan, with a traffic volume of 104 pcu/h.

4.2. Design principles

To design the complex interchange interweaving section for the case study project, it is necessary to follow the principles of traffic flow optimization, safety enhancement, and streamline simplification and intuition. Firstly, the design phase should prioritize the optimization and management of traffic flow, reasonably arranging the number and width of lanes to ensure they meet the traffic demand during peak hours. The length of the interweaving section should be precisely calculated to ensure sufficient space for vehicles to adjust their speed during lane changes and merging. Furthermore, due to the high complexity of the complex interchange, which may increase the burden on drivers while driving, the design should simplify traffic streamlines as much as possible, making them more intuitive and easy to understand and reducing unnecessary interweaving points [9].

4.3. Design scheme for complex interchange interweaving section under short-distance misaligned intersection conditions

4.3.1. Design features

The complex interchange system at the misaligned intersection node of the Shiwu Expressway has several distinct features. Firstly, the adjacent interchanges have a short spacing, with a center distance of only about 2.1 km, and the regional traffic density is relatively low. The design speed of the Shitian Expressway (the crossed highway) reaches 80 km/h, indicating a high road grade. Secondly, both the Shiwu Middle Expressway and the Shitian Expressway ramps adopt two-lane exits and entrances. After eliminating the influence of variable speed lanes and auxiliary lanes, the net distance between the interchanges is almost zero, and the vehicles entering and exiting the interweaving section between the interchanges have only a short length, which will affect the safety and traffic capacity of the straight-running traffic on the Shitian and Shiwu Expressways. Thirdly, due to the influence of the terrain and features at the engineering node, the interchange ramps have very limited space for arrangement, which restricts the layout of the complex interchange scheme. Based on the analysis of the above characteristics, the design needs to consider whether the length of the shared road provided by the scheme can meet the length requirement of the interweaving section.

4.3.2. Alternative solutions

Based on the analysis of the characteristics of the engineering node, this project proposes three design forms for the complex interchange interweaving section under short-distance misaligned intersection conditions:

(1) Setting auxiliary lane

This solution utilizes the existing roadbed and bridges of the Shitian Expressway to widen the road, adding an extra lane to the main line of the shared section of the Shibai Expressway. During the construction phase, the existing pile-slab wall of the Shibai Expressway will be directly utilized for support.

(2) Setting collecting-distributing lane

The construction of a separated collecting-distributing lane will be added outside the Shitian Expressway, which will then merge into the entrance and exit of the Shitian Expressway. The effective transfer of interweaving traffic flow will be achieved through the collecting-distributing lane and three connecting ramps. This solution includes two sub-solutions. Solution A is the westward solution, which sets up a 485m-long interweaving section to effectively solve the interweaving conflict problem of the Shitian Expressway (north intersecting expressway).

Solution B is the eastward scheme, which tilts the center of the intersection point towards the east. Based on ensuring high horizontal and vertical alignment indicators, it increases the length of the interweaving section of the collecting-distributing lane, extending it to 895m. This ensures that, with minimal differences in engineering scale, the normal traffic capacity of the main line of the Shitian Expressway is maintained by merging the collecting-distributing lane into the entrance and exit. Simultaneously, by increasing the spacing between the collecting-distributing lane and the ramp entrance and exit, the impact of traffic flow turning on the main line of the Shiwu Expressway is effectively reduced.

(3) Setting interweaving separation lanes

This solution involves setting up collecting-distributing lanes in the originally crowded corridor while also installing longer branch ramps on the outer side to achieve the separation of collecting-distributing lanes and turning traffic. This scheme will significantly increase the scale of the project. According to investigations, the recent traffic volume participating in interweaving and turning at this engineering node is 444 pcu/h (Shiyan→Wuxi). By implementing the separation of collecting-distributing lanes and reserving conditions for interweaving separation lanes, more room for traffic volume growth is reserved for the long term [10].

4.3.3. Comparative analysis of solutions

Comprehensive analysis shows that Solution (1), which involves setting up auxiliary lanes, has certain characteristics. After verifying the data, it is found that the traffic volumes of Shiwu Expressway and Shibai Expressway are 1276 pcu/h and 2240 pcu/h, respectively, and the turning traffic volume and interweaving traffic volume are 501 pcu/h and 1720 pcu/h, respectively. The interweaving area belongs to the main line segment of the Shitian Expressway. Therefore, referring to relevant specifications, the design speed should not be less than 70% of the main line design speed. The minimum interweaving section length can be calculated based on a design speed of 60 km/h for the interweaving traffic demand, resulting in a minimum interweaving section length of 600 m. However, under the influence of a large merging traffic volume in the shared road segment of the two expressways, the actual interweaving section length of 860 m provided by the project may lead to a decrease in the traffic capacity of the interweaving area. Therefore, although Solution (1) can save construction costs and has a high utilization rate of existing projects, the short distance of the shared segment and the huge interweaving traffic volume will inevitably bring negative impacts on the traffic capacity and safety of the main traffic flows of the two intersecting expressways.

Solution A under Solution (2) can solve the interweaving conflict problem of the Shitian Expressway (the crossed expressway), but it does not address the interference caused by interweaving conflicts on the main direction in the context of setting up collecting-distributing lanes on the Shiwu Expressway. Solution B can reduce the impact of turning traffic on straight traffic flow by appropriately increasing the distance between the exit and entrance of the connecting ramps of the collecting-distributing lanes, improving functionality while achieving economic savings.

Although Solution (3) can ensure highly smooth traffic flow organization and meet the rapidly growing demand for long-term turning traffic volume on the highway, it requires a larger scale of branch ramp engineering and special design to meet immediate needs. Additionally, there may be future road widening requirements, resulting in greater variability and overall higher costs. **Table 1.** compares the characteristics of three schemes combined with MALTB simulation, including dimensions such as traffic volume processing, safety, economy, and scalability.

Table 1. Comparison results of different schemes

Comparison Dimension	Scheme (1) Auxiliary Lane	Scheme (2) Option A	Scheme (2) Option B	Scheme (3) Independent Ramp
Traffic Volume Handling	-ShiWu Expressway: 1276 pcu/h -ShiBai Expressway: 2240 pcu/h -Weaving traffic volume: 1720 pcu/h	-Resolves weaving conflicts on ShiTian Expressway. -Turning traffic on ShiWu Expressway still interferes with the main flow.	-Increases distance between ramp exits/entrances to ≥ 300m, reducing turning traffic interference.	-Uses branch ramps to divert turning traffic (diversion ratio ≥ 40%), accommodating long-term growth needs.
Safety	-High risk: 5 additional conflict points in weaving zones, increasing accident probability by 35%.	-Reduces conflict points by 3 on ShiTian Expressway, but interference remains on ShiWu Expressway.	-Reduces conflict points by 60%, lowers risk of lane interference through optimized spacing.	-Fewest conflict points (only 2), physical isolation belt installed to reduce accident rates.
Economy	-Low initial investment, but high maintenance costs during operation due to increased accident repair frequency in weaving zones.	-Balanced cost and benefit, improved operational efficiency on ShiTian Expressway offsets some costs.	-Achieves optimal overall efficiency (cost savings of 15%, traffic efficiency improved by 18%).	-High initial investment, but long-term operational costs are reduced due to a 30% decrease in maintenance fees resulting from fewer accidents.- High initial investment, but long-term operational costs are reduced due to a 30% decrease in maintenance fees resulting from fewer accidents.
Scalability	-No reserved space, future expansion requires demolition and reconstruction.	-ShiTian Expressway is scalable, but development is restricted by the collector-distributor lanes on ShiWu Expressway.	-Collector-distributor lanes reserve 20% width allowance to support mid-term expansion.	-Fully independent system, supports multi-directional expansion (reserved expansion space for 5 lanes).

Based on comprehensive analysis, Option B of Scheme (2), which involves adding collector-distributor lanes, highly meets the requirements of the project case. It not only has a moderate scale but also demonstrates strong economic efficiency. This option can effectively reduce conflict points, support mid-term expansion, and ensure smooth organization of traffic flow. Ultimately, the engineering team selected Solution B under Solution (2).

5. Conclusion

In summary, this article analyzes the classification, development history, and design forms of interweaving sections in highway interchange systems. Taking the design of the complex interchange interweaving section of the Shiwu and Shibai Expressways in Shiyan, Hubei as an example, it explores specific scheme designs and selections for different design options. Relevant engineering teams can draw inspiration from this article to enhance their understanding of highway interchange systems, clarify design ideas and key points under different working conditions, and ultimately design cost-effective and functionally satisfactory complex interchange systems that meet the safety, economic, and efficient construction goals of highways.

Disclosure statement

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Total Station-Reflective Target Pier Deviation Measurement Error Control

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Abstract: In bridge engineering, monitoring pier offsets is crucial for ensuring both structural safety and construction quality. The total station measurement method using a reflector is widely employed, offering significant advantages in specific scenarios. During measurements, errors are influenced by various factors. Initially, misalignment causes the lateral relative error to increase before decreasing, while longitudinal relative errors fluctuate due to instrument characteristics and operational factors. Lateral movements have a more pronounced impact on these errors. Investigating the positioning layout of pier offsets holds substantial importance as it enables precise displacement monitoring, prevents accidents, aids in maintenance planning, provides valuable references for design and construction, and enhances the pier's resistance to deflection. Controlling and correcting subsequent errors is essential to ensure the overall safety of the bridge structure.

Keywords: Reflector; Total station; Pier deviation measuring point; Error analysis

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1. Introduction

In contemporary bridge engineering, precise pier positioning and displacement monitoring play a crucial role in ensuring structural safety and construction quality. Total stations are extensively utilized in this domain [1]. During measurements, various factors can introduce errors, with the reflective plate being a primary influencing factor. Its installation location, reflection efficiency, and compatibility with the total station are directly linked to the accuracy of pier offset measurement points [2]. Pier deflection encompasses vertical, lateral, and longitudinal displacements. Lateral deflection may lead to bridge deformation, while longitudinal deflection affects overall alignment and stability. Monitoring these aspects is essential for maintaining the safe operation of bridges. Consequently, investigating the error sources and influence mechanisms of reflectors and total stations holds significant theoretical and practical value for enhancing measurement accuracy and ensuring bridge safety. This study conducts a systematic analysis of reflector applications in total station-based pier offset measurements, exploring error causes such as reflector characteristics, installation deviations, environmental interference, and system errors inherent to total stations [3]. By integrating real-world engineering examples, this paper proposes error control strategies and optimization approaches, aiming to provide guidance for bridge measurement practices, promote advancements in bridge measurement technology, improve the precision of bridge engineering measurements, and ensure the safety and stability of bridges.

2. Total station measuring point setting method

In engineering measurements, the total station serves as a frequently utilized high-precision instrument [4]. Its point layout methods primarily consist of three approaches: prism-based, prismless, and reflector-based. Each method possesses its own set of advantages and disadvantages, making them suitable for various measurement scenarios [5]. The prism-based approach represents a traditional measurement technique that leverages reflective prisms to bounce back laser signals, achieving extremely high accuracy at the millimeter level. This level of precision is indispensable in projects such as bridge and building construction, where positioning accuracy is paramount. Additionally, the use of prisms can substantially extend the range of the total station, theoretically reaching several kilometers. In practical applications, with high-quality prisms, the effective range typically spans 1 to 3 kilometers, surpassing the capabilities of prismless modes. Furthermore, the prism-based method imposes minimal environmental constraints, delivering reliable results even under low-light or poor reflection conditions. It exhibits high data repeatability and reliability, making it ideal for long-term monitoring tasks. Nevertheless, this method necessitates direct line-of-sight between the total station and the prism, which can be hindered in complex terrains or densely built environments due to obstructions. Moreover, the requirement for manual installation and adjustment of the prisms adds complexity to operations and increases costs.

The prism-free arrangement offers convenient operation, eliminating the need for installing and adjusting reflector prisms. Measurements can be taken directly at the target point, significantly enhancing operational efficiency. This method is versatile and well-suited for environments where prisms cannot be installed, such as high locations, water surfaces, and hazardous areas, including suspended piers and cable measurements in bridge monitoring. Additionally, the cost of prism-free measurement is relatively low since there is no requirement to purchase or maintain prisms. Nevertheless, the accuracy of this approach is restricted and generally falls below that of prism-based methods. Consequently, when utilizing a prism-free total station for measurements, it is advisable to keep the measurement distance within 60 meters to ensure the required level of accuracy is maintained [6].

The retroreflector demonstrates significant advantages in specialized scenarios and serves as a crucial tool for total station measurements [7]. By returning the laser signal, it assists the total station in rapidly identifying and measuring target points, with flexible positioning that can be modified according to requirements. For instance, during tunnel monitoring, it is commonly attached to crown and sidewall monitoring points to track real-time tunnel deformation. In bridge construction, it is typically placed on pier surfaces or predetermined locations for high-precision measurements. Unlike prisms, retroreflectors do not require intricate installation or adjustment but can be directly adhered to the target surface. This significantly reduces preparation time and labor costs, offering distinct benefits in challenging environments such as high-altitude areas, water surfaces, and complex terrains where prism installation is difficult.

3. Application of the total station in bridge pier deflection detection

This experimental design utilizes a total station and reflective stickers for monitoring pier deflection. During the preparation stage, reflective stickers are affixed at critical locations, such as the base of multiple piers, serving as fixed reference points. These stickers remain immobile throughout the testing period [8]. In the observation phase, measurements are conducted using a total station. The device is positioned in an initial location where it can clearly detect and reflect signals from each pier while also meeting safety and observational requirements. The signal from the total station is directed toward the reflective sticker, which then bounces the signal back to the total station, enabling the collection of baseline observational data [9].

To facilitate multi-angle observations, the total station is relocated to various predetermined stations based on planned angles and distances. For instance, measurement stations can be established at specific intervals (such as 0°, 30°, 45°, 60°, and so on, up to the maximum angle) in a circular pattern around the pier [10, 11]. At each newly established station, a total station is utilized to measure the reflective paste markers on each pier, recording the angle, distance, and other data obtained from various perspectives. Once the measurements are completed, the extensive data collected are processed.

By employing specialized measurement software and incorporating known station coordinates and additional information, the data gathered from different angles are consolidated into a unified coordinate system. This process calculates the three-dimensional coordinates of each reflective patch measurement point. These measured coordinates are then compared with the design coordinates of the pier to determine the offset data in various directions. Through a thorough analysis of the multi-angle measurement data, the deflection of the pier can be assessed comprehensively and precisely, providing a crucial foundation for bridge maintenance and safety evaluations.

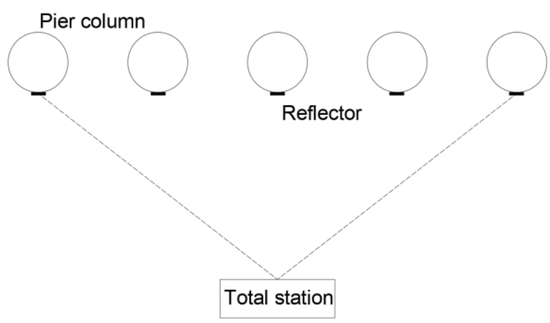

Figure 1. Schematic diagram of pier deflection observed by total station

4. Multi-angle observation pier deflection measurement point test

4.1. Test design

In the test design for the offset position of bridge piers, a method is employed where the total station is moved while the reflector plate remains stationary. Initially, at critical deflection measurement points on the pier, such as the pier top and midsection, reflective plates are evenly and securely attached as fixed reference points. This ensures their stability and prevents any displacement throughout the entire testing process [12].

In the planning of the total station's moving path, several stations are established based on specific angles, with the pier serving as the central reference point. At directions of 0°, 30°, 45°, 60°, and the maximum limit of 80°, the total station is positioned at a safe distance from the pier while ensuring clear visibility. The total station is sequentially set up at each station to measure the reflective plate measurement points located on the pier. Through this multi-angle observation method, comprehensive position information of the measurement points under various horizontal angles can be gathered, enabling precise analysis of the pier's horizontal deflection in all directions. The observation procedure adheres to an orderly approach. Initially, all reflector measurement points are measured at the 0° station, and the corresponding raw data, such as angles and distances, are documented. Subsequently, the total station is relocated to the 30° station, where the aforementioned measurement and recording steps are repeated. This process continues incrementally until measurements at the 80° station are finalized. Throughout the entire process, it is crucial to measure each reflective point strictly in accordance with the predetermined sequence at every station to prevent any omissions or duplicate measurements, thereby guaranteeing the completeness and precision of the collected data.

Following the test, the extensive raw data collected from various measuring stations are consolidated. With the aid of specialized measurement software referenced in Zhou's study [13], the three-dimensional coordinates of each measurement point are precisely determined within a unified coordinate system. This calculation leverages the measurement principles, known station coordinates, and other critical information. The obtained measurement coordinates are then meticulously compared against the designed coordinates of the pier, yielding the offset data for the pier. By conducting an integrated analysis of the data processing outcomes from multiple station angles, the deflection of the pier can be assessed comprehensively and with high precision. This process delivers robust and dependable data support for subsequent bridge maintenance decisions.

4.2. Test results

The graph illustrates the connection between longitudinal and lateral displacement and the relative error in the arrangement of bridge pier offsets when using a total station at various observation angles. Analyzing the pier displacement error data reveals that, generally, the lateral error exceeds the longitudinal error. The horizontal observation error at 0° is the highest (mean 1.13mm, standard deviation 0.74mm), whereas the horizontal error at 60° is notably minimized and remains the most consistent (mean 0.57mm, standard deviation 0.31mm). This suggests that enhancing the observation angle can efficiently mitigate lateral interference. Overall, within the angular range of 0–30 degrees, the lateral relative error surpasses the longitudinal relative error in most angular intervals. Additionally, the lateral relative error demonstrates significant variation, while the longitudinal relative error exhibits relatively mild fluctuations. These findings indicate that lateral movement considerably impacts the relative error under this measurement scenario [14].

Table 1. Displacement direction and relative error of pier under different observation angles

Observation angle	Pier displacement direction	Maximum error (mm)	Minimum error (mm)	Mean error (mm)	Standard deviation of error (mm)
0 °	Longitudinal	1.0	0.1	0.63	0.32
	Horizontal	2.0	0.3	1.13	0.74
30 °	Longitudinal	2.0	0	0.44	0.67
	Horizontal	1.9	0.2	1.06	0.62
45 °	Longitudinal	1.9	0.1	0.73	0.69
	Horizontal	1.2	0.1	0.73	0.42
60 °	Longitudinal	1.5	0.1	0.84	0.47
	Horizontal	0.9	0	0.57	0.31

5. Conclusion

The findings from the multi-angle observation experiment, where the total station was moved while the reflector remained stationary, are noteworthy. While the reflector lacks the precision of a prism, it offers significant advantages such as low cost, easy installation, and the ability to rapidly establish measurement points in challenging environments like narrow spaces or high altitudes, demonstrating strong adaptability [15]. In bridge safety evaluations, combining observations from multiple stations at varying heights enables comprehensive detection of deviations in bridge piers. This approach significantly enhances the accuracy of structural health assessments and provides critical evidence for identifying potential hazards and devising maintenance strategies. Regarding advancements in measurement technology, flexible station arrangements and the utilization of reflectors inspire researchers to refine measurement procedures and improve algorithms, driving the evolution of measurement techniques toward greater intelligence and precision. In practical applications, these results can support the lifecycle monitoring of various bridges, ensuring construction accuracy for new bridges and aiding in the upkeep and reinforcement of existing structures. In specialized bridge inspections or post-disaster emergency scenarios, the benefits of using reflective plates are evident, allowing for swift establishment of monitoring systems and safeguarding the integrity of transportation infrastructure.

Disclosure statement

The authors declare no conflict of interest.

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A Holistic Approach to Architecture
A Case Study: Music Center and Library, Tel-Aviv

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Abstract: The aim of this article is to present a unique interpretation of the holistic worldview, both in theory and in practice. It explores how this approach, along with a planning process fundamentally different from conventional methods, was implemented in the design and construction of the Music Center and Library in the city of Tel Aviv. This process forms a coherent representation of a complete worldview: a humanistic, holistic worldview developed and adopted through more than five decades of architectural practice across all scales of design. In this approach, a building is not regarded as a collection of isolated design elements, but as one hierarchical language, in which the building, its interior, and its ornamented details down to the handle of the door is one continuous system. Within this system, the building, its interior spaces, and even the smallest ornamental details, down to the door handles, are conceived as parts of a single, continuous whole. This worldview aligns with contemporary scientific discourse in fields such as cosmology, neurobiology, psychology, complexity theory, and Buddhist philosophy, disciplines with which this body of work is closely associated.

Keywords: Holistic; Phenomenology; Architecture; Organic; Music center and library

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1. Introduction: Architecture is made for people

The purpose of architecture, first and foremost, is to create a human environment for human beings. Nevertheless, modern society has lost sight of the central value, the human being, and created an environment in which there is a feeling of alienation between man and place.

Buildings influence both the quality of life and the fate of the physical environment over extended periods of time. Their true measure, therefore, lies in the test of time. The most cherished historic buildings, those that evoke a sense of being "at home" and invite repeated return, possess a timeless relevance. These are the ones that have the capacity to resonate emotionally, offering a profound and enduring architectural experience (**Figure 1**).

Figure 1. Villages that evoke a deep sense of belonging, The Island of Paros, Greece

Although this timeless quality exists in buildings in different places, rooted in different cultures and traditions (**Figure 2**), the experience they generate is similar and common to all people, no matter where or what culture they come from. Hence, Alexander's basic assumption was that behind this quality, which he calls "The quality without a name" lies a universal and eternal element common to us all as human beings [1].

Figure 2. Left to right: Tholos, 4th century, Delphi, Greece; Great Gander Pagoda, 7th–8th century, Hsi- an-Fu, China; Abuhab Synagogue, Safed, Israel.

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 Garbow *et al.*, "The buildings that have a spiritual value are a diagram of the inner universe, or the picture of the inner soul" [2].

The emotional interrelationship created between the users and the building at the Music Center and Library occurs at all levels of scale down to the light fixtures, the furniture, the railings, the golden color of the wall the tiles in the toilet and more (**Figure 3**). Details which were designed by me as inseparable organic part of the building.

Figure 3. Music Center and Library, designed as an inseparable organic part of the overall architectural composition.

Contemporary architecture and art in general sought to dissociate themselves from the world of emotions, by generating the design process to the world of ideas, consequently creating a conceptual relation between a man and their environment devoid of any emotion. The central argument presented here is that fostering a sense of belonging within the built environment requires more than a change in architectural style or trend. Rather, it demands a fundamental transformation of the prevailing mechanistic worldview, replacing it with a holistic perspective that reconnects individuals with their surroundings in a meaningful, emotionally grounded way.

2. Between two worldviews - the holistic approach vs the mechanistic approach

2.1. The relationship between the parts and the whole

The difference between the worldview which resulted in dissociating man from his environment and the worldview that considers man to be part of the physical world he lives in (as well as part of nature), emphasizes the difference between the holistic organic school of thought to which my own work belongs, and the mechanistic-fragmentary worldview. These are two different set of orders.

The mechanistic worldview, which has long dominated Western thought and underpins much of contemporary architecture, promotes a separation of elements, leading to environments composed of autonomous and mechanically ordered fragments. This fragmented approach is evident in urban developments such as Brasília in Brazil, Chandigarh in India, and the satellite towns of England. In these settings, the structured disconnection between the house and the street, the street and the neighborhood, and the neighborhood and the city contributes to a pervasive sense of detachment and alienation.

The house appears to be a random collection of objects; the street appears to be a random collection (catalogue) of buildings that do not create together a street, (often even prefabricated transported units made in a factory and superimposed on the site); the streets do not form together a neighborhood; and the neighborhoods do not create a city.

In contrast to these fragmented developments are buildings designed by those who recognized that architectural responsibility lies first and foremost in shaping the quality of the street, whose boundaries the buildings help define. These designers understood that urban design does not begin and end with arbitrary sketches drawn at a scale of 1:1000, but rather with a continual sensitivity to the scale of the human experience—the scale of 1:1. This sensitivity is expressed in the view of balcony railings from the street, the detail of an iron bar on a window, and the smell and sight of fruit trees in nearby gardens.

This school of thought bears a close resemblance to the approach embraced by the anonymous craftsmen who created Japanese folk art between the 13th and 19th centuries (**Figure 4**). Soetsu Yanagi, founder of the Museum of Folk Art in Tokyo, documented this unpretentious yet profound tradition in his book *The Unknown Craftsman*. He described these artifacts as the embodiment of a worldview in which the boundaries between art, philosophy, and the creator's spiritual or "God-given" state of mind are fluid and inseparable [3].

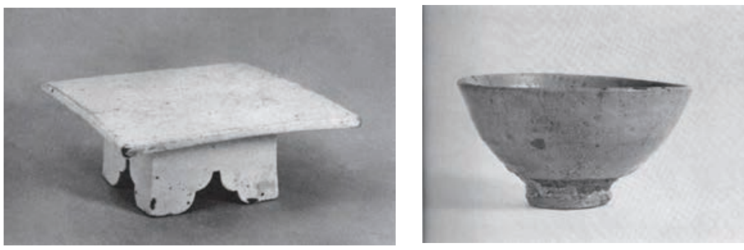

Figure 4. (from left) Ceremonial stand, porcelain, Yi dynasty (18th century), Korea; Kizaemon Ido tea bowl, Y dynasty (26th century), Korea

This approach was not understood by Le Corbusier, Oscar Nimier and others around the world, who were part of the mechanistic school of thought, who consciously considered architecture to be no more than icons-environmental sculpture, totally dependent on the arbitrary vision of its creators.

The holistic-organic approach that has been for many years at the forefront of scientific thought in general, implemented by Alexander in architecture, regards the socio-physical environment as a system, the existence of which depends on the proper, ever-changing interrelations between the parts [1, 4].

Moreover, the creation and existence of each part depend on the interrelations between that part and the whole. In any organic system, while each element has its own uniqueness and power, it always acts as part of a larger entity to which it belongs and which it complements (**Figure 5**).

Figure 5. Organic system

Within this conceptual framework, urban design, architecture, and interior design are not regarded as separate disciplines, but as components of a continuous and dynamic system. The building and its environment are not perceived as a collection of designed fragments, but as one hierarchical language, in which this historic square, the building, and its interior details is one continuous system [5].

Every design detail, at any level of scale, is derived from the larger whole to which it belongs, which it seeks to enhance and for whose existence it is responsible. The overall feeling of inner wholeness and unity, whether in a building, a street, a neighborhood, or a city, eventually evolves from the proper interrelations between its parts. This led to the focus being about the square at first, rather than the building itself, during the process of designing the Music Center and Library (**Figure 6**). All the decisions regarding the volume of the building, the construction materials, and the color were generated from the spirit of the square, meaning from the larger whole it had to be integrated with respect and enhancement.

Figure 6. Music Center and Library, Tel-Aviv. The square, the building and the interior are one continuous system.

3. The beauty is in the details

3.1. The detail is not an ornament for its own sake

The essence of a building's beauty lies in its spatial order and the nature of its details. These are not seen as a collection of isolated design elements, but as structural segments derived from a hierarchical language in which the square, the building, and the interior are perceived as a single, continuous system. Each specific detail originates from the larger whole to which it belongs, for which it holds responsibility, and which it is intended to enhance. As such, every detail, including the design of the furniture, lighting fixtures, and even the selection of flower colors in the garden, is treated as an integral part of the planning process, contributing to the creation of a distinct and unified architectural whole. In the case of the auditorium, for instance, it is the accumulation and coherence of these details that ultimately define the space.

The formal similarity among various details (**Figure 7**), such as the shape of the crown atop the building, the patterns of the cement tiles at the entrance porch, the reliefs on the surrounding fences, the form of the chairs in the auditorium, and the design of the light fixtures, serves as a series of visual echoes, all resonating from the same underlying design language.

Figure 7. (from top left) The shape of the auditorium chairs, the light fixture, the relief on the fence, the pattern of the cement tile, the ornament on the external steel panels, the crown on the building are all echoes of one voice.

In modern society, beauty has become a term of abuse, often associated with inefficiency, impracticality, lack of functionality, and high cost. That notion of beauty is true when it relates to details as decorative elements and ornamentation for its own sake.

The Shakers, a religious sect that created an abundance of useful furniture and utensils in the mid-eighteenth century, noted that the wholeness and beauty of form are products of pure functionalism, and that there is no room for beautiful forms that do not flow from a functional need.

At the same time, the Shakers did not interpret the concept of “pure functionalism” in the narrow sense adopted by modernist architects, for whom the expression "form follows function" was understood primarily in relation to the physical structure of a building. Instead, the Shakers embraced a broader interpretation that connected function to both the physical and spiritual experience of being within a space. This broader understanding was reflected in the design of the building. For example, while a solid wall might typically separate the entrance lobby from the auditorium, a transparent glass wall was used instead. This allows visitors, upon entering the building, to visually connect with the auditorium and enjoy a view extending to the orange trees in the rear garden (**Figure 8**).

Figure 8. The glass wall of the auditorium creates a visual continuity once entering the lobby.

The six silver painted iron columns that rise from all the floors of the building are structural. However, their precise location was determined by the way they would help to distinguish the public territory from the other areas at each floor (**Figure 9**). In other words, the structural layout of the building followed the social activities on the floors. The gold leaves capital of the iron column (**Figure 10**), the part which connects it to the beam, is functionally different from the other parts of the column and was therefore given a different form and color.

Figure 9. The location of the iron columns is defining a social area.

Figure 10. The gold leaves capital of the iron column.

The iron balustrades of the stairs and the auditorium are painted gold, providing a melody of its own. When the sunrays hit these decorated iron balustrades, they create beautiful silhouettes on the various surfaces (**Figure 11**). The interior walls are painted in golden texturing. The soft reflection of the light when it touches the walls creates an inner glow that envelops all parts of the building.

Figure 11. Sunlight hitting the decorated iron balustrades, creating beautiful silhouettes on the surface

4. The generative language of the building-A pattern language

Alexander's basic assumption was that beauty and harmony are objective properties related to the geometrical properties inherent in the structure itself and that feelings are an objective fact [4]. Accordingly, in his book *The Timeless Way of Building,* he states that all places of organic order that may seem unplanned and disorderly are a clear expression of order on a deep and complex level [1]. This order is based on absolute rules that have always determined the quality and beauty of a place and are the source of the good feeling in it. In other words, there is a direct connection between the pattern of events that occur in a place and the physical patterns, patterns of space in his terminology, that constitute it.

This assumption led Alexander and his team to empirical research, conducted at The Center for Environmental Structure in Berkeley, California, with the aim of exploring two primary questions:

(1) What is the nature of the spatial order present in places that make us feel good?

(2) What is the planning process to create an environment that possesses that same organic order?

Organic order can be achieved when all those participating in the planning process share a common language. In the past this language evolved out of tradition, when everyone knew exactly what should be done. Nowadays, a time of confused pathways, there is a need to revive a language that will restore order and wholeness in the environment. This phenomenon gave him rise to the hypothesis, that beyond what appears different, there is something else, much more basic and common to them all.

Empirical research conducted in the mid 1960 for over a decade by Alexander *et al.* at The Center for Environmental Structure in Berkeley California, aimed to analyze all those places that share a common pattern of events and feel similar, to identify the common element [4].

Their basic assumption was that just as every substance has a basic component called an atom, the man-made environment consists of "atoms" which he called patterns. Each pattern is an archetype of a structure that repeats itself in an infinite variety, and although its form varies from place to place, there is an underlying structure, the archetype, which remains the same (**Figure 12**).

Figure 12. (from the left), Arcade, Sehzade mosque, Istanbul, Turkey; Arcade, cloister, Capri island, Italy; Arcade, Shitennoji Temple, Osaka

The importance of these patterns, 250 in number as listed the book, *A Pattern Language*, lies in the fact that they constitute a system which generates an entire language [5]. It includes patterns from the city scale level to that of individual buildings and construction details. Each pattern in the language consists of other smaller patterns and is at the same time part of a larger pattern. In other words, each pattern is a pattern of relationships. The language is a generative one and the hierarchical order of the patterns it consists of is determined by the rules of the language itself.

What ultimately gives meaning to a house, a street, or a city is comparable to what gives meaning to a sentence in spoken language: its syntax. Architecture can be understood as a generative language, in which the hierarchical order of patterns is determined by the rules inherent to that language. Once the relevant set of patterns is identified for a particular project, a system of interrelationships naturally emerges, defining the connections among the various components of the building. As in any organic system, the underlying "genetic codes" not only govern the function of each individual element, akin to the behavior of cells, but also ensure their integration within the larger whole, in this case, the building as a complete organism.

5. The planning process

The planning process proposed here is fundamentally different from the common planning processes. Unlike the common ones, where planning first takes place in the office and is later transferred to the site, here the drawings were merely the recordings of the planning decisions taken on the site itself while being aware of the visible and hidden forces acting on the site itself [6, 7].

In his book *The Joy of Living and Dying in Peace* H.H. the Dalai lama writes: "Things have a natural and innate mode of existence…. Reality is not something that the mind has fabricated anew. Therefore, when we search for the meaning of truth, we are searching for reality, for the way things actually exist…." [8].

Once the list of patterns for the project was established, all planning decisions regarding the building complex were made directly on-site. Unlike the common planning process where the shape of the building is predetermined in the office with no relation to the site, and later superimposed on any site, here a dynamic process took place by which the plan of the building that was finally created was a structure of balance between the abstract pattern language chosen for this project and the living reality of the site itself.

6. A dialogue between a new building and the existing historical square

Bialik square is a micro-document of the architectural history of Tel-Aviv from 1920 to 1930. It was in the 1920's when European architecture was brought to Israel, carried out by Jewish refugee architects who immigrated to Israel from Europe, trying to become integrated with the local oriental architecture, thus named the "Eclectic period". It stemmed from a balance between their affinity to the land of Israel and their knowledge and love of it, and the use of cross-cultural and cross-national patterns brought by them from their European countries of origin. They consciously attempted to create a new "Israeli" architecture by integrating East and West. They understood that it was precisely that connection with the local reality in which they lived and created that could bring out the universal. A reality that was broad and complex and embodied landscapes, architecture, and local lifestyle.

The nature of their work until the mid-1930's, as opposed to the Bauhaus that was imported to Israel as a package deal, stemmed from a balance between their affinity to the land of Israel and their knowledge and love of it, and the use of cross-cultural and cross-national patterns brought by them from their European countries of origin. They consciously attempted to create a new "Israeli architecture". The patterns of space and the beautiful construction details that were used can't be considered as a matter of style. The architects of that time who used them understood in a most profound way what are the fundamentals of harmony in architecture. These were the timeless cross-cultural patterns which underlines the beauty and comfort in any building that transcends styles.

Evidently, a pattern such as an entrance hall, an arch, or a capital in the column can be found in buildings of all periods and cultures. These patterns were, on purpose, ignored by the modernists (in general), which resulted in the creation of an environment devoid of any emotions and meaning. The design aimed to create a building that would integrate organically with the square, based on the principle that the powerful presence of a building within a place arises from its integration into the context, rather than from efforts to distinguish it from its surroundings. Preserving the spirit of a historical environment is not an act of nostalgia, nor does it require a rigid repetition of its architectural language. The essential question in approaching the design was to determine the appropriate language that could foster a meaningful dialogue between the new contemporary building and the historic square, one that would preserve and enhance the square's human character. Rather than adopting conventional approaches, the design neither sought to reconstruct the past nor to disassociate from it by imposing an entirely new architectural order.

The façade of this building defines the boundaries of the square, and therefore determines the feeling it inspires. Thus, the dimensions of the building were generated out of the wish to be in harmony with the human scale of the square. The orange paint of the building's façade, which at first was expected to violate the tranquility of the square, was the element that complemented the blue color of the sky and the green color of the trees. The cornices that jut out of the façade belong morphologically both to the building and to the space next to it, and hence are the elements that unite them together (**Figure 13**). The entrance porch connects the building to the square in a gradual way. The dialogue between the building and the square continues through the high windows overlooking the square (**Figure 14**). The crown on top of the building provides a gradual link to the sky. A good boundary is an entity that both separates and connects two entities at the same time. The role of the crown is to provide a graduated link between the top of the building to the sky.

Figure 13. The orange building's façade with the cornices jutting out.

Figure 14. The high windows of the building overlooking the square.

7. Conclusion

The hope is that a holistic worldview will ultimately prevail, guiding the creation of buildings, streets, neighborhoods, cities, and villages that foster a genuine sense of belonging, places where individuals feel truly at home, and where artifacts are attuned to the human body. This vision applies across cultures, places, and times. It calls for the replacement of prevailing conceptions and approaches that pose a real threat to both the physical and human environments.

Disclosure statement

The author declares no conflict of interest.

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Study on the Improvement of Recreation Experience Quality of Urban Parks in Chongqing's Main Urban

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Abstract: In recent years, with the acceleration of urbanization and the introduction of the concept of a park city, the construction of city parks has received increasing attention. This paper selects three representative city parks in the main urban area of Chongqing as the research objects, sorts out relevant policy plans and cutting-edge theories, and understands and analyzes the current construction situation and development environment of city parks in the main urban area of Chongqing. Based on visitor opinions and feedback, the main influencing factors of recreation experience are summarized, and corresponding strategies are proposed based on the actual situation, hoping to provide a reference for the construction of city parks in Chongqing.

Keywords: City park; Recreation experience; Chongqing

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1. Research background

In recent years, Chongqing has vigorously developed city parks and issued a series of policy documents such as the "Chongqing Work Plan for Creating a National Ecological Garden City" and the "Guiding Opinions of Chongqing City Administration on Strengthening the Planning and Design of All-Age-Friendly City Parks." These policies emphasize the implementation of city renewal actions as the starting point, integrating the concepts of children's priority and care for the elderly into the planning and design of city parks, comprehensively strengthening the planning and construction of all-age-friendly city parks, continuously meeting the growing needs of the people for a better life, and serving high-quality development. City parks play an important role in citizens' lives, and improving the quality of recreational experiences in city parks is not only related to citizens' happiness but also a key to promoting green city development and achieving high-quality city life.

2. Overview of recreational experience in city parks

Research on recreational experiences in city parks at home and abroad mainly focuses on two aspects: influencing factors of recreational experiences and evaluation methods of recreational experiences.

2.1. Research on influencing factors of recreational experience in city parks

The factors that affect the recreational experience in city parks are diverse and complex. Some are prerequisite factors, such as accessibility; some are psychological factors, such as psychological emotions, cultural identity, and other demand expectations; and some are external factors, such as park landscapes and facility conditions. Therefore, when analyzing and evaluating recreation satisfaction, it is necessary to consider the actual situation of the research object comprehensively.

McCormack *et al.* found through research on the relationship between park utilization and physical activity that factors such as safety, aesthetics, park facilities, and landscape maintenance are important for park satisfaction [1]. Milman believes that the seven main factors affecting the satisfaction of theme park visitors are: diversity and quality of entertainment projects, cleanliness and safety, diversity and price reasonableness of food, quality of theme design, diversity and practicality of family activities, diversity and quality of entertainment facilities, and consumption price and reasonableness [2]. Bedimo-Rung *et al.* pointed out that park structure, facility conditions, accessibility, aesthetics, safety, and policies are relevant factors that affect park usage [3]. Domestic scholars such as Yin and Li pointed out that the accessibility of city parks is an important prerequisite for measuring and affecting recreation satisfaction [4, 5]. Another author, Li, took Nanjing Xuanwu Lake City Free Park as an example and summarized the factors that affect park leisure satisfaction into six aspects: leisure facilities, leisure services, leisure environment, leisure landscapes, accessibility, and leisure projects [6]. Based on Wuxi City Gardens, Wang *et al.* proposed that pricing, employee service, facility environment, crowding, convenience, safety, and time arrangement are important factors that affect visitor experience [7]. Xiao *et al.* took Guangzhou City Park as the research object and extracted six influencing factors of recreationists' satisfaction evaluation of city parks through factor analysis: landscape quality, infrastructure, recreation environment, recreation projects, service quality, and convenience. They also believed that there are significant differences in the satisfaction evaluation of city park recreationists [8].

2.2. Research on evaluation methods of recreational experience in city parks

Foreign scholars' measurement studies on recreational experiences in city parks are usually based on the Recreation Experience Preference Scale developed by Driver and others, namely REP (Recreation Experience Preference Scale). According to the characteristics of recreationists' physical and mental experiences, it is divided into 19 categories [9]. Ryan's "expectation-satisfaction" model better reflects the essential connotation and structural characteristics of the recreational experience and clearly reflects the process of how recreationists' motivations and expectations are realized in the recreation environment and form the recreational experience [10]. Domestic scholars tend to construct a recreational experience satisfaction evaluation model, collect data through questionnaire surveys and in-depth interviews, and conduct empirical research using quantitative methods such as factor analysis, fuzzy comprehensive evaluation, and IPA analysis.

Li *et al.* took Xi'an Fanchuan Park as an example. Based on field dynamics theory and field research, they constructed a satisfaction evaluation model for recreational experiences in city parks. They used fuzzy comprehensive evaluation to determine the indicator scores and finally obtained the satisfaction level order as:

natural environment stimulation, self-improvement, basic needs, cultural landscape stimulation, and deficiency compensation [11]. Yu *et al.* selected four forest parks in Harbin as the research area. Through a sample survey of forest park recreationists, they explored the differences between the pre-trip expectations of forest recreationists and the satisfaction of their actual recreational experiences. They used survey sample structure analysis, reliability and validity analysis, paired sample t-test, Pearson correlation analysis, and other methods to analyze the questionnaire data. They also used the IPA method to construct a matrix analysis table of pre-trip expectations and actual recreational experience satisfaction to explore the level of recreationists' recreational experience satisfaction and provide strategic suggestions for improving the business performance of forest recreation management units [12].

3. Development environment analysis

3.1. Macro environment analysis

This paper employs PEST analysis to examine the macro environment for the development of city parks in the main urban area of Chongqing, focusing on four aspects: politics, economy, social culture, and technology. The specific details are presented in **Table 1**.

Table 1. PEST analysis of the macro environment for the development of city parks in the main urban area of Chongqing

Political environment	Regulations on Urban Gardening and Greening in Chongqing City (revised in 2021)
	Regulations on the Management of Parks in Chongqing City (revised in 2022)
	Notice from the Chongqing Urban Management Bureau on Improving the Planning and Management of City Parks
	Implementation Plan for the Pilot Project of Open Sharing of Green Spaces in Chongqing City Parks
	Guiding Opinions of the Chongqing Urban Management Bureau on Strengthening the Planning and Design of All-Age-Friendly City Parks
Economic environment	As a direct-administered municipality and a popular tourist destination, Chongqing's economic development directly affects the living standards and leisure needs of its citizens. With the rapid economic growth in Chongqing in recent years, rising income levels, and consumption upgrades, there has been an increased demand for park quality, diversified services, and activities from the public.
Sociocultural environment	Chongqing is rich in cultural resources, with a variety of cultural backgrounds such as Bashu culture and Hongyan culture. There are numerous social and cultural activities like science popularization meetings and reading clubs, continuously stimulating cultural vitality.
Technological environment	The application of new technologies such as the Internet of Things, big data, and artificial intelligence can enhance the intelligent management level and service quality of parks, including features like smart navigation, intelligent lighting systems, and environmental monitoring.
	The maturity of social media and mobile internet technologies also provides technical support for park promotion, enhancing park popularity and visitor experience.

The Chongqing government places great emphasis on the construction of city parks, and relevant policies have been introduced in recent years to provide strong support. Rapid economic development offers robust backing for park construction, and the growth of the tourism industry also brings new opportunities for parks. The local society has a profound cultural heritage and rich cultural resources. Technology in related fields is becoming more mature, and the introduction of intelligent and information technology provides technical support for the interactive experience between parks and residents.

3.2. Micro-environment analysis

The development of city parks in the main urban area of Chongqing faces a relatively complex micro-environment, analyzed as follows:

3.2.1. Natural conditions

(1) Climatic factors

Chongqing has a wet and rainy climate, providing sufficient water and nutrients for plant growth. This is conducive to the construction of city park landscapes and creates a pleasant leisure environment for residents.

(2) Natural resources

Chongqing is known for its rich animal and plant resources. Additionally, thanks to its unique geographical location at the intersection of the Yangtze River and Jialing River, it boasts a natural water network. These superior natural resources offer more choices and possibilities for the park's content and landscapes.

(3) Topographical factors

Chongqing has a complex topography with many mountains, which limits the construction scale and layout of parks to some extent. However, it is precisely these topographical characteristics that make the city parks in the main urban area of Chongqing more distinctive. By rationally utilizing the topography, rich and diverse spatial layers and landscape effects can be created.

3.2.2. Demands

(1) Leisure demands of residents

With the improvement of living standards, residents' demand for leisure activities is growing. Therefore, as an important place for residents' leisure activities, the construction and development of city parks need to meet the diverse needs of residents, including providing comfortable rest spaces, rich entertainment facilities, and beautiful natural environments, to satisfy residents' preferences in leisure activities.

(2) High-quality development demands

The construction of city parks directly promotes the improvement of the city's ecological environment and achieves green urban development. As an important public space in the city, parks can attract a large number of people, drive the prosperous development of surrounding commerce, culture, tourism, and other industries, enrich citizens' spiritual and cultural life, and facilitate high-quality development.

The development of city parks in the main urban area of Chongqing presents both opportunities and challenges. How to fully utilize the advantages of natural conditions, overcome the limitations of factors such as topography, and meet the diverse needs of residents are issues that need to be deeply considered and resolved in the construction of city parks in Chongqing.

3.3. Analysis of factors influencing recreational experience

In this study, three popular parks in the main urban area of Chongqing—Zhaomu Mountain Forest Park, Chongqing Central Park, and Eling Park—were selected as survey samples. Through field visits and surveys, the recreational experiences of visitors were analyzed, and key influencing factors were summarized. The research found that there are multiple factors that affect the recreational experience in city parks, with the main ones being as follows:

(1) Green space area and activity scope

The area of green space and the scope of visitor activities are fundamental and decisive factors that influence the quality of the recreational experience in city parks. Adequate green spaces not only effectively improve park air quality, accelerate human metabolism, reduce fatigue, and meet the physiological needs of visitors, but also allow people to connect with nature, relieve stress, and enhance the recreational experience psychologically. Compared to other hard landscape areas, green spaces provide a softer and more inclusive spatial experience. Open green spaces offer a sense of psychological security, thereby optimizing the recreational experience.

(2) Transportation accessibility

As the link between residents and parks, transportation accessibility determines visitors' travel costs and comfort, affecting the actual utilization efficiency and visitor satisfaction of city parks. It encompasses not only the convenience of physical movement but also various aspects such as travel time, cost, congestion level, and the availability of transportation modes. Good transportation accessibility encourages visitors to choose city parks for their outings, providing a positive initial experience for their park visits. Additionally, convenient transportation increases effective recreational time, raises visitors' psychological expectations, and optimizes their recreational experience.

(3) Diversity of park functional facilities

With the improvement of living standards, people's demands for city parks have become increasingly diversified, and the completeness and diversity of functional facilities within the parks have gained more attention. Different visitor groups have varying needs for recreational facilities due to factors such as age, gender, interests, and physical condition. Meanwhile, modern life scenarios are rich and diverse, and people's recreational desires in parks cover various aspects such as fitness and exercise, parent-child interaction, social gatherings, cultural learning, and relaxation. Whether park facilities can provide corresponding support to meet these different needs and enable visitors to have a satisfactory recreational experience in different scenarios has become a topic of great concern.

4. Environmental quality

As key nodes of the city's ecosystem and important places for citizens' recreation, city parks' environmental quality directly impacts visitors' recreational experiences through sensory stimuli such as vision, hearing, smell, and touch. Specifically, the overall environment of city parks can be divided into three aspects: ecological environment, landscape environment, and sanitary environment. High-quality environmental conditions are core elements for city parks to attract visitors, enhance satisfaction and willingness to revisit, and achieve sustainable development.

5. Suggestions

(1) Optimizing the spatial layout of green spaces and strengthening their ecological functions

To make green spaces more useful and eco-friendly, parks should increase their size where possible and use the space more efficiently. In mountain parks with uneven terrain, more signposts can help visitors find their way, and tools like GIS (Geographic Information System) can be used to create accurate maps. By studying how visitors move through the park, paths and routes can be better planned to spread people out and help them enjoy more of the park.

During busy times, temporary barriers and flexible space management can help control crowding. This keeps the amount of green space per visitor more stable and makes the park more comfortable. Parks can also make the most of limited space by using vertical areas like rooftops and walls for planting. Working with universities or research centers can bring in new ideas for improving plant variety, colors, and layout. These changes can make the park look better, clean the air, reduce noise, and give visitors a more pleasant natural experience.

(2) Improving transportation accessibility

Park managers should actively communicate with tourism and transportation departments. Regarding traffic congestion and parking difficulties around some parks, they should collaborate with transportation departments to plan and optimize bus routes, increase the frequency of bus services during peak hours, and strengthen seamless transfer connections with rail transit stations. At the same time, surrounding idle land or underground spaces should be utilized to build new multi-level smart parking lots, introducing smart parking management systems to improve parking space turnover rates and alleviate parking pressure. Additionally, intelligent traffic monitoring equipment should also be installed at key nodes to monitor pedestrian and vehicle flows in real-time, provide early warnings of congestion, and scientifically guide traffic. Furthermore, collaboration with platforms such as shared bicycles and online car-hailing services can be used to optimize "last-mile" travel solutions, encouraging visitors to travel green and enter the park conveniently.

(3) Enriching park functional facilities

To better meet the different needs of visitors, parks should offer a wider range of functional facilities, such as fitness equipment, children's play areas, and comfortable seating. Creating spaces for cultural activities and social gatherings can also enrich the visitor experience. For example, parks can set up natural education areas for families, where activities like plant identification and insect observation are offered. Along hiking trails, smart fitness stations with solar-powered charging and health monitoring features can be added for fitness lovers. At the same time, parks should make full use of local cultural heritage, such as Bayu history, by expanding exhibition halls and using interactive multimedia to tell historical stories. Traditional craft workshops, like paper cutting and sugar painting, can also be included to let visitors participate and enjoy a deeper cultural experience.

(4) Strengthening environmental quality management

To better protect the park's natural environment, special ecological zones should be set up to limit damage from human activity and improve overall ecological health. The park's landscape design can also be improved by adding more variety and layers to make it more beautiful and interesting. A regular cleaning system should be in place, especially during busy times like holidays, to keep key areas such as dining spots and crowded paths clean and tidy. Water in the park should be checked regularly, and methods like plant-based cleaning and physical filters can help keep it clean. It's also important to educate visitors about respectful behavior in the park. Encouraging quiet walking, polite sightseeing, and reducing noise can help keep the park peaceful and enjoyable for everyone.

6. Conclusion

This study focuses on city parks in the main urban area of Chongqing, conducting an in-depth analysis of issues related to their recreation experience quality. In the context of strong policy promotion and increasing social demand, the construction of city parks has become increasingly critical. They not only carry the leisure needs of citizens but also play a vital role in the green development of the city. Through analyzing visitor feedback, it is found that the key factors influencing the recreation experience in city parks include green space area and activity scope, transportation accessibility, diversity of park functional facilities, and environmental quality. These factors affect visitors' physiological and psychological feelings from different dimensions, thereby determining the quality of the recreation experience. Based on the above analysis, strategies with strong pertinence and operability, such as optimizing the spatial layout of green spaces, improving transportation accessibility, enriching park functional facilities, and strengthening environmental quality management, can effectively enhance the quality of recreation experiences and meet the growing leisure demands of citizens. In the future, with urban development and the continuous increase in residents' needs, further research is still needed to improve the recreation experience in city parks. On the one hand, attention should be continuously paid to the application of new technologies in park construction and management, exploring how to better utilize technologies such as the Internet of Things and artificial intelligence to optimize the recreation experience. On the other hand, in-depth research can be conducted on the differentiated needs of different cultural backgrounds and social groups for recreation experiences, providing more precise theoretical guidance and practical suggestions for the refined and personalized development of city parks, promoting deep integration between city parks and urban life, and achieving sustainable urban development.

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Integrating Academic Research Methodologies like Participatory Action Research (PAR) into Design Thinking: A Framework for Group Housing Design

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Abstract: The integration of academic research methodologies into design thinking processes presents a transformative approach to addressing complex challenges in group housing, fostering inclusive, sustainable, and user-centered solutions. This research explores how methodologies such as Participatory Action Research, post-occupancy evaluations, and Research through Design can be systematically embedded within design thinking to bridge the gap between academic rigor and empathy-driven, iterative design practices. By synthesizing these paradigms, the study proposes a framework for group housing design that prioritizes co-design processes, empathy-based data collection, and participatory evaluation, while emphasizing adaptability through sociocultural insights and user feedback. Case studies analysis demonstrate the effectiveness of flexible, community-driven design, while emerging technologies like IoT-enabled cohousing signal new opportunities for innovation. Challenges, including scalability, long-term validation, and reconciling user autonomy with professional expertise, are critically analyzed. Ultimately, this research advances a hybrid methodology to redefine the conceptualization, implementation, and assessment of group housing, offering actionable pathways to achieve affordable, inclusive, and context-sensitive housing solutions.

Keywords: Design thinking, Academic research methodologies, Group housing, Participatory Action Research (PAR), Co-Design, Sustainable housing, User-centered design

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1. Introduction

1.1. Background and context

Group housing, made up of co-living buildings, dormitories, cohousing communities, and transitional shelters, is confronting growing affordability, sustainability, and social inclusion challenges. Traditional architectural and urban planning paradigms usually focus on technical efficiency and low costs at the expense of living experiences, resulting in housing solutions that do not respond to the socio-cultural, economic, and behavioral dynamics of shared living contexts [1]. Tovivic redefines architects as facilitators of community-driven processes, challenging traditional top-down housing paradigms. Participatory Action Research (PAR) has proven transformative in low-income settlements, as demonstrated by Nix *et al.* in Delhi, where residents co-designed sanitation systems through iterative workshops [2].

In response, design thinking has been a human-centered, iterative process that facilitates participatory decision-making, quick prototyping, and adaptable housing solutions [3]. Design thinking by itself, though, is not usually empirically backed and long-term tested, which makes it challenging to quantify the impact on housing performance over time [4]. On the other hand, scholarly research approaches like Participatory Action Research (PAR), Post-Occupancy Evaluation (POE), and Research through Design (RtD) offer systematic, evidence-based models that facilitate increased stakeholder participation, data-driven evaluation, and long-term flexibility [5, 6].

The fusion of academic scholarship with design thinking's flexibility presents a revolutionary potential to build participatory housing systems that are empirically sound and user-oriented. This research examines how the academic research approach can be methodically integrated into design thinking to formulate inclusive, sustainable, and flexible group housing interventions.

1.2. Research problem and significance

Despite the success of participatory methodologies in improving housing outcomes, scalability and systematic integration into design practice remain limited [7]. Current housing models often fail to meaningfully engage residents in the design process, leading to growing emphasis on participatory and evidence-based housing strategies, current interventions fail to harmonize two important aspects:

(1) Academic Rigor vs. Design flexibility: PAR and POE offer systematic validation frameworks but tend to be restricted to theoretical or small-scale contexts, preventing their practical scalability [8]. Design thinking is superior in user-led, iterative housing design (e.g., co-designed homeless shelters, but does not have standardized metrics for long-term assessment [7, 9].

(2) Scalability and Long-Term Adaptability: Although projects such as PREVI Lima (Peru) and Quinta Monroy (Chile) illustrate the success of flexible, community-based housing, their lessons are not fully realized because of methodological integration gaps [10, 11]. The absence of a hybrid model that integrates academic evidence with iterative design practices limits wider application in housing policy.

Christopoulos advocates for socially driven architecture that prioritizes marginalized voices, aligning with this study's goals. By filling in these gaps, this research advances a systematic methodology that combines empirical testing with co-design participatory, such that group housing interventions are flexible, scalable, and context-relevant.

1.3. Research objectives

This study aims to bridge the gap between academic methodologies and design thinking by developing a hybrid framework that strengthens participatory, evidence-based group housing solutions. The key objectives include:

(1) To explore how methodologies such as Participatory Action Research (PAR), Post-Occupancy Evaluation (POE), and Research through Design (RtD) can be integrated into design thinking for group housing [8].

(2) To assess the effectiveness of participatory and iterative housing design approaches in fostering adaptable, user-driven environments [12].

(3) To evaluate case studies that illustrate successful integration of research methodologies and design thinking in housing projects [13].

(4) To develop a scalable framework that enables the systematic incorporation of academic research principles into real-world housing design practices [14].

1.4. Methodology and approach

The research employs a mixed-methods research approach blending:

(1) Literature review: Analyzing current research methodologies, design thinking frameworks, and housing case studies [15].

(2) Case study analysis: Case study analysis of participatory housing projects like PREVI Lima, Quinta Monroy (Chile), Vauban (Germany), and Nightingale Housing (Australia) to identify best practices [10, 11].

(3) Framework development: Drawing together findings into a coherent framework combining academic concepts with iterative design thinking [16].

(4) Evaluation of challenges and opportunities: Determination of major challenges like scalability, validation, and power relationships between users and professionals [17].

1.5. Expected contribution

This study adds to the emerging body of evidence-based participatory housing by illustrating how research methods in academia can be integrated into iterative design thinking processes. Through the integration of academic rigor and participatory design approaches, this research opens up a path to affordable, inclusive, and flexible group housing solutions that balance both human requirements and empirical evidence.

2. Literature review

The integration of academic research methodologies with design thinking in group housing is rooted in decades of interdisciplinary inquiry. Traditional housing models have often prioritized technical efficiency and regulatory compliance over human-centered and participatory approaches, leading to rigid and standardized housing solutions that fail to address the social, cultural, and behavioral needs of residents [1]. To address this, researchers and practitioners have attempted to integrate participatory, evaluative, and experimental research methods into the housing design process, making sure that group housing solutions are adaptable, inclusive, and sustainable [3]. Academic research methods, including Participatory Action Research (PAR), Post-Occupancy Evaluation (POE), and Research through Design (RtD), provide systematic, evidence-based structures that complement the iterative, user-focused nature of design thinking [5, 6]. Still, despite the fact that these two paradigms have tremendous opportunities for cross-support, their joining is underutilized in existing literature, where major gaps regarding scalability, validity, and policymaking application still exist [7].

2.1. Methodologies of academic research in housing

2.1.1. Participatory Action Research (PAR) in group housing

Participatory Action Research (PAR) has also been extensively utilized in group housing schemes to build capacity in the community, popularize decision-making, and face systemic injustices [8]. Grounded in participatory, iterative knowledge production, PAR engages residents, designers, and policymakers in the research and development process in an active and systematic way, such that solutions for housing are not imposed upon but co-designed [5]. In low-income housing colonies in Delhi, for instance, PAR-informed co-design workshops allowed residents to create community-based sanitation systems and adaptive housing layouts that were consistent with their daily patterns and spatial requirements [14]. In the same way, in transitional housing initiatives, PAR approaches have assisted marginalized groups in owning their habitats, encouraging feelings of belonging and communal agency [12].

PAR is still limited by power inequality in participatory activities, even with its advantages. Architects, city planners, and policymakers can still exert disproportionate control, undermining residents' power and influence on major design choices [6]. Also, sustaining long-term resident involvement continues to be an issue, as participatory interest wanes as time passes, especially in those projects that are not supported institutionally or by policy [9]. Solutions to these problems include systematic integration of PAR into official housing policies, meaning that participatory processes must be effective beyond design stages [5].

2.1.2. Post-Occupancy Evaluation (POE) for housing performance

Post-Occupancy Evaluation (POE) is a systematic approach to analyzing the performance of housing after its occupation by residents, yielding rich information on spatial adaptability, user satisfaction, and environmental efficiency [18]. POE research has been instrumental in confirming the efficacy of participatory housing prototypes in ensuring that early design interventions are converted into long-term usability [7]. For instance, a Ghanaian mixed-methods POE explored how residents adjusted their housing arrangements, ventilation, and communal areas, resulting in improvements in follow-up design phases [18]. Likewise, social housing assessments in Europe have proved the significance of thermal comfort, spatial adaptability, and social cohesion in the provision of quality housing over the long term [11].

Although POE offers a strong evidence-based framework for housing improvement, its use in participatory design is limited. Most housing schemes focus on early user involvement but do not include longitudinal assessments, limiting the scope for data-driven adjustments [22]. In addition, funding and logistical issues frequently hinder the implementation of POE at scale, restricting its capacity to influence wider policy and regulatory environments [16].

2.1.3. Research through Design (RtD) for experimental models of housing

Research through Design (RtD) closes the gap between academic research and experimental design, enabling architects and urban planners to prototype and experiment with novel housing ideas in reality [16]. Through iterative prototyping, speculative design, and digital simulation, RtD enables the development of novel spatial arrangements and intelligent housing technologies [13]. In cohousing developments, for instance, IoT-driven prototypes have optimized collective decision-making and resource-sharing systems, keeping housing models responsive to resident behavioral changes [16]. Likewise, New Zealand's modular housing prototypes have experimented with incremental spatial adjustments so that residents can modify their living spaces over time according to individual needs and social interactions [9].

In spite of its potential, RtD encounters a number of practical issues. A majority of RtD experiments exist only in the conceptual phase, with few avenues for practical application in the real world [14]. Secondly, the speculative nature of RtD complicates its incorporation into policy-based housing projects that frequently need standardized guidelines and empirically tested methodologies [6]. For improved application of RtD, subsequent research needs to focus on narrowing the gap between experimental housing ideas and large-scale urban planning strategies [17].

2.2. Group housing design thinking

2.2.1. Empathy-based co-design

Design thinking emphasizes ethnographic studies, empathy development, and participatory workshops to guarantee that housing solutions are informed by the lived experiences of residents [3]. For example, co-design programs in transitional shelters for homeless individuals have shown how participatory interviews can redesign shelter operations to enhance accessibility and community integration [7]. Webber highlights the role of co-living prototypes in addressing transient housing needs, bridging design thinking with academic rigor. In the same way, student dormitory redesigns following co-design principles have been able to redevelop isolated living spaces into active community centers [12].

2.2.2. Iterative prototyping and flexibility

The iterative process of design thinking makes it possible to constantly improve housing models through prototyping and user feedback cycles [4]. This has been clearly seen in self-build housing developments, where residents have been able to incrementally change their homes through the use of scalable, modular structures [11].

2.2.3. Sustainability and systems thinking

Design thinking also embraces systems-based methodologies for tackling environmental sustainability in group housing [6]. Mota demonstrates how open-building principles enable resident-led adaptations, fostering long-term sustainability. The PREVI Lima project, for instance, employed adaptive, climate-responsive housing forms that changed over time through resident improvisations, making sure that participatory design and sustainability were incorporated [10].

2.3. Towards a hybrid framework

Though academic research methods and design thinking each have distinct strengths, their synthesis is underexplored within housing scholarship. Previous research indicates that a hybrid model incorporating participatory action, post-occupancy testing, and iterative prototyping has the potential to close the gap between empirical sophistication and creative flexibility [5]. Future research needs to prioritize the integration of participatory research within housing policy, utilizing digital technology for stakeholder participation, and creating scalable, cross-disciplinary methods to make group housing remain responsive, inclusive, and sustainable [7].

3. Case study analysis

Here, an elaborate analysis of 20 international case studies is undertaken that combine research approaches like Participatory Action Research (PAR), Post-Occupancy Evaluation (POE), and Research through Design (RtD) with design thinking in group housing schemes. Based on the frequent themes, innovation in methodology, and open questions, the analysis indicates how the case studies refine the suggested hybrid framework. A systematic summary table (**Table 1**) classifies these case studies in terms of academic approach, context, and important outcomes, then synthesizes the findings to develop connections between cases.

Table 1. A systematic summary table of case studies

Author citation	Academic methodology	Design thinking component	Context/ setting	Objective	Key methods used	Participation framework	Validation methods
[2]	Participatory Action Research (PAR)	Co-creation	Low-income settlements, Delhi, India	Integrate transdisciplinary methods for sustainable housing	Ethnographic studies, stakeholder workshops	Community-driven co-creation with residents, architects, policymakers	Reflections, recommendations
[8]	Participatory Action Research (PAR)	Collaborative design and making	Socially isolated, Newcastle, UK	Empower marginalized groups via housing production	Joint stakeholder design/build workshops	Ethics-focused participation with power redistribution	Participant reflections, feedback
[9]	System dynamics, Pattern language	Adjusted iterative design	Social housing estate, Hungary	Empower low-income communities via sustainable behaviors	Pattern language framework, focus groups	Residents codevelop design parameters	Participant feedback
[19]	Research through Design (RtD)	Prototyping, iterative stages	Transitional co-living, New Zealand	Develop spatial strategies for shared living	Iterative research studio model	Residents indirectly influenced design iterations	Design critique, iteration
[20]	Co-design, Human-centered design	Ideation, prototyping	Student dormitory, Milan, Italy	Create community-centric dormitory hubs	Workshop-driven prototyping	Dorm resident input during empathy, design, iteration	Community feedback loop
[7]	Participatory Action Research (PAR)	Feedback, ideation, improvement	Homeless housing, US	Empower unhoused individuals to evaluate/improve housing	Empathy interviews, participatory design	Homeless residents redesigned housing operations	Feedback analysis, design iteration
[5]	Participatory Action Research (PAR)	Co-creation phases (informal)	Affordable housing, Melbourne	Enhance affordability and sustainability via collaboration	Community-oriented workshops	Stakeholders from policy, community, developers	Reflective evaluative loop
[16]	Research through Design (RtD)	Speculative prototyping	IoT Cohousing, Netherlands	Develop speculative technologies for communal living	IoT prototypes tested in cohousing sites	Stakeholders evaluated speculative prototypes	Prototype usage, feedback
[10]	Case study	Integrating adaptability	PREVI project, Lima, Peru	Explore adaptive housing strategies for sustainable community living	Case study analysis	Retrospective evaluation of stakeholder influence	Retrospective case evaluation
[18]	Mixed Methods (Surveys, Observation)	Post-occupancy exploration	Social housing, Ghana	Explore residents' tacit feedback (spatial adaptations) for housing needs	Surveys, observation, behavioral mapping	Residents indirectly shaped findings via observed adaptations	Mixed-methods analysis
[21]	Ethnography, Behavioral research	Empathy-driven design	Rural housing, India (Barefoot College)	Train rural residents to build sustainable homes	Ethnographic interviews, skill-building workshops	Women trained as solar engineers/ builders	Participant feedback, observational studies
[4]	Post-Occupancy Evaluation (POE)	Redesign via feedback	Hulme Crescents, Manchester, UK	Transform failed social housing through resident input	POE surveys, participatory redesign workshops	Residents identified flaws and co-designed solutions	Longitudinal surveys, behavioral mapping

Table 1 (Continued)

Author citation	Academic methodology	Design thinking component	Context/ setting	Objective	Key methods used	Participation framework	Validation methods
[22]	Open-Building Framework	Incremental design	Iquique, Chile (Elemental's Half-House)	Co-design expandable housing for low-income families	Participatory workshops, incremental prototyping	Families co-designed "half-houses"	Resident feedback, adaptability metrics
[12]	Human-Centered Design	Co-design for marginalized groups	Homeless shelters, US	Improve shelter operations through user feedback	Empathy-driven workshops, prototyping	Homeless individuals evaluated and redesigned shelter layouts	Usability testing, iterative feedback
[14]	Systems Thinking	Holistic urban integration	Urban housing, Europe	Analyze multi-scalar housing challenges	Causal loop diagrams, network analysis	Policymakers, architects, and residents collaborated	Policy impact assessments
[1]	Experimental Design	A/B Testing	Modular housing prototypes	Compare design alternatives (shared vs. private spaces)	A/B testing of virtual/ physical prototypes	Residents tested prototypes in simulated environments	Quantitative metrics (occupancy rates, comfort)
[17]	Longitudinal Studies	Tracking long-term outcomes	Cohousing communities, Scandinavia	Assess sustainability and social cohesion over time	Longitudinal POE surveys, behavioral tracking	Residents participated in annual evaluations	Yearly surveys, adaptation tracking
[23]	Speculative Design	Future-focused prototyping	Smart cohousing, Netherlands	Explore IoT applications for communal decision-making	IoT sensor prototypes, speculative workshops	Residents and technologists co-designed smart systems	Prototype testing, scenario planning
[15]	Self-Build Methodologies	Resident-led construction	Segal self-build housing, UK	Empower residents to construct modular homes	Self-build workshops, modular design kits	Residents built homes with professional guidance	Construction quality audits, satisfaction surveys
[11]	Cultural Ethnography	Context-sensitive design	Informal settlements, Thailand	Address housing needs through localized participatory processes	Ethnographic mapping, community dialogues	Community architects facilitated bottom-up design	Cultural adaptation metrics

Author citation	Metrics/ Indicators used	Challenges or limitations	Outcomes/ findings	Relevance to goal	Novel contributions	Scalability
[2]	Sustainability, collaboration success	Power imbalances, communication gaps	PAR generated local solutions; transdisciplinary collaboration was key	High	PAR for transdisciplinary housing	Limited
[8]	Social inclusion, collective decision-making	Dominance by individuals with capital	Empowerment through ethics, power, and care mechanics	High	Ethics-driven participatory processes	Moderate
[9]	Shared spatial definitions, behavior change receptiveness	Scaling participatory methods	Residents defined shared spaces, increasing sustainability	Medium	Participatory pattern languages	Moderate
[19]	Social cohesion, shared vs. individual space optimization	Architectural focus (limited direct participation)	Spatial harmony through optional interaction	Low	Architectural strategies for co-living	Low
[20]	Co-designed solutions implemented	Limited long-term evaluation	Co-created hubs for student engagement and identity	Medium	Service + spatial design integration	Moderate
[7]	Program operation metrics, design quality	Single housing type focus	Marginalized residents involved in evaluation/ improvement	High	PAR combined with evaluation for redesign	Low

Table 1 (Continued)

Author citation	Metrics/ Indicators used	Challenges or limitations	Outcomes/ findings	Relevance to goal	Novel contributions	Scalability
[5]	Affordability, actor engagement levels	Political constraints	Innovative solutions revealed systemic inequality	High	PAR within unequal power dynamics	Moderate
[16]	Community cohesion, tech relevance	Long-term empirical support lacking	IoT tools revealed communal needs, sparked future discussions	Medium	IoT for community needs	Low
[10]	Adaptability, sustainability indicators	Limited generalizability	Contextual design factors supported user adaptability	Medium	Historical adaptability analysis	Limited
[18]	Resident satisfaction, tacit patterns	Limited to specific cases, no clear participatory stage	Residents indirectly influenced iteration designs	High	Tacit communication approach for housing needs	Moderate
[21]	Skill transfer rates, resident satisfaction	Replicating training models	Sustainable, low-cost housing with local ownership	High	Empowerment through skill-building	Moderate
[4]	Crime rates, resident satisfaction	Overcoming institutional distrust	Crime-ridden area transformed into livable community	High	POE-driven post-hoc redesign	Low
[22]	Affordability, resident agency	Balancing professional expertise with user autonomy	Affordable, adaptable housing with incremental expansions	High	Open-building principles for incremental design	Moderate
[12]	Co-design for marginalized groups	Homeless shelters, US	Improve shelter operations through user feedback	Empathy-driven workshops, prototyping	Homeless individuals evaluated and redesigned shelter layouts	Low
[14]	Holistic urban integration	Urban housing, Europe	Analyze multi-scalar housing challenges	Causal loop diagrams, network analysis	Policymakers, architects, and residents collaborated	High
[1]	A/B Testing	Modular housing prototypes	Compare design alternatives (shared vs. private spaces)	A/B testing of virtual/physical prototypes	Residents tested prototypes in simulated environments	High
[17]	Tracking long-term outcomes	Cohousing communities, Scandinavia	Assess sustainability and social cohesion over time	Longitudinal POE surveys, behavioral tracking	Residents participated in annual evaluations	Moderate
[23]	Future-focused prototyping	Smart cohousing, Netherlands	Explore IoT applications for communal decision-making	IoT sensor prototypes, speculative workshops	Residents and technologists co-designed smart systems	Low
[15]	Resident-led construction	Segal self-build housing, UK	Empower residents to construct modular homes	Self-build workshops, modular design kits	Residents built homes with professional guidance	Moderate
[11]	Context-sensitive design	Informal settlements, Thailand	Address housing needs through localized participatory processes	Ethnographic mapping, community dialogues	Community architects facilitated bottom-up design	Limited

3.1. Empowerment through Participatory Action Research(PAR)

Participatory Action Research (PAR) has been shown to be an empowering instrument that can change the lives of people by promoting resident agency and making locally initiated housing solutions possible. Examples like PREVI Lima and the Orangi Pilot Project illustrate the manner in which participatory methodologies have enabled decision-making by and for communities [6, 10]. The incremental housing model of PREVI, wherein core housing modules were planned to be adaptable in the long run to resident improvisations, affirms the hybrid framework's emphasis on adaptability and user-led development. Similarly, Orangi's infrastructure upgrading initiative involved residents in co-designing sanitation systems, demonstrating how engagement in the early design phases fosters long-term ownership.

Despite these successes, challenges remain in ensuring equitable participation in large-scale housing interventions. Nix *et al.* highlight issues of power imbalances within participatory processes, where architects and policymakers sometimes dominate decision-making, diluting the voices of marginalized residents [2]. Whitzman lists additional challenges, specifically institutional partnerships, wherein bureaucratic issues and poor communication most frequently constrain how deeply participants get involved [5]. Those kinds of hurdles call for the systems to maintain ordered yet agile mechanisms of participation to allow wide-ranging stakeholders with the opportunity to make valuable input to housing arrangements.

3.2. Sustainability and systems thinking

Post-Occupancy Evaluation (POE) and ethnographic research approaches increasingly influence sustainable and socially integrated solutions in housing. Such projects as Vauban District in Freiburg and Barefoot College in India have applied systematic assessment methods to create ecologically sustainable and culturally appropriate housing [1, 21]. These projects based their models on long-term resident input to enhance energy-efficient housing designs and community-driven skill-building initiatives. Indices of energy efficiency, resident health, and affordability formed the core around which iterative refinements of the design were driven, supporting the framework's utility in bridging empirical validation and participatory adaptation.

Yet, scalability for grassroots housing schemes has proven to be an ongoing challenge. The Tiny House Villages initiative encountered strict zoning legislation regulation and policy obstacles that prevented replication despite achieving successful, modular community-oriented housing [24]. This highlights the requirement for policy provision that fosters scalable models of sustainability to allow experimental, localized participatory housing solutions to be scaled up to wider urban and rural environments.

3.3. Technological innovation in cohousing

Emergence of technology-enabled participatory paradigms has opened up new possibilities for embedding digital technologies into shared living spaces. Examples of case studies like IoT-based Cohousing and speculative design investigate the ways in which new digital tools enable collective decision-making [16, 23]. Integrated smart technologies in cohousing societies have enhanced mechanisms for sharing resources, with real-time information on energy usage, shared facilities, and collective governance. These results support the framework's focus on data-driven design iteration, illustrating how digital engagement can inform user-focused housing interventions.

Even with these benefits, technological innovation in participatory housing comes with its drawbacks. Privacy concerns, digital access, and long-term data verification remain issues. Pira *et al.* pointed out that speculative design work tends to have limited longitudinal data, which hinders the ability to measure their long-term effects [23]. Additionally, Jenkins observes that technological exclusion is an actual threat in low-income housing, where infrastructural constraints could hinder residents from interacting meaningfully with digital resources [16]. Closing such gaps calls for the creation of ethical and affordable technological solutions that are inclusive and ensure privacy-protected communal data-sharing systems.

3.4. Balancing academic rigor and creativity

Balancing academic legitimacy and creative freedom is paramount in participatory housing design. Designs such as Elemental's Half-House model and Segal self-build housing effectively integrated structured methodologies and resident agency, facilitating incremental prototyping and user-led spatial adjustments [15, 22]. These examples demonstrate how the Empathize-Act-Reflect cycle of the hybrid model enables adaptive, real-world applications combining structured academic investigation with user-driven design thinking strategies.

Yet power relations continue to influence participatory housing outcomes. Institutional hierarchies tend to dominate over resident agency, especially in public-private housing partnerships. Melbourne's affordable housing partnerships reinforce how developer-led decision-making arrangements tend to diminish the influence of resident participation, promoting symbolic engagement instead of co-creation [5]. Such power imbalances are met by reversing toward community-driven governance arrangements, underpinned by policy arrangements that integrate participatory decision-making within formal housing development processes.

3.5. Case study validation of the proposed hybrid framework

Case studies under investigation strongly confirm the suggested hybrid framework by proving methodological congruence between various stages of design thinking. PAR approaches, especially in cases like Delhi Slum Redevelopment and Orangi Pilot Project, confirm the importance of initial-stage community interaction during the Empathize and Define stages [2, 6]. POE implementation, as practiced in the redevelopment of Hulme Crescents and Vauban District, demarcates the importance of longitudinal assessment in dictating iterative improvements in housing performance through the Testing and Reflection periods [1, 4]. RtD methods, utilized in speculative cases such as IoT-enabled cohousing and modular prototyping within Half-House, exemplify the significance of experimental design approaches in creating forward-thinking, resident-centric housing innovations [16, 22].

In addition to these strengths, there are still significant critical challenges. Few projects follow up on outcomes past ten years, which restricts longitudinal understanding of sustainability and impact. Power imbalances continue to influence participatory housing results, for example, institutionally managed projects in Melbourne [5]. Further, technological exclusion continues to be a danger for low-income communities, especially in projects that depend on digital platforms for resident engagement [16, 23].

3.6. Recommendations for practice

To increase the impact and scalability of participatory housing approaches, there are some specific recommendations arising from this review. Integration with policy is essential, with participatory frameworks influencing national housing policies. The Million Houses Programme offers a model for the scaling of participatory interventions through government-supported programs, supporting the necessity for institutional engagement in order to maintain grassroots housing initiatives [6].

Also, ethical technology needs to be formulated to ensure cohousing digital engagement is inclusive and privacy-aware. IoT-aided housing interventions demonstrate the possibility of collective decision-making with smart technology, but issues of privacy have to be mitigated through anonymized and user-managed data-sharing systems [16, 23].

Lastly, scaling up skill-developing models like Barefoot College's training methodology presents a way of empowering marginalized populations through participatory housing solutions [21]. Integrating technical training programs with participatory housing initiatives can foster sustainable, community-driven solutions through the blending of lived experience with professional skills to ensure long-term resilience and flexibility.

4. Framework: Integrating PAR into DT for group housing

This section presents a hybrid framework that systematically integrates Participatory Action Research (PAR) and academic methodologies into the design thinking process for group housing. The proposed framework emphasizes co-design, iterative validation, and sociocultural adaptability, addressing key challenges such as scalability, power imbalances, and longitudinal validation, as identified in the literature. By combining the structured rigor of academic research with the flexibility of design thinking, this framework provides a replicable model for evidence-based participatory housing design.

4.1. Framework overview

The proposed framework merges the iterative stages of design thinking with academic research methodologies such as Participatory Action Research (PAR), Post-Occupancy Evaluation (POE), and Research through Design (RtD) to form a unified, user-centered approach. **Figure 1** below illustrates how these academic processes align with each phase of the design thinking cycle, ensuring that housing interventions remain participatory, empirically grounded, and adaptable to evolving community needs [5, 7]

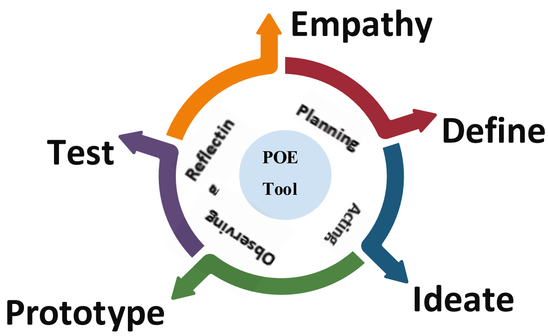

Figure 1. Integration of PAR and POE tools within the design thinking cycle

In practical applications, this framework has been tested in case studies such as PREVI Lima and IoT-enabled cohousing models, where participatory methodologies and iterative evaluation have informed adaptive, resident-driven housing modifications [10, 16].

4.2. Key components of the framework

The framework integrates academic methodologies into each stage of design thinking to ensure both participatory depth and empirical rigor. **Table 1** shows below outlines how different academic approaches are systematically mapped onto the design thinking process, specifying the expected outputs at each stage.

Table 1. Mapping academic research methodologies onto design thinking stages in the proposed framework

DT stage	Integrated academic methodologies	Expected outputs
Empathize	PAR workshops, ethnographic interviews [8]	Stakeholder personas, empathy maps
Define	Systems thinking, behavioral mapping [7]	Co-defined problem statements
Ideate	Co-design workshops, pattern languages [5]	Prototypes (e.g., modular layouts, IoT tools)
Prototype	A/B testing, RtD experiments [13]	Validated design alternatives
Test	POE surveys, longitudinal evaluations [18]	Metrics on satisfaction, adaptability

This structured approach ensures that design interventions remain stakeholder-driven, data-informed, and iteratively refined based on real-world feedback.

4.3. Integration process

The framework is implemented through three iterative phases, ensuring a seamless integration of PAR cycles and design thinking methodologies.

4.3.1. Phase 1: Empathize and plan (PAR + Design thinking)

The first phase focuses on identifying housing challenges through collaborative stakeholder engagement and ethnographic research.

(1) PAR activities: Stakeholder workshops to identify needs and define shared priorities. In PREVI Lima, residents actively shaped housing layouts based on family growth projections [10].

(2) Design thinking tools: Ethnographic interviews to map cultural and spatial pain points, ensuring that design decisions align with local social dynamics [12].

(3) Outcome: A co-developed understanding of housing constraints and aspirations, documented in empathy maps and stakeholder personas.

4.3.2. Phase 2: Ideate and act (Co-Creation and Prototyping)

The second phase centers on generating design alternatives and testing prototypes using co-design methodologies.

(1) PAR activities: Residents, architects, and policymakers collaborate in co-design workshops, iterating on modular housing layouts and smart technology integration [5].

(2) Design thinking tools: Prototyping of modular housing components (e.g., expandable floor plans, flexible partitions) and A/B testing of design alternatives using virtual reality simulations [23].

(3) Outcome: Low-fidelity prototypes refined based on stakeholder feedback and early-stage usability testing.

4.3.3. Phase 3: Test and reflect (Evaluation and iteration)

The final phase ensures longitudinal assessment and refinement of housing solutions through POE and behavioral mapping.

(1) PAR activities: Iterative feedback loops with residents, refining designs based on lived experiences.

(2) Academic tools: POE surveys measuring thermal comfort, social interaction, and housing adaptability [18].

(3) Outcome: High-fidelity designs validated through qualitative resident feedback and quantitative

performance metrics.

4.4. Tools and techniques

To operationalize the framework, a combination of co-design methodologies, technological tools, and longitudinal assessments is employed:

(1) Co-design workshops: Structured participatory design sessions, ensuring that residents actively contribute to housing solutions [8].

(2) Modular prototyping: Incremental housing adaptation models, as seen in the Segal self-build method, which allows residents to modify and expand their homes over time [11]. Modular frameworks, inspired by Hilmer's (2020) self-build method and Mota's (2015) open-building approach, enable incremental adaptations.

(3) IoT and digital tools: IoT tools and digital participation platforms bridge speculative design with empirical validation [16, 23]. Sensors embedded in communal spaces to track energy usage, resource-sharing efficiency, and spatial utilization in real-time.

(4) Longitudinal POE: Systematic tracking of resident satisfaction, adaptability, and community engagement over 6-month intervals [18].

4.5. Addressing key challenges

The proposed framework is specifically designed to address persistent barriers in participatory housing research.

(1) Power dynamics: Neutral facilitators ensure equitable participation in co-design processes [6]. Digital feedback tools (e.g., anonymous input apps) mitigate professional dominance in decision-making.

(2) Scalability: Modular frameworks allow replication across diverse housing contexts, adapting PREVI Lima's principles to urban cohousing models [10]. Policy integration ensures institutional support for scalable participatory housing models [5].

(3) Longitudinal validation: Embedded POE cycles every 6 months provide ongoing performance tracking, ensuring that housing solutions remain relevant and adaptable [18].

4.6. Framework contributions

The integration of PAR, POE, and RtD within design thinking provides a scalable and empirically validated model for participatory housing. The key contributions of this framework include:

(1) Bridging rigor and creativity: PAR ensures stakeholder inclusion, while POE provides empirical validation.

(2) Scalable solutions: Modular and digital tools enable context-sensitive housing adaptations.

(3) Policy relevance: Metrics derived from POE and participatory research inform equitable housing policies [5].

5. Discussion

Combining academic research approaches with design thinking in group housing offers transformative possibilities as well as ongoing challenges. The case studies examined here illustrate how Participatory Action Research (PAR), Post-Occupancy Evaluation (POE), and Research through Design (RtD) offer systematic processes for tackling sociocultural, economic, and spatial complexities of shared living. Studies like PREVI

Lima and the Orangi Pilot Project demonstrate PAR's ability to engender long-term resilience and citizen engagement by instilling resident perspectives in collaborative design [6, 10]. Interventions within such projects serve to reaffirm participatory empowerment in the hybrid approach as facilitated through iterative cycles of feedback and decision-making under the leadership of residents.

A disadvantage exists nonetheless in navigating uneven power relations between participants. Institutional partnerships, like Melbourne's affordable housing partnerships, tend to marginalize community engagement into a symbolic action, instead of an active contributor to the design and policy-making of housing [5]. This highlights the necessity of neutral facilitation procedures and policy protections to keep community voices central in participatory housing structures. Likewise, though technological advancements in cohousing, e.g., IoT-based communal governance and speculative design experiments, show new avenues for digital participation, their dependence on digital infrastructure threatens to leave out low-income groups [16, 23]. The case studies indicate that low-tech options, e.g., offline participatory workshops or hand-drawn spatial mapping methods, might be required to make these participatory tools more democratic.

One of the proposed framework's major strengths is bridging the academic rigor and creative flexibility found in incremental housing schemes such as Elemental's "half-houses" [22]. Such schemes use prototyping cycles and feedback loops from residents to guarantee housing remains affordable, adaptable, and culturally responsive. There is a fundamental gap in the collection of longitudinal data, making it impossible to measure long-term effects. While POE studies in Vauban District offer valuable insights into post-occupancy adaptation, few projects systematically track resident satisfaction and spatial adaptability beyond 10 years [1]. Addressing this gap requires a commitment to long-term validation metrics, ensuring that participatory housing remains responsive to evolving resident needs over time.

These findings cumulatively support the framework's promise in bridging empathy-based design with empirical evidence. Yet, systemic obstacles, such as policy limitations, funding imbalances, and stakeholder power relationships, need to be overcome in order to upscale these participatory models beyond individual pilots.

6. Recommendations for practice

In order to transfer this study into practice, some major recommendations are highlighted.

(1) Institutionalizing participatory metrics

Participatory success metrics, i.e., resident adaptability indices, co-design effectiveness measures, and post-occupancy performance assessments, should be incorporated into housing policy audits by policymakers. The Million Houses Programme illustrates that integrating participatory benchmarks within regulation instruments guarantees accountability in large-scale housing actions [2].

(2) Modular and incremental housing prototyping

Architects and urban designers need to embrace incremental housing prototypes that empower residents to co-design their living areas incrementally. Examples such as the Segal self-build approach and Elemental's Half-House demonstrate how modular prototyping facilitates adaptability and affordability, allowing flexible, user-led expansion [15, 22].

(3) Community skill-building and capacity development

Communities, especially marginalized ones, must be provided with participatory design training programs. Barefoot College's skill-building workshops provide a replicable model for technical empowerment and local ownership in housing solutions [21]. Governments and NGOs must institutionalize and fund similar training programs in participatory housing projects.

(4) Ethical and inclusive smart housing technologies

Technology innovators must give precedence to privacy-oriented, low-cost participatory technologies to democratize access to smart housing technology. IoT-integrated cohousing initiatives illustrate the promise of technology-augmented communal decision-making, but such interventions need to be made affordable, accessible, and privacy-oriented [16]. Technologies like anonymized IoT sensors and open-source digital pattern languages can support participatory housing without sacrificing inclusivity [9].

(5) Scaling participatory housing through cross-sector collaboration

Interdisciplinary collaborations among academia, government, and community organizations are essential to upscaling participatory housing from stand-alone pilot schemes. Experiences from the Million Houses Program underscore how institutional support and cross-sector partnerships guarantee the sustainability of participatory housing models [2].

7. Future research directions

This research points to a number of areas for future research to enhance participatory housing models and their alignment with academic research approaches.

(1) Longitudinal evaluations of participatory housing interventions

Most participatory housing projects lack long-term validation metrics. Future research should prioritize longitudinal studies, particularly in technology-driven housing models like IoT-enabled cohousing, to assess their sustainability and social cohesion over decades [16].

(2) Cross-cultural adaptations of PAR in housing

Research needs to investigate how PAR approaches can be applied across cultural settings. Tovivich's research on participatory housing in Thailand provides a starting point for seeing how localized participatory frameworks can be applied internationally while still being culturally specific.

(3) Cost-efficiency and policy impact of self-build housing

Quantitative studies of the economic feasibility of self-build housing and policy implications are necessary. Future research should investigate the economic efficiency of incremental housing typologies and model participatory zoning law modifications to determine their scalability [22, 24].

(4) Intersectional perspectives in housing equity

More focus should be put on gender, disability, and social equity in participatory housing studies. Fatima *et al.* underscore the significance of gender-sensitive co-design in homeless shelters, stressing the need for more participatory frameworks that are inclusive [12]. Future studies should build on intersectional design strategies to ensure participatory housing is responsive to diverse community needs.

8. Conclusion

This study proposes a hybrid framework for group housing that blends academic methods (PAR, POE, RtD) with design thinking's user-centric culture. Through the convergence of insights from 20 international case studies, the research shows that participatory strategies, when methodically integrated into empathy, ideation, and validation stages, produce housing solutions that are inclusive and evidence-driven. The emphasis of the framework on modular flexibility, such as seen in PREVI Lima's resident-organized housing additions, and ethical technology prioritization, such as discussed in IoT cohousing pilots, offer pragmatic directions to mitigate affordability, sustainability, and cultural resonance challenges.

Nonetheless, this research's use of qualitative case studies and localized interventions imposes limitations on generalizability. Systemic disparities, including zoning regulations and funding inequities, still slow the universal acceptance of participatory models. Nevertheless, the research adds a structured yet adaptable model for architects, policymakers, and communities to jointly address housing challenges, balancing empirical accountability with creative innovation.

This research creates a model that is disciplined but flexible to integrate scholarly rigour and design thinking for participatory housing. In mitigating power imbalance, sustainability issues, and exclusion by technology, the suggested model sets up a replicable model of inclusive, people-centered housing interventions. Research and practice need to engage longitudinally in assessing impact, foster intersectoral collaboration, and ethically include technology in pursuit of participatory, sustainable, and fairer housing options in the future.

Disclosure statement

The authors declare no conflict of interest.

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Management Measures for Large-scale Machinery and Equipment in Highway Construction

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Abstract: This article focuses on the management of large-scale machinery and equipment in highway construction, with the research objective of identifying issues at the management level and exploring more effective management measures. Through practical observation and logical analysis, this article elaborates on the management connotations of large-scale machinery and equipment in highway construction, affirming its management value from different perspectives. On this basis, it carefully analyzes the problems existing in the management of large-scale machinery and equipment, providing a detailed interpretation of issues such as the weak foundation of the equipment management system and the disconnection between equipment selection and configuration from reality. Combining the manifestations of related problems, this article proposes strategies such as strengthening the institutional foundation of equipment management, selecting and configuring equipment based on actual conditions, aiming to provide references for large-scale machinery and equipment management to relevant enterprises.

Keywords: Highway; Construction; Large-scale machinery and equipment management

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1. Introduction

A variety of large-scale machinery and equipment needs to be applied in highway construction. In construction management, the management of large-scale machinery and equipment is particularly important. After careful observation, comparison, and analysis, it can be found that although the importance attached to large-scale machinery and equipment management has significantly increased, there are many influencing factors related to equipment management in actual construction. Under the combined influence of many factors, various problems are likely to arise in equipment management. When these problems accumulate, the normal use of equipment and normal construction can be adversely affected. Therefore, it is particularly important to carefully manage large-scale machinery and equipment. For construction entities, how to systematically manage large-scale machinery and equipment while using them is also worthy of deep consideration[1].

2. Overview of large-scale machinery and equipment management in highway construction

2.1. Connotation of large-scale machinery and equipment management in highway construction

Large-scale machinery and equipment management in highway construction refers to the systematic planning, meticulous coordination, and control of large equipment used in construction, to ensure the safe and stable operation of various large equipment [2]. Through **Table 1**, it can be observed that there are many types of large-scale machinery and equipment used in highway construction, indicating that large-scale machinery and equipment management has the basic characteristic of high complexity. In large equipment management, it is also necessary to take into account different key points. Among them, the construction of the management system will have a lot of impact on subsequent management, and it is also very important to select and configure various equipment according to construction needs.

Table 1. Types and names of common large machinery and equipment in highway construction

Equipment type	Equipment name
Earthwork construction equipment	Bulldozer, excavator, loader, grader, etc
Road construction equipment	Concrete mixing equipment, asphalt paver, etc
Bridge construction equipment	Crane, prestressed tensioning equipment, etc
Tunnel construction equipment	Shield machine, rock drilling jumbo, etc

2.2. Value of large-scale machinery and equipment management in highway construction

The increasing focus on the management of large-scale machinery and equipment in highway construction is closely related to its important value. In summary, the value of large-scale machinery and equipment management is mainly reflected in ensuring the normal use of related equipment and supporting the construction of highway projects. From the perspective of ensuring equipment use, various types of large-scale machinery and equipment are usually required for highway construction. The management status of machinery and equipment will have a direct impact on whether the machinery and equipment configuration is reasonable and whether the performance can be exerted [3]. After doing a good job in various management tasks at this level, large-scale machinery and equipment can be more scientifically configured and used. From the perspective of supporting construction, large-scale machinery and equipment management can ensure that various equipment is in good operating condition. This can guarantee construction progress on the one hand and construction quality on the other. After fully utilizing various large-scale machinery and equipment for efficient construction, construction costs can also be effectively controlled. Using large-scale machinery and equipment to replace manual construction also helps improve construction safety [4].

3. Issues in large machinery and equipment management in highway construction

3.1 Weak foundation of equipment management system

Many construction enterprises actively engage in large machinery and equipment management during highway construction projects. However, the human and material resources invested in management often fail to fully translate into the expected management effectiveness. This situation is directly related to the weak institutional foundation of management [5]. For instance, some construction enterprises have historically not focused on the institutional development of construction management, resulting in a lack of institutional guidance for large machinery and equipment management. Both the absence and inadequacy of basic institutional frameworks constitute fundamental problems at the management level. Without the guidance and norms provided by basic institutional frameworks, various management activities cannot be effectively directed and standardized during implementation. Managing without proper standardization can easily lead to efforts becoming mere formalities. Furthermore, without institutional support and guarantees, management activities conducted at different levels and stages lack internal coherence, and there is a lack of holistic advantages in management practices. More seriously, when management is conducted haphazardly without institutional guidance, it can easily give rise to new management issues. This indicates that the weak institutional foundation of large machinery and equipment management is not only a standalone management problem but also a potential trigger for other management issues [6].

3.2. Equipment selection and configuration not based on reality

The large machinery and equipment that may be used in highway construction are diverse. However, many construction enterprises fail to conduct a detailed analysis of equipment usage needs and also lack adequate construction research and planning. This leads to certain deficiencies in the selection and configuration of large machinery and equipment. One common problem in large machinery and equipment management is that equipment selection and configuration are not based on reality. Inadequate early planning prevents construction enterprises from accurately grasping the demand for large machinery and equipment during construction. Additionally, when some personnel lack sufficient understanding of the performance, characteristics, and scope of application of large machinery and equipment, equipment selection can be somewhat blind [7]. Regardless of the reason, equipment selection and configuration that are not based on reality can have many adverse effects on normal construction. For example, when large machinery and equipment are not delivered to the site in a timely manner, construction schedule management will be affected. At the same time, when the number of large machinery and equipment on site is significantly higher than the construction demand, equipment usage fees during construction will increase, driving up construction costs.

3.3. Insufficient standardization of equipment maintenance management

Large machinery and equipment management in highway construction involves multiple levels of management tasks, among which equipment maintenance management is a crucial aspect. The performance of large machinery and equipment is directly affected by maintenance conditions. Whether maintenance is proper not only impacts equipment usage but also extends to the construction of highway projects [8]. Some construction enterprises have not paid attention to the systematic maintenance of large machinery and equipment, especially when some equipment is rented. Their maintenance often lacks scientific planning support, maintenance records are filled out irregularly, and problems such as chaotic management of wearing parts and other spare parts are common. Additionally, many construction enterprises lack professional maintenance talent for large machinery and equipment, making it difficult to guarantee high-quality maintenance. When it is difficult to fully ensure scientific and standardized maintenance, deficiencies in this aspect can easily lead to hidden faults or safety hazards during equipment use. Insufficient standardization of maintenance management is also not conducive to extending the service life of large machinery and equipment and may even directly lead to an increase in equipment failure rates.

3.4. Low effectiveness of equipment safety management

Large equipment management in highway construction includes safety management, which is also an important component of construction management. When the construction volume of highways is large and the frequency of using large equipment is high, the pressure on equipment safety management is significantly higher. Although many construction enterprises attach great importance to safety management during the use of large machinery and equipment, the effectiveness of safety management is relatively low. For example, some equipment operators have a relatively weak safety awareness, and construction enterprises have not provided systematic safety education to relevant personnel, which is a common cause of equipment usage risks. In on-site safety supervision, there are limitations in the supervision of large machinery and equipment usage. Some supervisors have low comprehensive literacy and find it difficult to discover equipment safety issues in a timely manner. Most of the supervision they conduct is not routine supervision. Equipment safety management is highly professional, and it is not advisable to rely solely on on-site inspections for safety supervision. When multiple large machinery and equipment are used simultaneously in highway construction projects, the drawbacks of traditional safety management methods are further amplified.

4. Large machinery and equipment management measures in highway construction

4.1. Strengthen the institutional foundation of equipment management

The management of large machinery and equipment in highway construction relies heavily on institutional support. Integrating the concept of institutionalized management into management practices, building and strengthening the institutional foundation on this basis is crucial. For example, a certain highway construction enterprise places great emphasis on institutional development in large machinery and equipment management. The specific institution includes various management requirements (as shown in **Table 2**). The establishment and implementation of this institution provide effective guidance for various management activities. Simultaneously, the institution fully considers management affairs at different levels, proposes various management requirements, and the implementation of the institution also enhances the comprehensiveness of large machinery and equipment management to a certain extent. For highway construction enterprises, they also need to actively carry out institution building based on the needs of large machinery and equipment management, refine the management requirements in the institution, provide institutional guidance and norms for management practices, create a better institutionalized management environment, and avoid other management problems caused by irregular management.

Table 2. Basic content of large machinery and equipment management institution

System content module	Management components
Equipment purchase (lease) and acceptance	Management of equipment purchase (lease), acceptance criteria and processes, etc.
Equipment ledger and file management	Ledger establishment, file management, etc.
Equipment use and operation management	Operating procedures and standards, operator management, etc.
Equipment maintenance and servicing management	Maintenance plan development and implementation, maintenance quality assessment, etc.
Equipment safety management	Safety supervision, identification of safety hazards, safety rectification, etc.

4.2. Selection and allocation of equipment based on actual conditions

In the management of large-scale machinery and equipment for highway construction, attention should be paid to the scientific selection and reasonable allocation of equipment to avoid adverse effects on normal construction due to improper selection and allocation. For example, highway construction enterprises should carefully analyze construction requirements before formal construction, and determine the types and quantities of large-scale machinery and equipment required based on the analysis of project scale, progress, technology, and quality requirements. Equipment selection should consider equipment versatility and compatibility to facilitate flexible configuration of large-scale machinery and equipment at different construction stages. Taking the selection of loaders as an example, some models of loaders have multiple operating functions, and selecting such loaders can improve their comprehensive utilization rate. In the allocation of large-scale machinery, it is necessary to fully integrate the construction process and needs to ensure coordination in the use of large-scale machinery and equipment. Taking concrete pouring construction as an example, it is advisable to calculate the production capacity of the concrete mixing station, transportation distance, and the demand for concrete quantity during construction to determine the number of mixer trucks and pump trucks, which can not only ensure a stable supply of concrete during construction but also take into account the economic principles in the use of large-scale machinery and equipment. After effectively selecting and configuring various large-scale machinery and equipment based on highway construction needs, the value of large-scale machinery and equipment in construction can also be fully utilized.

4.3. Standardized equipment maintenance management

Large-scale machinery and equipment used in highway construction cannot be separated from maintenance management, which is directly related to the performance and service life of related equipment. Apart from giving sufficient attention to maintenance management issues, construction enterprises should also standardize equipment maintenance management. For example, a highway construction enterprise develops equipment maintenance plans in the maintenance management of large-scale machinery and equipment, and carries out standardized maintenance and maintenance quality supervision based on specific plans. Working with equipment manufacturers and technical personnel, and combining equipment maintenance requirements, the maintenance plan includes maintenance cycles, projects, and responsible persons, and also puts forward detailed requirements for routine maintenance, regular maintenance, and special maintenance matters. After developing a strict maintenance plan, the construction enterprise will carry out large-scale machinery and equipment maintenance based on the plan, fill in maintenance records in detail, promptly report problems and perform equipment maintenance to ensure stable equipment operation, and inspect and evaluate equipment maintenance quality based on the maintenance quality supervision mechanism. Thanks to the standardized maintenance management of large-scale machinery and equipment, the performance of different equipment is guaranteed, and the service life can also be extended, which also provides great help in avoiding equipment performance problems. Naturally, highway construction enterprises need to standardize equipment maintenance.

4.4. Dynamic safety management of equipment

Safety management is a top priority in highway construction, and its importance is self-evident in the management of large-scale machinery and equipment. At this stage, most construction activities require the use of large-scale machinery and equipment, which necessitates dynamic safety management. Specifically, highway construction enterprises should establish a safety inspection mechanism related to the use of large-scale machinery and equipment, and assign safety inspectors, technicians, and operators on the construction site to conduct safety inspections together. Safety inspections should take into account safety performance checks, inspection of protective device configuration, electrical system checks, and brake system checks. Since the safety risks in the use of large-scale machinery and equipment are difficult to completely avoid, highway construction enterprises should develop emergency plans, clarify emergency response divisions based on common safety accidents involving large-scale machinery and equipment used in construction, organize regular emergency drills for construction workers, and focus on strengthening the safety awareness of operators. By conducting regular safety inspections and dynamically managing the safety of large-scale machinery and equipment based on these inspections, potential safety hazards in equipment use can be identified in a timely manner. This provides numerous guarantees for the normal use of large-scale machinery and equipment in construction. Naturally, highway construction enterprises need to consider safety management as the core of large-scale machinery and equipment management.

5. Conclusion

Through research, it can be found that multiple key points need to be considered in the management of large-scale machinery and equipment in highway construction, and managing related equipment is also of great value. At this stage, there are some problems in the management of large-scale machinery and equipment, and solving these problems is the key to improving the effectiveness of management. Consolidating the foundation of equipment management systems can provide institutional support for management practices. Selecting and configuring equipment based on construction needs can provide more assistance for highway construction. While using various equipment, it is also necessary to carefully maintain the equipment and normalize equipment safety management. Besides managing from the above perspectives, detailed evaluations should also be conducted during management. On this basis, various problems can be solved, and continuous optimization can be carried out, which can also promote the improvement of management effectiveness.

Disclosure statement

The author declares no conflict of interest.

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