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Study on the Construction Technology of Subgrade Pavement in Road and Bridge Settlement Section

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Abstract: With the continuous development of China's economy, the construction of roads and bridges work has put forward higher requirements. Due to various factors, the long-term use of roads and bridges will produce a settlement phenomenon. Therefore, it is crucial to address settlement issues during the construction of roads and bridges to ensure that the quality of subgrade and pavement construction meets national regulations. This paper introduces the harm of subgrade pavement subsidence, analyzes the causes of subgrade pavement deformation, and discusses the technical points of subgrade pavement construction, hoping to provide some reference for relevant practitioners.

Keywords: Road and bridge; Settlement section; Subgrade and pavement; Construction technology

Online publication: August 14, 2024

1. Foreword

In road and bridge engineering, subgrade and pavement in settlement sections are often an important factor affecting structural stability and service life. Since the settlement section is located in the transition area between the bridge and the road, the geological conditions are complex. Due to a variety of factors, it is prone to uneven settlement, leading to road deformation and bridge damage. Scientific and reasonable construction technology can not only improve the quality of the project, but also significantly improve the driving conditions, reduce the maintenance cost, extend the service life of roads and bridges, and ensure traffic and operational efficiency.

2. Hazard of subgrade and pavement settlement of road and bridge

2.1. Affect the driving safety

Subgrade and pavement settlement will lead to uneven connection between the bridge and the subgrade, causing strong turbulence when vehicles pass through. This increases the operational difficulty for drivers, making it easy to lose control and potentially leading to traffic accidents. Especially at night or under bad weather conditions, the driver's reaction time is limited, and the uneven road surface may lead to vehicle instability. In the process of driving, if the road is suddenly uneven, it will overwork the vehicle suspension system, affecting the stability and handling performance of the vehicle, and further increasing the risk of accidents. Settlement of subgrade and road surface will cause the failure of the drainage system, resulting in water accumulation on the road. The water will reduce the friction coefficient of the road surface, decreasing the adhesion between the vehicle tires and the road, which increases the risk of skidding, especially during breaking and turning. Water will also lead to a water film effect on the road, causing the vehicle to lose contact with the road at high speed, resulting in the vehicle being completely out of control and increasing the risk of serious traffic accidents. The settlement difference between the bridge and the road will cause a jumping phenomenon at the bridgehead, impacting the vehicle chassis and suspension system and increasing road safety risks [1].

2.2. Shortening the service life of the roads

Unsmooth pavement and structural deformation caused by settlement can accelerate the aging and damage of pavement materials. The stress concentration caused by the settlement will cause fatigue cracks under the action of a vehicle load. These cracks gradually expand, leading to serious issues such as road peeling and potholes, reducing the service level of the road surface, requiring frequent repairs and maintenance, and increasing the economic cost of road upkeep. Especially the asphalt pavement, under repeated settlement stress, is prone to asphalt aging and crack expansion, shortening the service life of the pavement. Subgrade settlement will damage the stability of the subgrade and lead to the decline of the overall performance of the pavement structure. The uneven settlement of pavement caused by subgrade settlement will weaken the binding force between pavement structure layers, leading to stripping between pavement layers and loose structures. This phenomenon not only reduces the carrying capacity of the road surface but also makes the road surface more likely to produce permanent deformation under the vehicle load, which further aggravates the settlement and damages of the roadbed and road surface. The decreased stability of the subgrade will also affect the effectiveness of the pavement drainage system, increase the risk of water accumulation, and accelerate the aging and damage of the pavement materials. The settlement difference between the bridge and the road will lead to uneven abutment force, produce additional stress, and increase the risk of damage to the abutment and bridge foundation [2].

3. Analysis of deformation causes of subgrade and pavement in the settlement section of a road bridge

3.1. Deformation of the back foundation

The deformation of the platform back foundation is mainly due to the uneven compaction degree. During the construction process, the compaction degree can be affected by various factors such as construction sequence, material quality, mechanical equipment, operation experience, and so on. If the compaction is insufficient or uneven, the foundation will settle under the load, making the soil structure loose, reducing its bearing capacity, and leading to the deformation and settlement of the foundation. The selection of mechanical equipment and the technical level of the operator directly impact the compaction effect. If the vibration frequency, compaction frequency, and other parameters of the compaction mechanical equipment do not meet the required specifications, it will lead to uneven compaction of the foundation. The platform back foundation is often located in the gully section, and the compressibility and water content of the foundation soil significantly affect the foundation's stability. The gully section soil has high compressibility and large water content. These characteristics will make the foundation prone to compression deformation and settlement under the action of load. When the water content of the foundation soil is high, the bonding force between the soil particles is reduced, and the bearing capacity decreases, which leads to the large settlement deformation of the foundation under the action of load. When the soil with high compressibility is subjected to an external load, its volume compression is obvious and the foundation settlement is significant. The deformation of the platform back foundation is closely related to the filling height. The higher the height of the bridge embankment filling, the greater the stress of the foundation. Consequently, the greater the filling height, the higher the probability of foundation settlement and deformation. A high filling will put the foundation under greater vertical pressure, increasing the risk of settlement [3].

3.2. Embankment deformation

Improper design of the drainage system can cause the embankment deformation. If the permanent and the temporary drainage systems are not effectively combined, the subgrade drainage is not smooth, and water accumulation increases the water content of the foundation soil, reducing its bearing capacity, and easily causing the settlement and deformation of the subgrade. If the subgrade drainage design is insufficient and the rainwater or groundwater cannot be discharged in time, it increases the foundation soil water content which decreases the bearing capacity and aggravates settlement deformation. During construction, if the poor soil on the original ground is not thoroughly removed, it can lead to settlement and deformation of the subgrade under dynamic and static loads. In the construction process of high filling embankment, if it is not operated under standard order, such as the technical specifications are not observed in the process of layered rolling, it will lead to insufficient subgrade compaction, or improper thickness control of layered filling, which causes the settlement and deformation of subgrade. If the construction materials do not meet the quality requirements, such as mixed with mud and marsh soil, large soil block, etc., the deformation problem of the embankment is aggravated. The settlement of the embankment showed significant differences under different geological conditions. On soft land foundations or high-water content, the embankment is prone to cause settlement and deformation. On hard rock foundations, the embankment deformation is small. Inadequate or improper geological investigation before construction will lead to adverse geological conditions in the construction process and increase the risk of embankment deformation. Improper foundation treatment fails to effectively improve the bearing capacity of the foundation, which will make the embankment produce large settlement deformation under the action of load [4].

3.3. Bridgehead deformation

There is a rigid and flexible structure transition between the abutment and the subgrade. The deformation characteristics of the rigid abutment and the flexible subgrade are different, resulting in the deformation differences. The abutment is usually set on the bearing layer with high bearing capacity and small foundation settlement, while the filling height of the flexible subgrade is generally high, which can cause compression deformation under the long-term weight of the bridgehead. Improper handling of the rigid and flexible transition between the abutment and the subgrade will aggravate the deformation of the bridgehead. The quality of the bridgehead back affects the deformation. The selection of fillers with high water content, large pores, and strong compressibility will produce significant compression deformation under the action of load, leading to the settlement of the bridgehead. If the construction unit treats the soft land foundation improperly or selects unqualified fillers to save the cost, it will seriously affect the quality of the later compaction operation, and lead to the settlement deformation of the bridgehead subgrade under the long-term load action. Improper foundation treatment leads to the deformation of the bridgehead, and the platform back area is often located in the river area. The soft land foundation has high water content, large porosity, and low shear strength, making it susceptible to disturbance during construction. This leads to damage to the natural structure and a decrease in strength. The high subgrade filling increases the base stress, which improves the foundation subsidence rate and causes the deformation of the bridgehead. Improper treatment of the soft land foundation with a lack of effective reinforcement measures will easily lead to the settlement and deformation of the bridgehead foundation [5].

4. Technical key points of subgrade and pavement construction in the road and bridge settlement section

4.1. Set the base plate position reasonably

When determining the position of the slab, the construction personnel shall ensure that the top surface of the slab is consistent with the top surface of the subgrade. Construction personnel should pass detailed measurements and calculations to ensure that there is no height difference between the plate and subgrade, to avoid turbulence when vehicles pass. Before the construction, accurate topographic measurements must be carried out and high-precision instruments of the whole station must be used to determine the elevation of the base plate position where the design should be adjusted according to the measurement results. During the process of connecting the plate and the road, it is necessary to appropriately raise the height of the connection end of the plate and the pavement. According to the longitudinal slope of the road and the bridge deck design requirements, the reverse slope of the base plate connecting end is calculated. Generally, the setting of the reverse slope needs to consider the smoothness of the longitudinal section of the line to avoid the impact when vehicles pass through. During construction, the height adjustment can be achieved by adding a layer of asphalt mixture or cement mixture at the connecting end of the slab to ensure a smooth connection between the slab, the bridge deck, and the road surface. The position of the slab should consider the actual use and traffic flow of the bridge. For a bridge with a large traffic flow, the design of the length and width of the plate should meet the stability and comfort requirements of vehicle use. The length of the base plate is generally determined according to the span and structure form of the bridge, usually between 5 and 10 m. The specific value should be adjusted according to the design standard of the bridge and the actual situation. The width of the slab should be the same as the width of the bridge deck to ensure that vehicles do not deviate [6].

4.2. Connecting technology of bridge abutment and base plate

The connection between the abutment and the base plate should adopt the anchor bolt technology to ensure that the two are firmly connected. The anchor should be high-strength steel. Generally, steel number 22 is used as the anchor material. The layout spacing of the anchor bolts is generally controlled at 75~80 cm, and the specific spacing should be designed according to the force situation of the abutment and the base plate. When installing the anchor bolt, drilling should be drilled at the connection position between the abutment and the base plate, and the aperture and depth should be determined according to the specifications and force requirements of the anchor bolt to ensure sufficient anchoring force after insertion. The connection between the abutment and the base plate should be fixed with a horizontal tie rod. The horizontal rod can be made of high-strength thread reinforcement where the diameter and length of the rod should be designed according to the force at the connection. When installing the horizontal rod, the rod hole should be reserved at the connection between the abutment and the base plate to ensure that the rod can pass through the joint and be fastened with nuts at both ends. After installing the rod, the tension test should be conducted to ensure that the rod has sufficient tension to resist the deformation at the connection between the abutment and the base plate. The connection between the abutment and the base slab should be waterproof to prevent rainwater from infiltrating into the connection gap and causing structural damage. Waterproof treatment can use polyurethane waterproof coating or waterproof coil material, coating or laying of waterproof materials at the connection place, to ensure the seamless connection of the waterproof layer and avoid water seepage problems. During construction, it is necessary to ensure the bonding strength and durability of the waterproof materials to prevent damage due to temperature changes or vehicle loads [7,8].

4.3. Block support technology

The platform support should be fitted with linoleum or rubber pads at the connection between the abutment and the abutment plate to ensure sufficient support and deformation capacity. The size of the oil felt or rubber bearing is generally 2 cm thick, and the specific size should be determined according to the bridge design requirements and the force of the bearing. When laying the support, ensure that the support surface is flat, without wrinkles or bumps, and that the contact surface between the support and the abutment and the plate is uniform. The spacing between the supports should be strictly controlled at about 80 cm. The design of support spacing should comprehensively consider the force situation and deformation requirements of the connection between the abutment and base plate, to ensure that the bearing can evenly distribute the load and avoid local stress concentration. During construction, it is necessary to use accurate measuring tools to measure and adjust the support spacing to ensure it meets the design requirements. Protect the support to prevent damage during construction. Construction personnel should avoid heavy object stacking or mechanical operation on the support to prevent support deformation or damage. After the laying of the support, protection measures should be carried out in time, such as covering the protective film or support frame, to prevent the support from being damaged by external forces [9].

4.4. Chamfer technique

The contact position of the platform end and the bull leg is designed to be chamfered, which can reduce the turbulence and vibration of vehicles. The design of the chamfer should be carried out according to the bridge structure and vehicle driving conditions. Commonly, the angle of the chamfer is between 15° and 30°. During the chamfering construction, the concrete cutting machine or grinding machine can be used to cut and polish the platform end to ensure that the chamfer angle and surface flatness meet the design requirements. Chamfer construction should be closely combined with foundation treatment, drainage design, pavement material selection, and other links. Foundation treatment should ensure that the foundation at the chamfered position has sufficient bearing capacity and stability to prevent foundation settlement from affecting the effectiveness of the chamfering. The drainage design should set up an effective drainage system in the chamfered position to prevent rainwater accumulation at the chamfer, which may lead to road sliding or structural damage. The pavement material selection should consider the durability and skid resistance of the chamfer to ensure the safety and comfort of vehicles when passing. After the completion of the chamfer construction, a quality inspection should be conducted to ensure that the angle and surface flatness of the chamfer meet the design standards. Quality testing can use a laser measuring instrument or level instrument to measure the chamfer angle and surface flatness, ensuring that the construction quality meets the requirements. During the testing process, if the chamfer angle or surface flatness is found to not meet the standard, it should be corrected in time to ensure that the construction quality meets the design requirements [10,11].

4.5. Joint treatment technology

A gap of a certain width will be formed at the connection of the base plate and the bridge abutment. To avoid leakage problems in the gap, reasonable technology is needed to carry out joint treatment. Usually, asphalt catkins, glass fiber, and other materials can be used to fill the gap. During construction, the filling materials should be evenly distributed into the gap to ensure that the filling is dense and free of voids. Filling materials should have good durability and waterproof performance, and can be kept stable for long-term use. The joint treatment requires heating asphalt filling to improve the sealing effect of the gap. Heating asphalt pouring requires special heating equipment to heat the asphalt to the appropriate temperature, and then evenly pour into the filling material. During the perfusion process, the asphalt should be ensured that the gap is filled and closely combined with the filling material to avoid leakage or uneven filling. After perfusion, cooling and curing should be performed to ensure that the asphalt forms a stable sealing layer with the filling material. Seal and durability testing should be performed after joint treatment. The water tightness test can be used to assess the water tightness of the seal. Durability testing can test the joints by simulating vehicle loads and environmental changes to ensure that they remain stable for long-term use. During the testing process, if the sealing or durability is found to not meet the standard, the repair and reinforcement should be made promptly to ensure that the joint treatment quality meets the design requirements [12–15].

5. Epilogue

The continuous optimization and improvement of subgrade and pavement construction technology of road and bridge settlement sections helps improve the engineering quality and prolong the service life. Through scientific foundation treatment, reasonable structural design, and the application of high-quality materials, the settlement and deformation can be effectively avoided, and a smooth transition between bridge and road can be guaranteed. In future engineering practice, it is necessary to continuously pay attention to the application of new technologies and new materials, constantly improve the construction methods and quality control measures, provide more reliable and durable technical support for road and bridge engineering, and promote sustainable development of transportation infrastructure.

Disclosure statement

The author declares no conflict of interest.

References

[1] Lou P, Li Y, Xiao H, et al., 2022, Influence of Small Radius Curve Shield Tunneling on Settlement of Ground Surface and Mechanical Properties of Surrounding Rock and Segment. Applied Sciences, 12(18): 9119.

[2] He J, Liao S, Tan Y, et al., 2022, Analytical Study on the Ground Settlement Induced by Pipe-Roof Tunnelling Considering the Interaction between Socketed Pipes. KSCE Journal of Civil Engineering, 27(1): 417–430.

[3] Tavallaienejad A, Salari H, Behnia C, et al., 2022, Comparative Study on the Design Process of a Shallow Subway Station Isfahan Metro, Iran, Based on Risk Assessment. Indian Geotechnical Journal, 53(3): 562–582.

[4] Zhang J, Cheng Z, 2022, Prediction of Surface Subsidence of Deep Foundation Pit Based on Wavelet Analysis. Processes, 11(1): 107.

[5] Abbasi SJ, Weng X, Iqbal MJ, 2024, Numerical Analysis of Differential Settlement in Road Due to Widening Considering Different Reinforcement Techniques. Applied Sciences, 14(5): 1740.

[6] Chen S, Cui J, Liang F, 2022, Centrifuge Model Investigation of Interaction between Successively Constructed Foundation Pits. Applied Sciences, 12(16): 7975.

[7] Jang J, Lee JY, Redwan M, et al., 2023, Hydrogeological characteristics and water chemistry in a coastal aquifer of Korea: implications for land subsidence. Environmental Monitoring and Assessment, 195(11): 1289.

[8] Chen R, Zhou X, Yu M, et al., 2023, Bayesian updating for ground surface settlements of shield tunneling. Frontiers in Earth Science, 11: 1–12.

[9] Ma B, Wu S, Chen Q, et al., 2024, The influence of existing piles on station settlement during the construction of a tunnel undercrossing under existing stations. Scientific Reports, 14(1): 14024.

[10] Hu T, Xu J, 2024, Prediction of Buildings' Settlements Induced by Deep Foundation Pit Construction Based on LSTM-RA-ANN. Applied Sciences, 14(12): 5021.

[11] Cai G, Zou X, Zhang Q, et al., 2023, Performance of the suspension method in large cross-section shallow-buried tunnels. High-Speed Railway, 1(4): 224–232.

[12] Park S, Kim DS, Kim U, et al., 2022, Low Compressibility at the Transition Zone of Railway Tracks Reinforced with Cement-Treated Gravel and a Geogrid under Construction. Applied Sciences, 12(17): 8861.

[13] Mei Y, Zhou D, Shi W, et al., 2022, Laws and Numerical Analysis of Surface Deformation Caused by Excavation of Large Diameter Slurry Shield in Upper-Soft and Lower-Hard Composite Stratum. Buildings, 12(9): 1470.

[14] Gao X, Tian W, Pang Q, et al., 2023, Analysis of the response subsidence and grouting treatment in the goaf of multi-layer inclined coal seam. Scientific Reports, 13(1): 20711.

[15] Hu D, Zhou R, Xiao L, et al., 2023, A Supershallow Buried Large-Span Rectangular Pipe Jacking Tunnel Undercrossing an Expressway: Construction Method, Monitoring Results, and Numerical Simulation. International Journal of Civil Engineering, 22(5): 757–771.

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Research on the Spatio-Temporal Evolution and Driving Forces of Green Spaces in the Central Urban Area of Zunyi City

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Abstract: Green space, as a medium for carrying out urban functions and guiding urban development, is becoming a scarce resource along with the urbanization process and the intensification of environmental problems. In the face of the spatial mismatch between high demand and low supply, it is of great significance to clarify the evolution mechanism of green space to undertake national spatial planning, protect the natural strategic resources in the urban fringe area, and promote the sustainable development of the "three living spaces." The study focuses on the Zunyi City Center, selecting the 20 years of rapid development following its establishment as a city as the study period. It explores the dynamic evolution of green space and the main driving forces during different periods using remote-sensing image data. The study shows that from 2003 to 2023, the total scale of green space has an obvious decreasing trend along with the expansion of the urban built-up area. A large amount of arable land is being converted to construction land, resulting in a sudden decrease in arable land area. In the past 10 years, the comprehensive land use dynamics have accelerated. Still, the spatial difference has gradually narrowed, indicating that the overall development intensity of Zunyi City's central urban area has increased. There is a gradual spread of the trend to the hilly areas. The limiting effect of the mountainous natural environment on the city's development has gradually diminished under the superposition of external factors, such as economic development, industrial technological upgrading, and policy orientation so the importance of the effective protection and rational utilization of urban green space has become more prominent.

Keywords: Green space; Spatio-temporal evolution; Driving force; Zunyi city center

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1. Introduction

The construction of a national spatial planning system is an important task in the construction of China's ecological civilization system, and the delineation of "three zones and three lines" is a core policy tool based on the spatial planning system for all-area and all-type of use control [1]. Green space, as the carrier of all elements of "mountains, water, forests, fields, lakes, and grasses," is an important component of national spatial planning and an ecological base on which urban development depends. It provides multiple irreplaceable services such as supplying resources, improving the environment, and maintaining social stability [2–6]. In recent years, the attention to urban green space research locally and internationally has been increasing year by year. It has become a hot area in which multiple disciplines are involved, especially the quantitative research on green space patterns based on remote sensing images and Geographic Information System (GIS) spatial analysis has made great progress, among which, the analysis of spatial and temporal evolution of green space under the acceleration of the urbanization process is the basis for quantitative research [7–10]. Since the study of the spatial and temporal evolution of green space patterns has important reference value for curbing the disorderly expansion of small and medium-sized cities and promoting their development transformation, this paper takes Zunyi, a provincial sub-center city in Southwest China, as the object of the study, and conducts a periodical comparison study on the rapid transformation process of the green space of the central city in the past 20 years with the help of remote sensing data and reveals the influence of the green space on the urbanization process. Based on the results of the analysis, the driving forces affecting the evolution of green space are revealed to provide a basis for the rational planning of Zunyi's urban ecological structure.

2. Overview of the study area

Zunyi is located in the northern part of Guizhou Province, at the southern foot of Dalou Mountain and the northern bank of the Wujiang River. It is one of the major towns in western China and belongs to the main area of comprehensive development and construction in the middle and upper reaches of the Yangtze River as planned by the state. Zunyi abolished the county and established it as a city in 2000, with a total area of 30,762 km^2. The planning scope of the central urban area has been increased from 216 km^2 as determined by the city general plan in 2000 to 515 km^2 in 2010, and to 1003 km^2 in 2016. In the past 20 years, the population of the central city has increased by nearly five times to 1.3 million, making it the area with the most obvious expansion of construction land and the most serious erosion of green space.

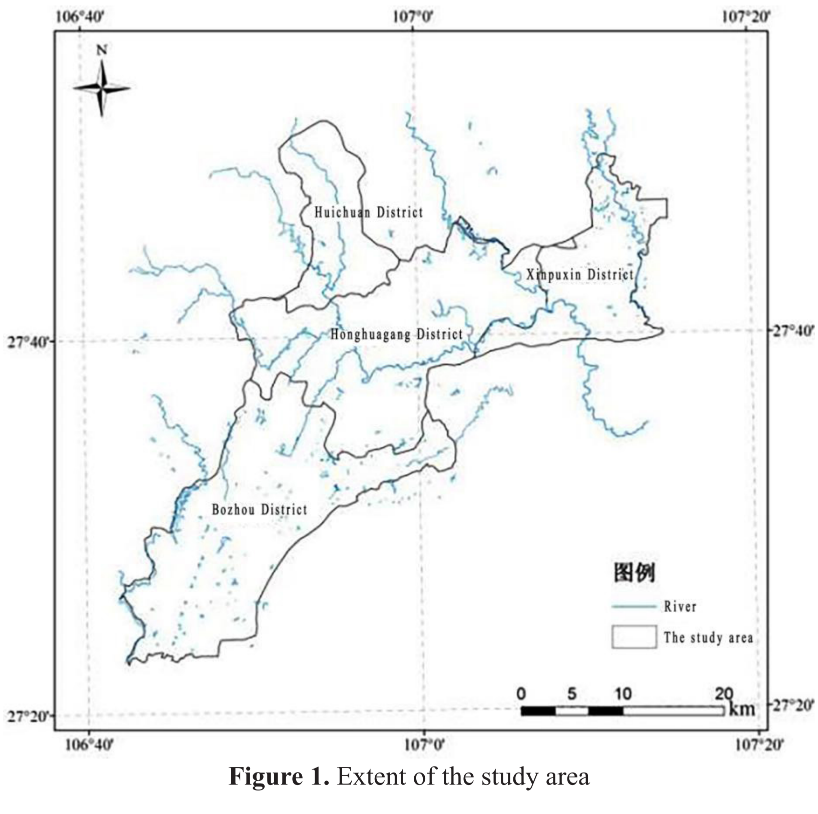

Figure 1. Extent of the study area

3. Data sources

3.1. Remote sensing data acquisition

The remote sensing image data used in this paper were downloaded from the United States Geological Survey (USGS) website for free of charge according to the strip number (path: 127, row: 41), LandsatTM5 data in 2003 and 2013, and LandsatTM8 data in 2023, with the spatial resolution of 30 m × 30 m. In addition, the 30 m resolution of the Digital Elevation Model (DEM) data and Zunyi City administrative map were downloaded through the geospatial data cloud platform of the Chinese Academy of Sciences (CAS) Computer Network Information Center which was supplemented with the interpretation of remote sensing images in combination with the field research data.

3.2. Research methodology

3.2.1. Classification and Decoding

Firstly, the geometric correction, radiometric correction, and atmospheric correction preprocessing procedures were carried out on the ArcGIS10.0 software platform for the 3-phase remote sensing images, and the error of the geometric correction was controlled within 0.5 image elements by the resampling verification method. Secondly, from the actual situation of land use types in Zunyi City, the study area was categorized into two major categories, urban space, and green space, according to the research intention (Table 1). With the help of ENVI5.0 software, the 3-phase remote sensing image maps were categorized using the maximum likelihood supervised classification method based on the established image decoding flags. Finally, the classification results were evaluated by establishing the confusion matrix between each type, and the overall classification accuracy reached more than 90%, with Kappa coefficients ranging from 83.29% to 93.48%, which satisfied the requirements of this study.

Table 1. Spatial classification system of remote sensing image data

First classification	Secondary classification	Contents
Green space	Woodland	Refers to the growth of trees, shrubs, bamboo, and herbaceous plants on the land, which includes tree woodland, shrub woodland, bamboo woodland, pastureland, swamp grassland, and other types of land. It also encompasses parks' green space, green protection space, green space in plazas, accessory green space within urban construction land, and green spaces in urban and rural areas outside of the urban construction land. These areas serve to protect the ecological environment, natural resources, and cultural resources, and provide open space for fitness, security, isolation, species protection, garden seedling production, and other functions.
	Plow land	Refers to land primarily planted with agricultural crops, including vegetables, with sporadic fruit trees or other trees. This includes paddy fields, dry lands, irrigated lands, orchards, tea gardens, other gardens, and other land types.
	Body of water	Refers to natural land of waters and water facilities, including rivers, lakes, reservoirs, ponds and mudflats, ditches, marshes, and other types of land.
Urban space	Building site	Refers to land used for residential living, commerce, services, industrial production, material storage, public administration, public services, transportation, and special functions.

Source: Organized according to Classification of Land Use Status (GB/T21010-2017) [11] and Urban Green Space Classification Standard (CJJ/T85-2020) [12].

3.2.2. Land-use transfer analysis

Using the Markov model to calculate the land use state transfer matrix can comprehensively reflect the area transfer between each land type and with the construction land in different periods [13]. Based on this, the spatial transfer distribution map of each land use type in Zunyi City Center is produced, to specifically portray the direction of land use change guided by urban construction.

$$S_{ij}=\begin{bmatrix} S_{11} \cdots S_{1n} \\ \vdots \ddots \vdots \\ S_{n1} \cdots S_{nn} \end{bmatrix} \quad (1)$$

where S_{ij} denotes the total area transferred from land class i to land class j during the study period and n is the number of transfers during the study period.

3.2.3. Degree of change in land-use dynamics and spatial variation

The attitude of a single land category can quantitatively reflect the speed of land use dynamics in green space, but it cannot characterize the spatial difference of the phenomenon of strong and weak changes in land use. Thus, with the help of ArcGIS, the 3-period remotely sensed interpretation of classification maps was divided into grids of grid size of 2 km × 2 km, according to the size of the study area divided into grids of 314, and then the Excel software was used to sum up the amount of change in the area of each land category within each grid, and then analyze the statistical characteristics of the annual integrated rate of change of all land categories in different periods. Using Excel software, to sum the amount of area change of each land category in each grid, count the comprehensive dynamic attitude of land use in each grid, and analyze the statistical characteristics of the annual comprehensive rate of change of all land categories in different periods. Then using the Kriging interpolation method, interpolate the spatial localization, and produce a spatial distribution map of the change of the comprehensive dynamics of land use in the Zunyi downtown area in different periods. This map was used to visualize the regional differences in land use changes.

The integrated dynamic variability formula [14]:

$$K =_s \sum_{i=1}^{n} \left| U_b - U_a \right| \times 2 \sum_{i=1}^{n} U_a \times T^1 \times 100\% \quad (2)$$

Where U_a *and* U_b denote the area of a land type at the beginning and the end of the study period respectively, T is the length of the study period, and n is the number of land use types.

4. Results and analysis

4.1. Dynamic evolution of the size of green space land classes

As can be seen from **Figure 2**, Zunyi City Center in the withdrawal of land after the establishment of more than twenty years, along with the continuous advancement of urbanization, the built-up area of the city is a continuous rapid expansion trend, while the green space in the process of urban radial expansion is constantly being eaten up. From as high as 97% of the space in 2003 accounted for a decline of 83% in 2023, of which the cuts in arable land area are the most dramatic, along with the area of forests and grasslands and waters in this period. There are different degrees of increase, but the rise is relatively small. It is also worth noting that in the northwest, northeast, and southwest directions of the city, the urban space stretches towards the mountainous areas, resulting in the fragmentation of forest and grassland with relatively high vegetation cover.

As shown in **Table 2**, during the decade of 2003 to 2013, the area of forest and grassland, water, and construction land all show a small growth trend and only the cultivated land is significantly less, which shows that the new forest and grassland, construction land and water are mostly converted from the cultivated land on the outskirts of the city. Additionally, the expansion of urban space in this period depends on the extension of the river valley and the axis of the traffic trunk line, mainly manifested as the continuous filling along both sides of the axis. 2013 to 2023 is the rapid economic and social development of Zunyi city in the past 10 years, manifested as a drastic change in the area of the green space and the construction space. The loss of a large amount of green space, which is still the largest reduction of cultivated land, and the area of the forested meadow has also appeared to decrease slightly, indicating that in the past 10 years, the area of construction land has also shown a small increase. This indicates that the expansion of construction land in the past 10 years has caused double coercion on cropland and forest grassland, and urban construction has gradually spread to the surrounding mountains and forests.

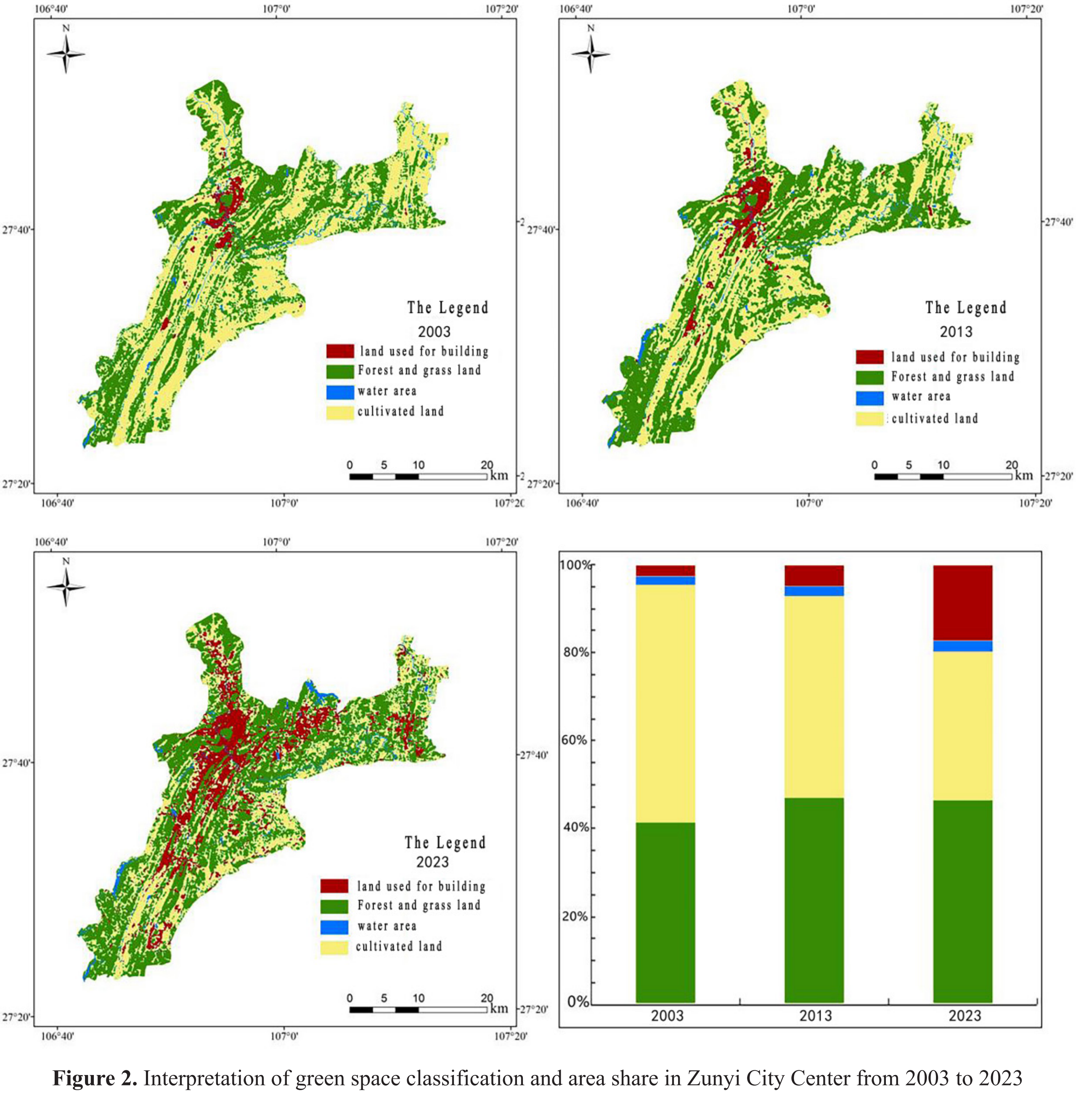

Figure 2. Interpretation of green space classification and area share in Zunyi City Center from 2003 to 2023

Table 2. Area change of green space and urban construction space in Zunyi City Center from 2003 to 2023

Year / The twelve two-hour divisions of the day	Area proportion	Woodland	Plow land	Body of water	Building site	Total	
						Green space	Urban space
2003	Area (km^2)	415.01	540.48	20.87	26.38	976.36	26.38
	Percentage (%)	41.39	53.90	2.08	2.63	97.37	2.63
2013	Area (km^2)	471.57	458.78	23.96	48.42	954.31	48.42
	Percentage (%)	47.03	45.75	2.39	4.83	95.17	4.83
2023	Area (km^2)	466.09	337.67	25.31	173.67	829.07	173.67
	Percentage (%)	46.48	33.67	2.52	17.32	82.68	17.32
2003-2013	Incremental (km^2)	56.56	-81.7	3.09	22.04	-22.05	22.05
	Incremental (%)	13.63	-15.12	14.81	83.55	-2.26	83.59
2013-2023	Incremental (km^2)	-5.48	-121.11	1.35	125.25	-125.25	125.25
	Incremental (%)	-1.16	-26.40	5.63	258.67	-13.12	258.67

4.2. Dynamic evolution of green space land category transfer

From **Table 3** and **Table 4**, it can be seen that green space decreased from 238.6 km^2 to 216.56 km^2 between 2003 to 2013, indicating an increase of 22.04 km^2 in 10 years. The largest conversion was from cultivated land to construction land, and the transfer from green space to construction land increased by 125.26 km^2 between 2013 and 2023, becoming the main source of new construction land. During this period, the increase in construction land primarily resulted from the encroachment of arable land. However, compared to the previous period, the amount of forest and grassland converted to construction land has increased significantly, while the amount of arable land has decreased, resulting in the shrinkage of arable land area and a slight decrease of forest and grassland area. Watersheds experienced a greater net transfer into than out of land compared to other categories in both periods, resulting in a significant increase in their area.

Table 3. Transfer matrix of green space and urban construction space land categories in Zunyi City Center, 2003 to 2013 (unit: km^2)

Classification Plow land		Green space			Urban space	Transferred area	Change in area
		Plow land	Woodland	Body of water	Building site		
Green space	Plow land	387.53	128.57	6.07	18.31	152.95	-81.69
	Woodland	63.91	338.77	5.98	6.35	76.24	56.56
	Body of water	5.09	3.52	11.46	0.80	9.41	3.09
Urban space	Building site	2.26	0.71	0.45	22.96	3.42	22.04
Transferred area		71.26	132.8	12.5	25.46	-	-

Table 4. Transfer matrix of green space and urban construction space land categories in Zunyi City Center, 2013 to 2023 (unit: km^2)

Classification Plow land		Green space			Urban space	Transferred area	Change in area
		Plow land	Woodland	Body of water	Building site		
Green space	Plow land	251.88	108.19	6.43	92.29	206.91	-121.12
	Woodland	79.61	352.67	4.51	34.79	118.91	-5.49
	Body of water	3.31	3.97	14.05	2.64	9.92	1.35
Urban space	Building site	2.87	1.26	0.33	43.96	4.46	125.26
Transferred area		85.79	113.42	11.27	25.46	-	-

4.3. Dynamic evolution of green space land-use categories

As shown in **Figure 3**, although the dynamic change rate of all land classes in the Zunyi City Center urban area was faster, the spatial difference in land use changes was greater during the 10 years from 2003 to 2013indicating localized areas of rapid change. From 2013 to 2023, the spatial distribution of these dynamic changes showed an irregular circular diffusion pattern with a continuous and contiguous trend. While overall land use exhibited rapid changes, the spatial differences in these changes gradually narrowed, primarily characterized by the transformation of green space across categories and a significant transfer of land to construction.

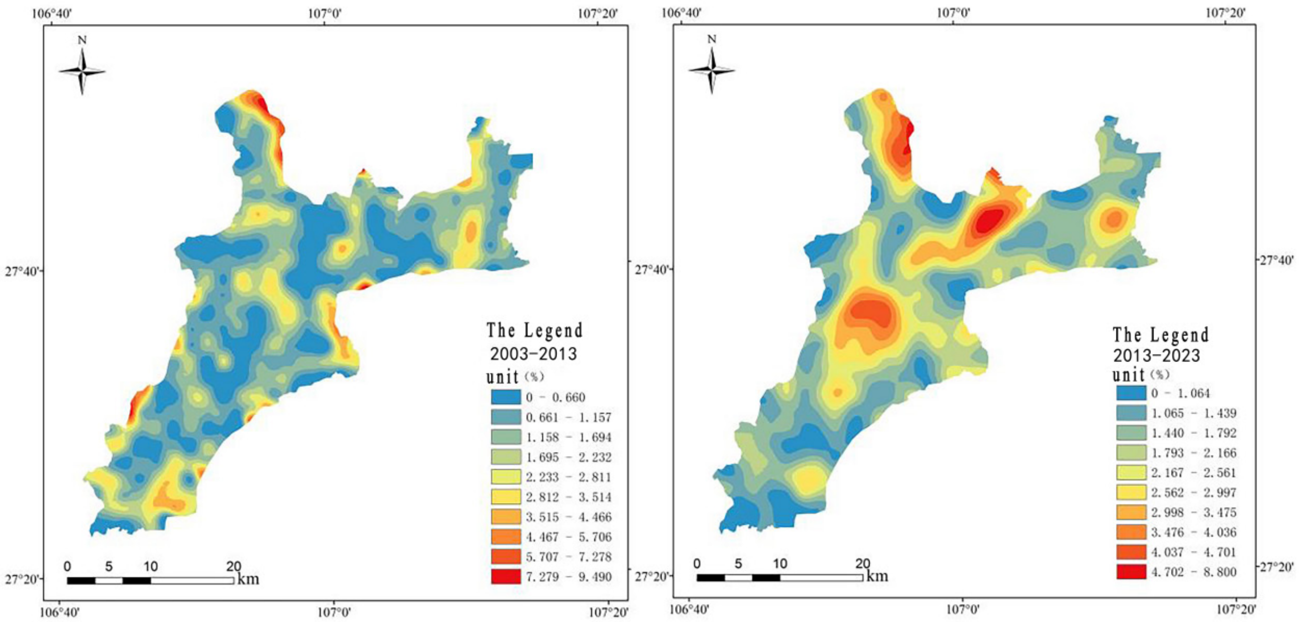

Figure 3. Spatial distribution of comprehensive dynamic changes in land use in the central urban area of Zunyi City Center, 2003 to 2023

4.4. Analysis of the driving forces influencing the dynamics of green spaces

4.4.1. Natural environmental factors are binding for the evolution of green space

Zunyi, as a typical mountainous city characterized by "eight mountains, one water, and one field," has a mountainous area accounting for 64.3% of the land, a hilly area accounting for 29.4%, and flat dams and river basins comprising only 6.3% of the land area [15]. The undulating topography and complex geomorphology are the main constraints on the city's development. Urban construction initially utilizes gently sloping areas and gradually transforms the complex terrain. Steep slopes and highlands with high construction costs have become restrictive areas, inhibiting uncontrolled growth. Consequently, urban expansion exhibits a pattern of clustered development, contrasting with the "sprawling" development typical of flat cities. Over time, urban construction has increasingly filled in valley basins and spread into hilly areas, causing trends in the hilly areas to align more closely with those in the valley basins. This indicates that urban construction efforts intensifying and the relationship between urban construction and green space shifting from benign interaction to competitive conflict.

4.4.2. Economic and technological factors as enablers of green space evolution

In just over 20 years since its withdrawal as a city, Zunyi has rapidly transitioned from early industrialization to the middle to last stages of development. This catch-up development mode has driven high-speed economic growth. However, as the level of urbanization exceeds 50%, the environmental crisis caused by incremental city development at the expense of green space has become increasingly prominent. Entering the post-industrial development stage, the city's outward expansion trend slows, shifting focus to the adjustment and optimization of internal functions. This shift encourages a deceleration in crude development, leading Zunyi to gradually prioritize improving the city's overall quality rather than solely pursuing economic growth.

4.4.3. Policy regulatory factors as a pulling force in the evolution of green space

In recent years, high-quality development under the leadership of ecological civilization has gained national consensus, and Zunyi has recognized the crucial role of the ecological environment in industrial growth. To reduce the high dependence on urban expansion and natural resource consumption, effective policy regulation is key to the city's transformation [16,17]. In 2019, Zunyi City established the Bureau of Natural Resources to implement the central, provincial, and municipal guidelines and policies on natural resource management. This marked a new stage in Zunyi's governance of its "mountains, water, forests, fields, lakes and grass" community life system. However, Zunyi faces challenges due to a lack of traditional ecological planning, ineffective implementation and monitoring mechanisms, and prominent multi-sectoral management conflicts. Local exploration is just beginning, and the city must also address the central government's changing regulations and market-oriented adjustments. Consequently, planning will encounter more problems and challenges in allocating green space, increasing efficiency, improving quality, and coordinating rights and interests.

5. Conclusion and discussion

(1) Based on multi-temporal remote sensing data, we extracted quantitative information on green space in Zunyi City Center for three periods by using Remote Sensing (RS) and GIS technology and conducted a comparative analysis of two time periods from 2003 to 2023 in terms of the scale of land use, transfer of land use, and utilization of land use. The results show that the total scale of green space has been decreasing significantly along with the expansion of the built-up area of Zunyi City in the past two decades after it was established. In particular, the intensity of urban expansion in the last decade has increased by 5.16 times compared with that of 10 years ago. Arable land has been transferred to construction land in large quantities, resulting in a sudden decrease in the area of arable land. There are frequent transitions between categories in green space, and the rate of increase and growth of construction land is the most significant.

(2) From the analysis of the green space evolution process in Zunyi City Center in the past 20 years, it can be seen that the green space is a complex territorial system coupled with nature and various socio-economic elements, and the natural environment, economic technology, and policy regulation are the main driving forces affecting the evolution.

Disclosure statement

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References

[1] Sun X, 2023, Basic Considerations of "Three Zones and Three Lines" in the National Spatial Planning System. Urban Planning, 47(06): 51–56 + 88.

[2] Andren H, 1994, Effects of Habitat Fragmentation on Birds and Mammals in Landscapes with Different Proportions of Suitable Habitat: A Review. Oikos, 71(3): 355.

[3] Sullivan WC, Jiang B, 2024, Urban Green Space as a Force for Change: Global Wisdom and Chinese Perspectives. Chinese Garden, 40(01): 6–13.

[4] Peschardt KK, Stigsdotter UK, 2013, Associations between Park Characteristics and Perceived Restorativeness of Small Public Urban Green Spaces. Landscape and Urban Planning, 112: 26–39.

[5] Peschardt KK, Schipperijn J, Stigsdotter UK, 2012, Use of Small Public Urban Green Spaces (SPUGS). Urban Forestry and Urban Greening, 11(3): 235–244.

[6] Saphores JD, Li W, 2012, Estimating the Value of Urban Green Areas: A Hedonic Pricing Analysis of the Single Family Housing Market in Los Angeles, CA. Landscape and Urban Planning, 104(3/4): 373–387.

[7] Yang Z, Zhang H, Ding Y, et al., 2015, Content and Prospect of Urban Green Space Research. Progress in Geoscience, 34(1): 18–29.

[8] Tao Y, Li F, Wang R, et al., 2016, Research Progress on Quantitative Methods of Urban Green Space Pattern. Journal of Ecology, 33(8): 2330–2342

[9] Xu XG, Duan XF, Sun HQ, et al., 2011, Green Space Changes and Planning in the Capital Region of China. Environmental Management, 47(3): 456–467.

[10] Li F, Jie S, Li X, 2018, Research on the Spatiotemporal Evolution of Green Space in the Central City of Beijing Based on Multi-Source Data Analysis (1992–2016). Landscape architecture, 25(08): 46–51.

[11] Ministry of Natural Resources of the People's Republic of China, 2017, Organized according to Classification of Land Use Status, GB/T21010-2017.

[12] Ministry of Construction of the People's Republic of China, 2018, Urban Green Space Classification Standard, CJJ/T85-2020.

[13] Zhu H, Li X, 2003, Discussion on the Methodology of Regional Land Use Change Index Modeling. Journal of Geography, 58(5): 643–650.

[14] Zhang L, Yang G, Liu J, 2014, Analysis of Land Use Dynamic Changes and Hotspots in Fushun City from 1986 to 2012. Journal of Geography, 34(2): 185–191.

[15] Construction Committee of Zunyi City, 1993, Urban Construction Annals of Zunyi City, Zunyi People's Publishing House, 1993: 1176–1989.

[16] Lin J, Song M, Zhang A, 2018, Functional Positioning and Implementation Analysis of National Spatial Planning. China Land, 4(01): 15–17.

[17] Zhang T, 2014, The Coordination Role of Planning and the Challenges Faced by Chinese Planning. Urban Planning, 38(01): 35–40.

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Discussion on Cost Budgeting and Cost Control Strategies for Prefabricated Construction Projects

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Abstract: In the process of China's national economic development, the construction industry is a very important component and has a direct impact on the level of China's economic construction. Nowadays, the development speed of the prefabricated construction industry is constantly accelerating. To effectively ensure the economic benefits of engineering projects, it is necessary to comprehensively strengthen cost budgeting and cost control. This article analyzes the cost budget of prefabricated construction projects, introduces the application advantages of prefabricated construction, and proposes specific cost budgeting and cost control measures, hoping to provide some reference for relevant researchers.

Keywords: Prefabricated building; Engineering cost budget; Cost control

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1. Introduction

With the rapid development of the modern construction industry, the application of prefabricated buildings has become more widespread. They have significant application advantages by not only simplifying construction processes but also having good energy-saving effects, which can further promote the sustainable development of the construction industry. In the process of carrying out prefabricated construction projects, to effectively ensure the investment benefits of the project, relevant construction enterprises need to do a good job in cost budgeting, increase cost control efforts, strictly control cost expenditures, ensure the special use of funds, and avoid resource waste problems, thus improving the cost management level of the project, enhancing the economic benefits of construction projects, and effectively promoting the healthy development of China's prefabricated construction industry.

2. The application advantages of prefabricated construction engineering

Regarding the analysis of prefabricated construction projects, relevant construction companies need to produce building components in advance in the production plant area according to specific design requirements before carrying out the actual project. Then, the prefabricated components should be transported to the construction site and assembled according to specific requirements. Afterward, the relevant construction personnel need to use concrete or grout anchors to effectively connect the prefabricated components and ensure that they meet the construction standards. In the construction of prefabricated building projects, relevant components include walls, floors, beams, columns, and other parts. It is necessary to ensure that they meet the construction standards of residential buildings, effectively improve the application rate of components, and achieve a rate exceeding 53%. Adopting this architectural form can shorten the construction period, reduce labor consumption during construction, and further ensure the quality of prefabricated building construction. Therefore, the application advantages are very significant. However, when applying this type of architectural form, due to the influence of relevant factors, there are still some problems in cost management, and the advantages of cost budgeting have not been effectively reflected. In this regard, relevant personnel need to fully analyze the main factors affecting project cost, comprehensively strengthen cost budgeting work, effectively control construction costs, and thus improve the overall construction efficiency of prefabricated buildings [1].

3. Control strategies for cost budgeting of prefabricated construction projects

3.1. Optimize design drawings

For prefabricated construction projects, it is essential to do a good job of drawing design before construction starts and arrange cost personnel to fully study the design drawings. Based on the instructions of the design drawings, combined with the overall plan, and other factors, it is crucial to ensure a full grasp of the content of the drawings. This can better determine the dimensions and improve the installation quality of the components. After optimizing the design drawings, it is vital to fully utilize materials to prevent cost waste. In addition, during the meeting review process, it is required to determine the changes made to the drawings and supplement their content to effectively control component costs. For example, in the specific design work, if the components are not properly divided, it will have an impact on the transportation of the components, increasing tower crane costs, a decrease in material utilization, and ultimately a waste of resources [2].

3.2. Improve the construction plan

In the construction process of prefabricated buildings, it is necessary to conduct an in-depth analysis of the design drawings and develop a reasonable construction plan. For project cost budget management and control, by determining the construction plan, the efficiency of project construction can be effectively improved, and the quality of project construction can be enhanced. During on-site construction, it is imperative to effectively process and install components to enhance the management and control of project costs. At the same time, relevant construction companies should also allocate professional construction personnel to ensure that they fully inspect the construction site, clarify the construction process, and effectively improve the rationality and accuracy of the project cost budget. After clarifying the construction plan, it is fundamental to use it as a reference and strictly implement it to prevent operational errors [3].

3.3. Prepare a bill of quantities

In the process of cost budget management for prefabricated construction projects, it is essential to accurately prepare a bill of quantities to strengthen cost control. For prefabricated buildings, they have certain particularities. Therefore, before actual construction, relevant construction personnel should have a clear understanding of the structural technology and clarify the relationship between components and cast-in-place parts. This can better implement budget control work. For example, cost management work for stacked and floor slabs involves the procurement and transportation of finished products, as well as effective lifting. During the construction process of the steel reinforcement body, relevant personnel should calculate the amount of steel reinforcement work, with the thickness of the concrete formwork as the main indicator, to accurately calculate the amount of formwork used. In this process, it is crucial to combine the process flow and accurately calculate the cast-in-place height. For composite beams, it is fundamental to clarify the precast thickness, cast-in-place layer thickness, and slab thickness, and construct a reasonable model to determine the beam height and cast-in-place height [4].

3.4. Material price control

In the cost budgeting work of prefabricated buildings, to effectively control the project cost, it is necessary to pay more attention to the cost of prefabricated components, strengthen their price control, and ensure reasonable inquiry and pricing. Nowadays, with the continuous acceleration of the development pace of China's construction industry, the production technology level of prefabricated components has also been significantly improved, and many new materials have emerged, which has also increased the difficulty of market inquiry. In this regard, relevant construction companies should establish an inquiry team to effectively implement the secondary deepening design, and based on specific circumstances, make tentative material prices, to scientifically and reasonably prepare a bill of quantities and improve the control level of project cost.

3.5. Effective cost budget planning

In prefabricated construction projects, to effectively control the cost budget, the level of project cost should be reasonably controlled. For prefabricated construction projects, when their cost is high, it is vital to conduct an in-depth analysis of the main reasons for increasing their cost and implement targeted control measures. Generally speaking, compared to cast-in-place concrete construction, prefabricated buildings incur production, transportation, and miscellaneous expenses during the construction period. Therefore, in actual management and control of construction costs, it is crucial to accurately calculate the costs of materials, machinery, and labor, and combine them with market changes to effectively summarize the changes in market prices and accurately predict their future prices. To improve the cost budget level, it is also required to reasonably compress the cost of raw materials, which can reduce the budget.

3.6. Establish a sound cost budget review system

Based on the analysis of the current situation of budget review work in prefabricated construction enterprises, it can be found that the review system of some enterprises is not yet perfect, and they do not have a correct understanding of the importance of review work. Specifically, for engineering projects, it is necessary to ensure their effective creation of benefits and achieve maximum benefits to effectively enhance the investment efficiency of the project. By improving the cost budget review system, it is possible to ensure the orderly conduct of pre-settlement review work, effectively play the important role of review work, and further enhance the level of engineering cost budget management. Therefore, in the context of the rapid development of the market economy, relevant construction enterprises need to pay more attention to budget review and improve the relevant review system to enhance their competitiveness and effectively ensure the scientificity and practicality of cost budgeting. In the actual construction of the budget review system, the first step is to prepare well, ensure the acquisition of complete information materials, and verify the authenticity of the materials. Secondly, in the early stage of the audit work, it is mandatory to fully consider the construction process, construction technology, and building scale based on the specific construction status of the project, to reasonably determine the budget audit method and improve the quality and efficiency of the audit work.

3.7. Improve the professional competence of budget personnel

For budget auditors of construction companies, it is required to effectively enhance their professional competence. In this regard, relevant audit departments need to organize staff to effectively carry out professional training activities, ensure their effective learning of professional knowledge and skills, effectively improve the quality of budget audit work, and ensure accurate audit results. At the same time, relevant construction companies should effectively enhance the work awareness of auditors and improve their work level.

Firstly, it is imperative to enhance the practical application ability of auditors in information technology. At the current stage, relevant construction companies have effectively applied various information software, and it is vital to ensure that auditors can operate this software correctly. Therefore, it is crucial to strengthen training in information technology operations, so that they can improve the efficiency of accounting work.

Secondly, it is essential to effectively cultivate the professional skills of auditors to ensure that they fully grasp the main content of budget review and can efficiently carry out accounting work. Finally, it is obligatory to fully integrate various types of engineering information. For example, after retrieving the engineering quantity, its authenticity should be verified to ensure that on-site visa work can be carried out in an orderly manner [5].

4. Cost control strategies for prefabricated construction projects

For prefabricated construction projects, it is necessary to comprehensively strengthen construction management work, to effectively improve the effectiveness of construction projects and control construction costs from multiple perspectives. In construction engineering, it is necessary to effectively ensure the construction quality and application effect, ensure that the later application of the building can meet relevant standards, and thus improve the cost control level of the engineering project. In prefabricated construction, it is vital to continuously improve the production technology level of its components, and optimize the production mode reasonably, to reduce production costs. Specifically, to effectively control the cost of prefabricated construction projects, it is vital to start from the following aspects.

4.1. Cost control during the engineering design phase

For prefabricated buildings, it is necessary to effectively deepen component design during the engineering design phase. In the implementation process of engineering projects, it is essential to select multiple prefabricated solutions. At this time, it is mandatory to compare and optimize the design work from the perspectives of economy, technology, and other aspects to improve its completeness and further ensure the feasibility of the solutions. For prefabricated components, it is required to effectively deepen the drawings and complete the processing and production of the components to ensure the accuracy of component manufacturing, to effectively control project costs. In actual design work, it is obligatory to effectively enhance the professional quality of designers, so that they can carry out creative design, reduce the workload of designers, further improve design efficiency, and effectively control design costs. Simultaneously, it is imperative to effectively deepen the design, pay more attention to the component decomposition diagram, and increase its reuse frequency, which can improve the prefabrication rate. In design work, it is important to optimize the design template reasonably, and for similar or identical projects, a unified design template should be adopted, which can reduce the construction cost at the source. In addition, during the design phase, it is fundamental to pay more attention to issues related to component production and installation, optimize the disassembly process reasonably, control the quantity and types of components, optimize their production and installation processes, and reduce the amount of mold investment.

4.2. Cost control during the production and manufacturing phase

Compared to the on-site pouring of components, the factory production cost of prefabricated components is relatively high, mainly including labor costs, raw material consumption costs, water and electricity costs, component storage and production costs, as well as supporting pipeline, production mold, embedded device, and others. Firstly, when controlling the production cost of prefabricated components in practice, it is mandatory to effectively improve the production technology level and adopt the form of an assembly line to carry out production work. This can reduce labor input and effectively ensure production efficiency. In the actual production process, non-destructive connection devices should be used and production platforms should be built reasonably to improve productivity, extend the operating life of the platform, reduce the amortization of mechanical costs, and effectively save the production cost of prefabricated components. Secondly, in the production process of prefabricated components, it is necessary to collaborate with fixed factories to strengthen cooperation and ensure the effective production of prefabricated components. By adopting this approach, construction waste can be effectively collected, achieving a centralized collection mode and preventing the impact on the ecological environment caused by the dispersion of waste. For structural components, it is required to use energy-saving and emission-reduction technologies, and effectively control the temperature of the components to reduce energy consumption, ensure that the last shift can be recycled, shorten the maintenance time, and reduce production costs.

4.3. Cost control during the transportation phase of components

After the production of prefabricated components is completed, they need to be effectively transported to the construction site of prefabricated buildings. Before carrying out transportation work, it is vital to make reasonable planning and design of transportation routes, and scientifically and reasonably formulate transportation plans, to effectively control transportation costs. Before the construction of prefabricated buildings, it is crucial to effectively transport prefabricated components to the site, mainly for the installation of components on the first floor, and make reasonable transportation arrangements for the remaining components according to the usage progress, to avoid stacking a large number of components on-site. From the perspective of transportation costs, the starting point and destination of the transportation are the factory and the construction site, respectively. The transportation route should be planned according to the traffic situation, and vehicles should be selected reasonably. During transportation, it is also mandatory to closely contact the site, label the components according to the construction sequence, and place them in order. This can improve transportation efficiency, ensure effective lifting of components on-site, and save secondary handling costs. During this period, analysis should be conducted based on road conditions, taking into account the number, weight, and size of components, to make reasonable choices for transportation routes, lifting devices, and vehicles, to optimize the transportation plan. At the same time, for prefabricated component manufacturers, it is advisable to choose manufacturers that are closer to the construction site as much as possible, which can reduce transportation costs. If essential, temporary component manufacturing plants can be built. Relevant management personnel also need to pay more attention to the size of prefabricated components. When their size is large, it can reduce transportation costs. To better complete transportation work, relevant transportation personnel should fully consider the size and shape of the components, maintain their weight within 5 t, and control their length at around 5 m. This not only improves transportation efficiency but also saves transportation costs. Moreover, it is imperative to pay more attention to the handling methods, which usually include three types: vertical, inclined, and horizontal. The handling method should be selected based on the shape of the components to accelerate the transportation progress and save transportation costs.

4.4. Cost control during the construction and installation phase

In the on-site construction process of prefabricated building projects, the specific cost includes machinery, labor, materials, vertical transportation, component installation, and other aspects. To effectively control the cost of this stage, relevant construction enterprises are required to achieve synchronous construction. Initially, when installing prefabricated components in practice, it is important to first divide the overall construction work reasonably, transform it into different streamlined forms, and ensure that multiple processes are carried out simultaneously. This can shorten the construction progress of the project and comprehensively improve the construction efficiency. Simultaneously, construction companies need to arrange professional talents and adopt scientific and effective repair methods to ensure that gaps between components can be effectively repaired, thereby avoiding the risk of grout leakage and reducing maintenance costs in the later stage. Secondly, it is necessary to optimize the engineering structural system and design a reasonable construction plan. For prefabricated buildings, it is fundamental to effectively improve the prefabrication rate of the building, and effectively separate prefabricated components, to further improve production efficiency and reduce the difficulty of installing prefabricated components on site. For the prefabrication rate, relevant management personnel need to strengthen control. Once it is too high, it will lead to an increase in mechanical and labor costs. Therefore, it is required to carry out reasonable design for the prefabrication rate and effectively improve assembly efficiency to effectively control costs. Finally, in the current stage of construction project management, the application of Building Information Management (BIM) technology has gradually become more widespread, which can greatly meet the needs of engineering construction, construct three-dimensional information models reasonably, effectively utilize relevant data information, combine data analysis results, simulate on-site construction, and predict possible problems in advance. During the construction of prefabricated buildings, the use of such technology can effectively simulate the on-site installation process of prefabricated components, and adjust the construction plan reasonably based on the simulation results, further ensuring the quality of installation construction, improving installation efficiency, and reducing the cost of engineering installation construction.

5. Conclusion

In summary, for prefabricated construction projects, to improve their construction efficiency, relevant construction enterprises need to attach great importance to the cost budget management of the project and adopt scientific and effective cost control measures to strictly control the construction cost, ensure the accuracy of the cost budget, avoid exceeding the budget, improve the level of project cost management, enhance the economic benefits of prefabricated construction projects, and promote the sustainable development of the prefabricated construction industry.

Disclosure statement

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References

[1] Xu J, 2021, Construction Project Cost Management Model Based on Big Data. Journal of Physics: Conference Series, 1852(2): 022017.

[2] Pham H, Luu TV, Kim SY, et al., 2020, Assessing the Impact of Cost Overrun Causes in Transmission Lines Construction Projects. KSCE Journal of Civil Engineering, 24(1): 1029–1036.

[3] Rachmawati F, Mudjahidin M, Widowati ED, 2022, Work rate modeling of building construction projects using system dynamic to optimize project cost and time performance. International Journal of Construction Management, 24(2): 213–225.

[4] Sahadi S, Sriyono E, 2022, Examining workers motivation in construction project with structural equation modelling. Cogent Engineering, 9(1): 153–159.

[5] Chen S, 2022, Construction Project Cost Management and Control System Based on Big Data. Mobile Information Systems, 2022(1): 1–7.

[6] Ibrahim AH, Mohamed L, 2021, Assessment of Construction Project Cost Estimating Accuracy in Egypt. The Open Civil Engineering Journal, 15(1): 290–298.

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Experimental Study on Mechanical Properties of Self-Compacting Recycled Concrete

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Abstract: The application of self-compacting recycled concrete can solve the problem of environmental pollution caused by construction waste but its mechanical properties have not been unified and need further study. The strength of recycled concrete is unstable, and its performance still needs further study. The combination of fixed sand and stone volume method and free water cement ratio method is used to determine the mix ratio of self-compacting recycled concrete. 24 sets of slump expansion tests and 24 sets of cube axial compression tests were carried out to study the effect of recycled aggregate replacement rate on the flow performance and axial compressive strength of self-compacting recycled concrete, and the performance conversion formula of self-compacting recycled concrete was given. The results show that with the increase of the regenerated coarse aggregate substitution rate, the fluidity and filling property of the self-compacting regenerated concrete mix decreased. The failure of self-compacting recycled concrete is mainly due to the failure of strength between old mortar and new mixture. As the substitution rate increases from 0 to 100%, the axial compressive strength decreases by 15.2%.

Keywords: Self-compacting recycled aggregate concrete; Axial compression test; Mechanical property; Substitution rate

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1. Introduction

With the continuous advancement of urbanization, infrastructure construction is in a stage of steady development, and the shortage of natural resources is not difficult to foresee [1]. Additionally, the demolition of waste infrastructure, the dumping of test waste and construction leftovers have led to a sudden increase in construction waste, which not only occupies a large amount of land resources but also causes serious pollution to the ecological environment [2]. Therefore, the solution to the construction waste pollution problem is imminent. The application of recycled concrete can not only effectively solve the environmental pollution problem caused by construction waste, but also conform to the environmental protection concept of sustainable development in China and help to solve the problem of lack of natural resources [3]. At present, the research on self-compacting concrete has been relatively mature. Zhang Yong *et al.* used the slump expansion test to test the static stability of self-compacting concrete and found that there was a good correlation between the basic working performance of self-compacting concrete and its static stability [4]. Fernando *et al.* studied the flow and mechanical properties of self-compacting concrete by adding metakaolin and fly ash (binary and ternary mixed cement) [5]. The results show that when metakaolin and fly ash are used to add minerals, the working performance of self-compacting concrete can be ensured while the cement dosage can be reduced. Abdalhmid *et al.* studied the performance and hardening state of self-compacting concrete with different fly ash replacement rates and water-binder ratios [6]. The results show that the addition of fly ash can significantly improve the working performance of self-compacting concrete, but has negative effects on its compressive strength, flexural strength and hydration rate. Mahmoud *et al.* studied the working performance and mechanical properties of self-compacting recycled concrete containing air entraining agent and silica fume [7]. It was found that air entraining agent and silica fume played an important role in stabilizing the freshness of the mixture. Sasanipour *et al.* studied the effect of adding recycled aggregate on the physical properties (including mechanical properties and durability) of self-compacting concrete with the substitution rate of coarse and fine aggregate as the parameter [8]. The results show that the coarse-fine aggregate has significant influence on the compressive properties of self-compacting concrete but little influence on its tensile properties. With the increase in replacement rate, its durability decreased slightly. Silva *et al.* studied the working performance and physical properties of self-compacting recycled concrete by taking masonry slag and concrete waste as substitutes and found that recycled aggregate negatively impacted the working performance of self-compacting concrete, but it could meet the standard requirements [9]. The laws of its mechanical properties are similar to those studied in literature [8]. Wu Chunyang *et al.* studied the effect of non-continuous graded recycled coarse aggregate on the performance of self-compacting concrete, and the results showed that non-continuous graded recycled aggregate could be used for the preparation of self-compacting recycled concrete [10,11]. The elastic modulus is higher than that of continuous graded recycled concrete, but it is lower than that of ordinary concrete.

To sum up, domestic and foreign scholars have conducted a lot of experiments and theoretical analyses on self-compacting concrete and recycled concrete but there are few studies on self-compacting recycled concrete. Currently, there are different conclusions about the axial compressive properties of recycled concrete which needs to be further studied. In this paper, slump expansion test and cube axial compression test of self-compacting recycled concrete are carried out, and the influence of substitution rate on its working and mechanical properties is analyzed. The formula for calculating the cube compressive strength of self-compacting recycled concrete with respect to the substitution rate is modified.

2. Mix ratio design of self-compacting recycled concrete

According to the Technical Regulations for the Application of High-strength Concrete, this paper designs 60 MPa and 80 MPa self-compacting recompacted concrete with replacement rates of 0, 50%, 75% and 100% [10]. In this paper, the working performance was taken as the preliminary judgment criterion in the process of trial mixing, and axial compression tests were carried out on the 7-day and 28-day concrete cube test blocks respectively. The test mix ratio meeting the performance was finally adjusted and optimized, as shown in **Table 1**. It is worth noting that the self-compacting recycled concrete with a water-binder ratio of 0.33 produced a large segregation phenomenon.

Table 1. Mix ratio of self-compacting reclaimed coarse aggregate concrete

Number	Cement	Coarse aggregate		Machine-made sand	Water		Water reducer	Fly ash	Swelling agent	Silica fume	Water-binder ratio
		Natural	Regeneration		Mixing water	Additional water					
S60-0	334	848	0	808	166	0	13	127	42	27	0.31
S60-1	334	424	424	808	166	8	13	127	42	27	0.31
S60-2	334	212	636	808	166	11	13	127	42	27	0.31
S60-3	334	0	848	808	166	15	13	127	42	27	0.31
S80-0	378	848	0	808	141	0	14	144	48	30	0.23
S80-1	378	424	424	808	141	8	14	144	48	30	0.23
S80-2	378	212	636	808	141	11	14	144	48	30	0.23
S80-3	378	0	848	808	141	15	14	144	48	30	0.23

3. Performance of self-compacting recycled concrete

In this paper, according to the requirements of "Technical Regulations for Application of Self-compacting Concrete", slump expansion and expansion time T500 of its working performance test indexes are taken as the basis for the research and judgment of self-compacting recycled concrete's working performance and its anti-segregation ability is also observed to assist the judgment [12]. The slump spread and spread time T500 test must be carried out quickly after the completion of mixing, and the instrument uses the laboratory standard slump cylinder. The test results show that the working performance of the self-compacting recycled concrete in this paper meets the requirements of secondary self-compacting recycled concrete. The working performance indexes of self-compacting recycled concrete with different replacement rates are shown in the table, and the slump expansion test is shown in **Figure 1**.

Table 2. Working performance of self-compacting recycled concrete

Number	Slump spread (mm)	Spread timeT_{500} (s)	Segregation resistance
S60-0	635	3.5	Good
S60-1	595	3.9	Good
S60-2	580	4.1	Good
S60-3	585	4.2	Good
S80-0	610	3.2	Good
S80-1	600	3.6	Good
S80-2	585	3.9	Good
S80-3	570	4	Good

(a) Slump expansion test with strength of 60 MPa

(b) Slump expansion test with strength of 80 MPa

Figure 1. Slump expansion test of self-compacting recycled concrete

4. Mechanical properties of self-compacting recycled concrete

4.1. Compressive strength of cube

The compressive strength of concrete cube is an important index of concrete strength. In this paper, according to the requirements of "Test Method for Mechanical Properties of Ordinary Concrete", a standard cube test block of 150 mm × 150 mm is made and maintained in a standard curing room for 28 d to test the strength of the standard cube test block. The test instrument adopts an electro-hydraulic servo pressure testing machine, and the loading and final failure patterns are shown in **Figure 2**.

(a) Cube test block test instrument

(b) Failure pattern of S60-0 test block

(c) Failure pattern of S80-0 test block

Figure 2. Failure patterns of part of the test block

As seen from the figure, the failure form of the self-compacting recycled concrete cube test block is basically similar to that of ordinary concrete, both of which are manifested as brittle failure caused by insufficient bearing capacity. However, with the increase of the replacement rate of recycled coarse aggregate, it means that there is more old mortar inside the concrete, resulting in a greater possibility of shear failure on the contact surface between old mortar and coarse aggregate inside the concrete, which advances the failure time of concrete to a certain extent and reduces its strength. By comparing **Figure 2 (b)** and **Figure 2 (c)**, it can be seen that the failure modes of 60 MPa and 80 MPa concrete test blocks are completely different. The concrete test blocks with lower strength give off a "muffling sound" when they are damaged, and the degree of breakage is small, while the self-compacting recycled concrete with higher strength makes a violent "popping sound" when they are damaged, and the degree of damage is greater. The compressive strength of the self-compacting recycled concrete cubes with different numbers is shown in **Table 3**.

Table 3. Compressive strength of self-compacting recycled concrete cube

Number	Compressive strength of cube (MPa)	Axial compressive strength (MPa)
S60-0	82.5	66.4
S60-1	77.6	63.0
S60-2	73.0	59.5
S60-3	70.5	57.9
S80-0	100.3	80.5
S80-1	95.8	77.8
S80-2	92.4	75.5
S80-3	89.5	74.0

In order to visually analyze the influence of the substitution rate on the strength of self-compacting recycled concrete, the data in **Table 3** are drawn as shown in **Figure 3**:

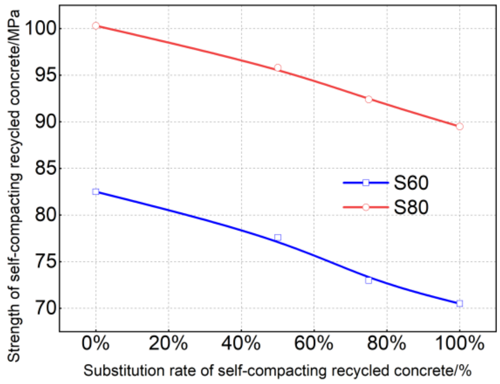

Figure 3. Strength of self-compacting recycled concrete

As shown in **Figure 3**, the cube compressive strength of self-compacting recycled concrete decreases monotonically with the increase of the substitution rate. When the design strength is 60 MPa, the cube compressive strength of self-compacting recycled concrete with 100% substitution rate decreases by 14.5% compared with that of ordinary concrete, while when the substitution rate is 50%, the strength only decreases by 5.9%. When the design strength is 80 MPa, the strength of self-compacting recycled concrete with 100% replacement rate is reduced by 10.8% compared with ordinary concrete, while the strength of self-compacting concrete with 50% replacement rate is reduced by 4.5% compared with ordinary concrete. It can be seen that the influence of recycled coarse aggregate on the compressive strength of self-compacting recycled concrete will become weak with the increase of its design strength and when the replacement rate of recycled coarse aggregate is about 50%, its strength is close to that of ordinary concrete.

In order to describe the relationship between the axial compressive strength of self-compacting recycled concrete and its regenerated coarse aggregate replacement rate, regression analysis was carried out on the test results of this paper and the test data in literature [13,14]. The regression curve is shown in **Figure 4** and the calculation expression is shown in the following equation:

$$f_{c(\rho)} = (1 - 0.131r) f_c$$

In the formula: $f_{c(\rho)}$—Axial compressive strength of self-compacting recycled concrete, MPa.

f_c—Axial compressive strength of self-compacting recycled concrete when the replacement rate is 0%, MPa.

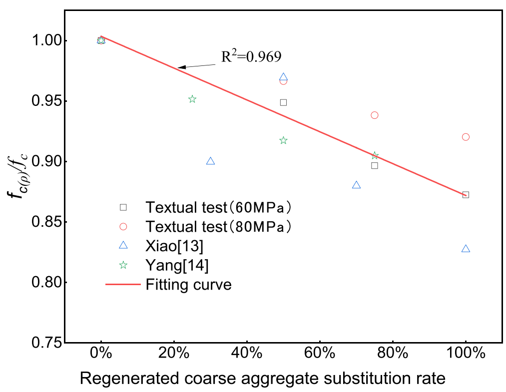

Figure 4. Fitting curve of axial compressive strength of self-compacting recycled concrete

5. Conclusion

In this paper, a suitable high-strength self-compacting recycled concrete was prepared. The flow performance and compressive strength were studied and analyzed through cube axial compression test and slump expansion test, and the following conclusions were obtained:

(1) The various mix ratio design methods of self-compactness recycled concrete are essentially different, and this paper suggests that the fixed sand and stone volume method combined with free water-cement ratio method in the code should be used. With the decrease of water-cement ratio, the slump spreading degree decreases, and the spreading time increases. With the increase of regenerated coarse aggregate substitution rate, slump expansion loss is serious.

(2) The axial compressive strength of high-strength self-compacting recycled concrete decreases significantly with the increase of the replacement rate of recycled coarse aggregate. The replacement rate increases from 0 to 50%, the axial compressive strength of 60 MPa and 80 MPa test blocks decreases by 5.9% and 4.5%, and when the replacement rate becomes 100%, the strength decreases by 14.5% and 10.8%. Furthermore, the expression between the axial compressive strength of self-compacting recycled concrete and its substitution rate is obtained by fitting regression based on the test data.

Disclosure statement

The author declares no conflict of interest.

References

[1] Deng S, Zhang X, Luo Y, 2006, Current Situation Analysis and Research Prospect of Waste Concrete Recycling. Concrete, 2006(11): 20–24.

[2] Xiang X, 2017, Study on Axial and Partial Mechanical Behavior of Steel Tube Self-Compacting Recycled Concrete Short Columns, thesis, Southwest Jiaotong University.

[3] Niu J, Xu Y, Xie C, 2020, Analysis of Bond Strength Between Rebar and Recycled Concrete Based on Statistical Regression. Journal of Yangtze River Scientific Research Institute, 37(06): 156–159.

[4] Zhang Y, Zhao Q, Li H, et al., 2016, Relationship Between Basic Working Performance and Static Stability of Self-Compacting Concrete. Journal of the Chinese Ceramics, 44(02): 261–267.

[5] Fernando P, Alexandre V, Adriano MB, 2018, Efficient Self-Compacting Concrete with Low Cement Consumption. Journal of Cleaner Production, 2018(175): 324–332. https://doi.org/10.1016/j.jclepro.2017.12.084

[6] Abdalhmid JM, Ashour AF, Sheehan T, 2019, Long-Term Drying Shrinkage of Self-Compacting Concrete: Experimental and Analytical Investigations. Construction and Building Materials, 2019(202): 825–837.

[7] Nili M, Sasanipour H, Aslani F, 2019, The Effect of Fine and Coarse Recycled Aggregates on Fresh and Mechanical Properties of Self-Compacting Concrete. Materials, 12(7): 1120.

[8] Sasanipour H, Aslani F, 2020, Durability Properties Evaluation of Self-Compacting Concrete Prepared With Waste Fine and Coarse Recycled Concrete Aggregates. Construction and Building Materials, 2020(236): 117540.

[9] Silva YF, Delvasto S, Izquierdo S, et al., 2021, Short and Long-Term Physical and Mechanical Characterization of Self-Compacting Concrete Made with Masonry and Concrete Residue. Construction and Building Materials, 2021(312): 125382.

[10] Wu C, Ma J, Pan Z, et al., 2015, Experimental Study on Basic Mechanical Properties of Self-Compacting Concrete with Discontinuous Graded Recycled Coarse Aggregate. Architectural Structures, 45(10): 69–73.

[11] Wu Ch, Ma J, Pan Z, 2014, Experimental Study on Work Performance of Self-Compacting Concrete with a Discontinuous Gradation of Recycled Coarse Aggregate. Concrete, 2014(10): 109–113.

[12] China Construction Industry Press, 2012, Technical Specification for Application of Self-Compacting Concrete, JGJ/T 283-2012.

[13] Xiao J, Yang J, Huang Y, et al., 2011, Axial Compression Test of Recycled Concrete Restrained by Steel Tube. Journal of Building Structures, 32(6): 92–98.

[14] Yang Y, Ma G, 2013, Bending Properties of Recycled Concrete for Stainless Steel Tubes. Journal of Dalian University of Technology, 2013(004): 572–578.

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Loading Stress Analysis of Cement Concrete Pavement in Mountainous Areas

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Abstract: The suitable cement concrete pavement for mountainous areas is a form of low-cost cement concrete pavement that uses unconventional graded stones in different proportions in ordinary concrete, allowing the concrete to fully contact the stones and form a stable and well-bonded slab with large particle stones. As large particle stones replace a certain volume of cement concrete, they have good economic performance and are a low-cost form of cement concrete pavement. This study researches the use of ANSYS tools to analyze the influence of geometric dimensions and material properties of rigid pavement structural layers on the mechanical properties of pavement structures.

Keywords: Pavement engineering; Suitable cement concrete pavement for mountainous areas; Finite element analysis; Mechanical property

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1. Preface

In 2003, the Ministry of Transport proposed a strategic plan for the development of county-level and rural roads, proposing to build 100,000 to 200,000 km of township and rural roads annually. The research project "Technology and Process of Suitable Cement Concrete Pavement in Mountainous Areas" focuses on the characteristics of road construction materials and road traffic in mountainous and semi-mountainous areas. By using materials such as excavated stones and river pebbles as additives to cement concrete, the concrete fully contacts with the stones, forming a stable and well-cemented slab. Since large particle stones can replace cement concrete with equal volume while meeting mechanical properties, the economic performance can be greatly improved [1].

2. Calculation model

In the process of calculating the load stress of cement concrete pavement, the assumption of inter-layer sliding is adopted to describe the contact conditions between the slab and the foundation. This assumption is based on the influence of factors such as the type, composition, and usage process of the base material on the inter-layer contact condition. However, in practical situations, the inter-layer contact condition is not completely fixed but shows a changing state between continuous and sliding [2].

This study adopts a model of a finite size four-sided free thick plate on an elastic foundation, and the contact between the plate and the foundation is arbitrary. Moreover, considering practical operability, the focus is on stress calculation and analysis for smooth and continuous extreme conditions [3].

3. Three-dimensional finite element analysis of road load stress

To deeply explore the stress and displacement characteristics of pavement structures under load, this study uses three-dimensional isoparametric elements to discretize and numerically solve concrete slabs. To simulate different bonding situations between layers, this study introduces orthogonal anisotropic contact elements between concrete slabs and foundations [4].

3.1. Basic theory of three dimensional isoparametric element method

The basic formula of the three-dimensional twenty-node isoparametric element method is:

Coordinate transformation formula: $X=\sum_{i=1}^{20} N_i X_i \quad Y=\sum_{i=1}^{20} N_i Y_i \quad Z=\sum_{i=1}^{20} N_i Z_i$

Displacement mode: $u=\sum_{i=1}^{20} N_i u_i \quad v=\sum_{i=1}^{20} N_i v_i \quad w=\sum_{i=1}^{20} N_i w_i$

Strain matrix: $\{\varepsilon\}=[B_i]\{\delta_i\}(i=1,2,\ldots 20)$

Stress matrix: $\{\sigma\}=[D][B]\{\delta\}^e$

Element stiffness matrix: $[K]=\iiint [B]^T [D][B] dxdydz$

Load matrix: $\{R\}=\iiint [N]^T \{q\} ds$

By collecting all the stiffness equations of the elements and establishing the balance of the entire structure, the balance equation of the entire structure is represented by the overall stiffness matrix [K], load matrix {R}, and node displacement matrix [δ]:

$[K]\{\delta\}=\{R\}$

By solving the equilibrium equation, the unknown node displacement can be obtained, and the stress can be calculated accordingly [5].

Experience has shown that using curved edge elements for numerical integration, the stress calculated at the integration point has the best accuracy, while the stress calculated at the node has the worst accuracy. This is because the accuracy of interpolation functions is usually poor near the edge of the interpolation region, so the derivative of the shape function and the accuracy of stress inside the element are better than at the boundary of the element.

3.2. Establishment of inter-layer arbitrary contact model

The contact between the concrete slab and the foundation is neither completely continuous nor smooth but between the two. As theoretical research, it is necessary to find a reasonable inter-layer contact model. Introduce surface units between the surface layer and the base layer to simulate the different inter-layer contact conditions between the surface layer and the base layer.

In elastic theory, the equilibrium equations, geometric equations, and coordination equations of isotropic materials are consistent with those of anisotropic materials, but the difference lies in their stress-strain equations [6].

The structural relationship of anisotropic linear elastic materials satisfies the generalized Hooke's law, i.e:

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_x \\ \gamma_y \\ \gamma_z \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_x \\ \tau_y \\ \tau_z \end{Bmatrix}$$

Abbreviated as:

$$\{\varepsilon_x\} = [S]\{\sigma_x\}$$

In the formula, [S] is called the flexibility matrix and is referred to as the flexibility constant.

It can also be written as:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{yz} \\ \tau_{zx} \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & c_{36} \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & c_{46} \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56} \\ c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & c_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{yz} \\ \gamma_{zx} \\ \gamma_{xy} \end{Bmatrix}$$

Abbreviated as:

$$\{\sigma_x\} = [C]\{\varepsilon_x\}$$

In the formula, [C] is called the stiffness matrix or modulus matrix, and is called the elastic constant. The flexibility matrix and modulus matrix are mutually inverse, i.e:

$$[C] = [S]^{-1}, [S] = [C]^{-1}$$

In general, each strain component in an anisotropic body is a linear function of all stress components. Represented in tensor form as:

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$$

This is the generalized Hooke’s law, also known as the constitutive relationship equation. Since stress and strain are both second-order tensors, in three-dimensional space, the stiffness matrix is a fourth-order tensor containing elements that represent a corresponding elastic constant.

In this way, the contact layer becomes a part of the foundation, and the entire structure becomes an isotropic linear elastic body that is completely continuous between layers. The load stress analysis of the structure is completely equivalent to the theory and method used by isotropic three-dimensional isoparametric elements.

3.3. Completely continuous stress analysis of plate and foundation

The basic calculation model is a finite size four-sided free plate on an elastic foundation, and the plate is in continuous contact with the base layer. The basic load is taken as the single rear axle double wheel group wheel load, with an axle load of 100 kN and a pressure of 0.7 MPa. For the convenience of finite element analysis and calculation, the load application surface is taken as a square with a side length of 18.9 cm.

3.3.1. Analysis of stress at the bottom of concrete slabs based on the geometric dimensions of the foundation

When using spatial isoparametric elements to calculate elastic layered structures, its convergence is influenced by the rationality of element partitioning and the choice of calculation area size. Under the condition of ensuring that the calculation range is sufficiently broad and the density of units is coordinated with the field gradient, the calculation results will approach an accurate solution [6].

The parameters used for calculation are: the plane size of the board is 5×6 m^2, and the board thickness is 25 cm; The base layer (Lime-fly Ash Macadam) is 6 m wide, equal in length to the foundation, with a thickness of 2×16 cm; The plane dimension of the elastic foundation is, with a depth of z (m). The material parameters are shown in **Table 1**.

The model established using ANSYS 10.0 finite element program is shown in **Figure 1** and **Figure 2**.

The maximum stress calculation results at the bottom of the plate under standard load are shown in **Table 2**.

Table 1. Physical parameters of materials

Project	Resilience Modulus, E (MPa)	Poisson's Ratio, μ	Thickness, h (m)	Density, ρ (kg/m³)
Road surface layer	33000	0.15	0.25	2700
Lime-fly Ash Macadam	1500	0.2	0.32	2500
Soil base layer	50	0.35		1800

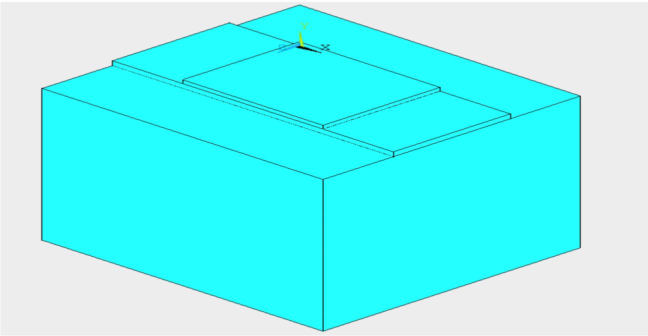

Figure 1. ANSYS finite element calculation model

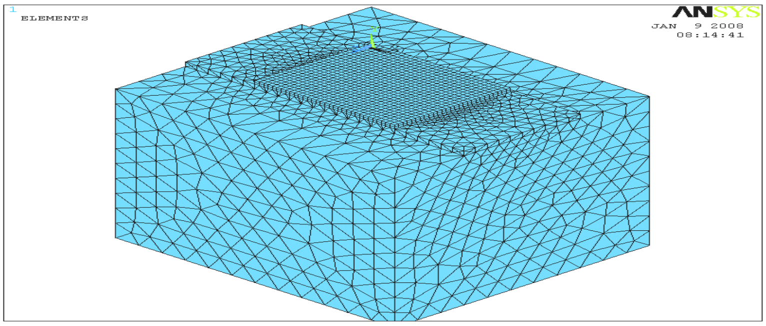

Figure 2. Grid partitioning model

Table 2. Comparison of the plane dimensions of the foundation with the stress of the plate

Identifier	(1)	(2)	(3)	(4)
Foundation size (x,y,z) (m)	7,6,4.5	9,8,4.5	10,9,4.5	11,10,4.5
Calculate point stress value (MPa)	1.2207	1.2855	1.2937	1.3060
Identifier	**(5)**	**(6)**	**(7)**	**(8)**
Foundation size (x,y,z) (m)	12,11,4.5	13,12,4.5	14,13,4.5	20,15,4.5
Calculate point stress value (MPa)	1.3057	1.3038	1.3175	1.3100

From the calculation results in **Table 2**, it is found that when the depth of the foundation is constant, the stress at the bottom of the slab gradually increases with the increase of the geometric size of the foundation plane. When the geometric size of the foundation plane reaches a certain degree, the stress at the bottom of the slab reaches its limit, and the stress at the bottom of the slab gradually increases and converges with the increase of the geometric size of the foundation plane. The impact range of the load on the foundation is a limited area, approximately 12×11 m^2.

The influence of foundation depth on the stress of the slab is calculated in **Table 3**.

Table 3. Foundation depth and bottom stress table

Identifier	(1)	(2)	(3)	(4)
Foundation size (x,y,z) (m)	12,11,4.5	12,11,6	12,11,10	12,11,12.5
Calculate point stress value (MPa)	1.2207	1.3101	1.3252	1.3452
Identifier	**(5)**	**(6)**	**(7)**	**(8)**
Foundation size (x,y,z) (m)	12,11,15	12,11,17.5	12,11,20	12,11,25
Calculate point stress value (MPa)	1.3635	1.3225	1.3223	1.3215

From **Table 3**, it is found that when the geometric plane size of the plate surface is constant, the stress at the bottom of the plate gradually increases with the increase of the foundation depth. When the foundation depth reaches a certain level, the stress at the bottom of the plate reaches its limit. As the foundation continues to deepen, the stress at the bottom of the plate gradually decreases and converges; The influence range of the load on the depth of the foundation is a limited area, approximately 17.5 m. The maximum tensile stress at the bottom of the plate calculated by ANSYS finite element method converges to 1.32 MPa.

3.3.2. Analysis of the effect of geometric dimensions of concrete panels on the load stress at the bottom of the panels

According to the mechanical model of concrete pavement, the influence of base layer on the load stress at the bottom of the slab under the same pavement structure conditions is calculated, and the parameters of the plane size of the concrete slab are 5×6 m^2 and the slab thickness is 25 cm; The base layer (Lime-fly Ash Macadam) is 5 m wide, equal in length to the foundation, with a thickness of 2×16 cm; The geometric dimensions of the elastic foundation are $12 \times 11 \times 17.5$ m^3. The calculation results are shown in **Table 4**.

Table 4. Comparison table of load stress of concrete panel

Size of cement concrete slab (m)	6×5×0.25	6×5×0.25	6×5×0.25	6×5×0.25	6×5×0.25	6×5×0.25	6×5×0.25
Rebound modulus of soil foundation (MPa)	50	50	50	50	50	50	50
Base rebound modulus (MPa)	250	500	750	1000	1300	1500	1700
Loading stress calculation results (MPa)	1.8165	1.6803	1.5700	1.4787	1.3805	1.3217	1.2674

According to the parameters and results calculated in **Table 4**, the tensile stress at the bottom layer of the concrete slab under load gradually decreases with the increase of the elastic modulus of the base layer.

The influence of concrete slab size on the stress at the bottom of the slab, calculation parameters, and results are shown in **Table 5**.

Table 5. Comparison table of concrete panel load stress and plate thickness

Size of cement concrete slab (m)	6×5×0.18	6×5×0.2	6×5×0.22	6×5×0.24	6×5×0.25	6×5×0.26	6×5×0.30
Rebound modulus of soil foundation (MPa)	50	50	50	50	50	50	50
Base rebound modulus (MPa)	1500	1500	1500	1500	1500	1500	1500
Loading stress calculation results (MPa)	2.0731	1.6558	1.5056	1.3777	1.3805	1.2740	1.1009

From the analysis in **Table 5**, it can be concluded that under the same pavement structure and load, as the thickness of the cement concrete slab gradually increases, the maximum tensile stress at the bottom of the BSSC board shows a gradually decreasing trend. Especially when the thickness of the cement concrete slab does not reach 25 cm, the effect of reducing the tensile stress at the bottom of the slab becomes more prominent with the increase of slab thickness. When the cement concrete slab is larger than 25 cm, the tensile stress at the bottom of the slab decreases slowly with the increase of slab thickness. Therefore, the cement concrete pavement is optimal for heavy-duty traffic with a pavement thickness of 25 cm.

3.4. Stress analysis of absolute smooth contact between board and base

Introducing an orthogonal anisotropic contact model to achieve smooth contact between plates and foundations. Since the computational structure is divided into two types of elements, namely ordinary elements and contact elements, they exhibit isotropic linear elasticity and anisotropic linear elasticity in material properties.

Calculations using three-dimensional finite element and plate element under identical conditions were used to compare both methods. The plane calculation size of the cement concrete slab is 480 cm × 360 cm, and the load position is the lateral movement of the axial load in the middle of the slab length. During the trial calculation, the foundation size is taken as small z = 12 × 11 × 17.5 m^3. Parameters of cement concrete slab and base: E_S = 50 MPa, E_c = 33,000 MPa,μ_c = 0.15, μ_s = 0.2, h_c = 25 cm, E_1 = 0.005 MPa, μ_{12} = 0.01, μ_{13} = 0, G_{13} = 0.03 MPa, h_0 = 0.1cm. The calculation results are summarized in **Table 1** to **Table 8**. From the tables, it can be seen that the calculation results using three-dimensional isoparametric elements after introducing orthogonal anisotropic contact elements are consistent with those using plate elements. The maximum error is 1.93%, and the error at the critical load level is only -0.1%, indicating that this article meets the theoretical requirements in terms of computational accuracy when used to simulate absolute smooth contact between layers.

Table 6. Comparison table for calculating the maximum bending tensile stress at the bottom of the plate

Calculate the distance between the point and the center of the board (cm)	Calculation Methods		
	Plate	Absolute smoothness	Completely continuous
2	1.3629	1.3365	1.2848
32	1.5059	1.4795	1.3992
150	1.5939	1.6082	1.5125
180	2.1758	2.1736	2.0713

By calculating and examining the changes in the thickness and modulus ratio of cement concrete slabs h_c, when the modulus ratio E_c / E_S changes, the change in the maximum bending tensile stress at the bottom of the plate is compared with the calculation results of the complete inter-layer continuity. The comparative calculation results are listed in **Table 7** and **Table 8**.

Table 7. Comparison table of normal stress σ for different plate thicknesses

Plate Thickness, h_c (cm)	18	20	22	24	26	28	30
Absolute smoothness	2.073	1.656	1.506	1.378	1.274	1.147	1.101
Completely continuous	2.474	1.968	1.783	1.625	1.488	1.339	1.246
Difference rate (%)	16.2	15.9	15.5	15.2	14.4	14.4	11.6

Table 8. Comparison table of normal stress σ at different modulus ratios

Modulus Ratio, E_c / E_S	33000/ 250	33000/ 500	33000/ 750	33000/ 1000	33000/ 1300	33000/ 1500	33000/ 1700
Absolute smoothness	1.817	1.680	1.570	1.479	1.381	1.322	1.267
Completely continuous	2.285	2.074	1.878	1.750	1.589	1.490	1.413
Difference rate (%)	20.5	19	16.4	15.5	13.1	11.3	10.3

Note: The values in the table are calculated based on h_c = 25 cm

From **Table 7** and **Table 8**, it can be seen that the tensile stress σ at the bottom of the cement concrete slab decreases with h_c increasing, and increases with E_c / E_S increasing. As the thickness and modulus of the plate increase, the influence of inter-layer contact conditions (absolutely smooth or completely continuous) on σ decreases. The influence of boundary conditions on pavement stress-strain is not constant. As the structural and mechanical parameters related to inter-layer contact conditions change (the thickness of the plate increases and the relative stiffness of the plate increases), the degree of influence of inter-layer contact conditions on the maximum bending tensile stress at the bottom of the plate gradually weakens.

4. Conclusion

Based on the theory of anisotropic linear elasticity, this paper successfully constructed an “orthogonal anisotropic contact model”. Using this model, combined with the spatial finite element method, the load stress of the elastic foundation slab and the cement concrete pavement structure under any contact conditions can be analyzed in depth to ensure that the analysis accuracy meets the theoretical requirements.

Based on ANSYS finite element theory calculation and analysis, it is recommended that the appropriate thickness of the slab pavement be 25 cm for the actual needs under heavy traffic conditions. At the same time, a large amount of calculation and analysis were conducted on the two extreme cases of smooth contact and continuous contact between the slab pavement and the foundation, to provide reliable reference data for the engineering design department.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Yuan B, Peng Y, Gao M, 2013, Finite Element-Based Load Stress Analysis of Asphalt Concrete Overlay on Old Cement Concrete Pavement. Highway, 2013(04): 85–89.

[2] Yuan B, Peng Y, Gao M, 2013, Load Stress Analysis of Asphalt Overlay on Old Cement Concrete Pavement [J]. Zhongwai Highway, 33(02): 55–59.

[3] Zhou Y, Tan Z, Tian B, 2010, Load Stress Analysis of Cement Concrete Pavement Based on Thin Plate Elements. Journal of Tongji University (Natural Science Edition), 38(05): 685–691.

[4] Zhang Z, Yang X, 2010, Stress Analysis of Steep Slope Cement Concrete Pavement in Mountainous Areas. Highway, 2010(02): 60–62.

[5] Han H, Wang C, 2009, Load Stress Analysis of Cement Concrete Pavement on Low Traffic Volume Roads. Highway Traffic Technology, 2009(S1): 19–22.

[6] Yu H, Huang D, Tang W, 2008, Stress Analysis of Asphalt Overlay on Old Cement Concrete Pavement in Mountainous Areas. Journal of Wuhan University of Technology, 2008(07): 57–61.

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The Study on the Evolution of Urban Spatial Structure in Zhuhai City Based on Spatial Syntax

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Abstract: With the deepening of the Guangdong-Hong Kong-Macao Greater Bay Area strategy and the accelerated integration and development of the east and west sides of the Pearl River Estuary, Zhuhai's hub position is becoming more and more prominent. The city of Zhuhai has a dense water network and is divided into two urban areas, the east and the west, under the influence of the Mordor Gate waterway. Based on the theory of spatial syntax, this paper carries out an analytical study on the urban spatial structure of Zhuhai, identifies the distribution characteristics of urban POIs, and provides theoretical support for the urban development of Zhuhai.

Keywords: Spatial syntax; POI data; Transport network; Urban spatial structure

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1. Introduction

The regional pattern of Zhuhai has been influenced by the Hong Kong-Zhuhai-Macao Bridge (HZMB), which has transformed it from a transport "terminal" to a transport "hub" on the west bank of the Pearl River Estuary. The bridge connects three places, turning the moat into a road, making Zhuhai the only city on the Mainland connected to Hong Kong and Macao by land.

At present, Zhuhai is seizing major opportunities in the "four zones" of the Guangdong-Hong Kong-Macao Greater Bay Area, the modern International Special Economic Zone, the Hengqin Section of the Guangdong Free Trade Zone, and the Hengqin Guangdong-Macao Deep Cooperation Zone, and promoting the construction of a modern international special economic zone. Therefore, this study will introduce multivariate big data and space syntax analysis technology to analyze the current urban spatial characteristics of Zhuhai and provide an important basis for proposing a reasonable development plan for Zhuhai [1,2].

2. Research background

2.1. Development history of Zhuhai urban pattern

At present, Zhuhai is constantly improving the “twin cities” structure in the east and west, accelerating the adjustment of the urban pattern, strengthening the political, economic, scientific, educational, and cultural functions in the eastern urban area, and strengthening the supporting functions of industrial transportation services in the western urban area, promoting the rapid connectivity of various groups in the city, and accelerating the formation of a new urban look featuring industrial coordination, convenient life, and livable business. To sum up, it is of great practical significance to carry out research on the development of the Zhuhai Twin City structure, dig deep into its mechanism, and predict its specific impact in advance.

2.2. Changes in urban traffic pattern in Zhuhai

From the perspective of urban development, the external corridor represented by the Hong Kong-Zhuhai-Macao Bridge, Huangmaohai Bridge, and the Shenzhen-Zhuhai-Corridor in the bidding process, and the internal main connection line represented by the Zhuhai Bridge, Honghe Bridge, Xianghai Bridge, and Jinhai Bridge will form a comprehensive transportation core network of the Special Economic Zone. In the process of integrated development of the east and west sides of the Pearl River Estuary, Zhuhai will realize more initiatives. It will have a substantial effect on the urban pattern of Zhuhai. Therefore, it is of great significance to study urban spatial networks in combination with urban bridge traffic networks.

3. Research methods

This study will introduce mature “space syntax theory” and GIS multivariate big data analysis method to analyze the evolution process of the urban spatial structure of Zhuhai city through the traffic network [3]. The study of urban form is a classic field of application of space syntax [4,5]. One of the main and essential purposes of space syntax is to understand the natural structure of physical cities, and then explain the structural logic and constructive influence of urban space. The research results of urban form are not limited to the analysis and prediction of urban traffic network characteristics by using space syntax but also involve the correlation of traffic network characteristics with urban density and urban diversity, and the correlation of traffic network with urban life to measure the social representation of urban form [6]. The research will be carried out in an orderly manner from three steps: network model construction, urban traffic axis index calculation, and spatial index analysis [7].

4. Research results

4.1. Structural characteristics of urban traffic network

Influenced by the geographical division of the tributaries of the Pearl River System, the urban space of Zhuhai is divided into two parts, the main urban area in the east and the sub-urban area in the west. The eastern main urban area is not as vast as the western sub-cities in terms of land area and radiation range, but the former is better than the latter in terms of traffic network density and urban positioning. The two urban areas are currently connected by four core cities: Jinhai Bridge, Honghe Bridge, Zhuhai Avenue and Xianghai Bridge. The space syntax software (Depth software) is used to calculate the accessibility index RN of its traffic network, and the traffic road is assigned a color according to its value. The higher the RN value, the closer it is to red [8-10]. Otherwise, the closer it is to yellow (**Figure 1**).

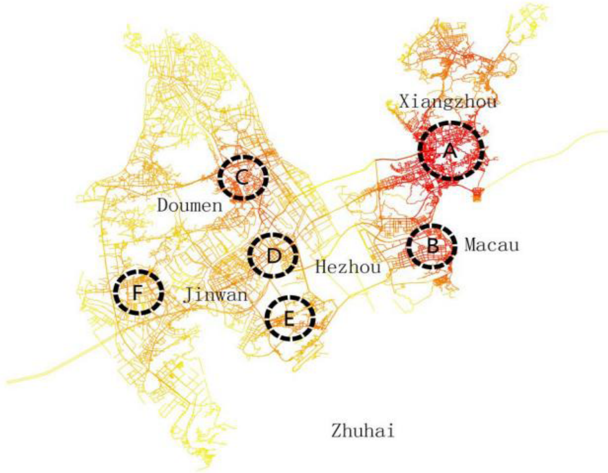

Figure 1. Urban transport accessibility in 2024

According to the urban transportation accessibility analysis chart, the high accessibility area of the eastern main urban area mainly includes two parts: Xiangzhou Old City Area A and Hengqin Port New City Area B. It shows that the convenience of urban traffic in the above two areas is much higher than that in the neighboring urban areas, and the urban traffic flow and people flow easily converge here, and the corresponding urban land value also increases rapidly. However, it is not difficult to find that due to the influence of the coastal line and the administrative boundary of Zhongshan, the radiation range of urban traffic in the two places is severely restricted, and the high-accessibility areas are excessively concentrated, and urban traffic faces great traffic pressure, accompanied by frequent congestion. The core path connecting Yinwan Road and Jialin Mountain Tunnel with Xiangzhou Old City Area A and Hengqin Port New City Area B is blocked by terrain and lacks other traffic to share the traffic flow. Therefore, the development of traffic connections between the two also has great limitations.

The high accessibility traffic in the western urban area can be divided into: Doumen Jingan Baijiao Area C, Jinwan Hongqi Area D, Jinwan Sanzao Area E, and Pingsha New City Area F. The distance of each section is moderate, from south to north, and east to west in sequence. Each section is closely connected by two city-level expressways, Zhuhai Avenue and Huxin Road. Compared with the high integration degree of the eastern main urban area, the traffic accessibility and traffic density of each area in the western urban area are reduced, but the regional radiation range is wider, and there is plenty of reserved space for development. Meanwhile, the traffic links of each area effectively promote the coordinated development of neighboring areas. In addition, the completion of Xianghai Bridge, Honghe Bridge, and Jinhai Bridge in recent years will successively strengthen the traffic links between Doumen Jingan Baijiao Area C, Jinwan Hongqi Area D and Jinwan Sanzao Area E and the eastern main city, bringing more urban vitality and urban function support for the development of Zhuhai Twin cities.

4.2. Analysis of urban POI distribution

In this study, spatial network analysis technology is used to conduct a correlation analysis of urban POI migration changes. The POI data of Zhuhai City in 2023 were visualized, and the specific data included 110,460 points of interest in urban commerce, industry, residence, urban public construction, etc. It is not difficult to find that the POI density of Xiangzhou Old City Area A is much higher than that of other areas, and the urban vitality is the best. The second is Doumen Jing'an Baijiao Area C. The POI density of Hengqin Estuary New

Town Area B does not match the current situation of high accessibility and dense traffic, which reflects that its actual development status and urban vitality are not ideal. Currently, due to the limitation of the urban land administrative boundary, the POI in the eastern part of Zhuhai will gradually move to the western part of the city, and inject urban vitality into the four core areas in the west. Simultaneously, in the process of absorbing urban POI, the west of Zhuhai also promotes the development of the whole city.

5. Conclusion

Based on the theory of space syntax, this paper analyzes and studies the urban spatial structure and traffic network of Zhuhai city and identifies the distribution characteristics of urban POI. It is found that there is a high correlation between urban transportation networks and urban vitality. The vitality of eastern cities is greatly limited and gradually migrates to the west.

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References

[1] Xu Y, Chen X, 2021, Quantitative Analysis of Spatial Vitality and Spatial Characteristics of Urban Underground Space (UUS) in metro area. Tunnelling and Underground Space Technology, 2021(111): 103875. https://doi.org/10.1016/j.tust.2021.103875

[2] Yamu C, Nes AV, Garau C, 2021, Bill Hillier's Legacy: Space Syntax—A Synopsis of Basic Concepts, Measures, and Empirical Application. Sustainability, 13(6): 3394. https://doi.org/10.3390/su13063394

[3] Blanchard P, Volchenkov D, 2008, Intelligibility and first passage times in complex urban networks. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2008(464): 2153–2167. https://doi.org/10.1098/rspa.2007.0329

[4] Batty M, 2022, Integrating space syntax with spatial interaction. Urban Informatics, 2022(1): 4. https://doi.org/10.1007/s44212-022-00004-2

[5] Nag D, Sen J, Goswami AK, 2022, Measuring Connectivity of Pedestrian Street Networks in the Built Environment for Walking: A Space-Syntax Approach. Transportation in Developing Economies, 2022(8): 34. https://doi.org/10.1007/s40890-022-00170-7

[6] Sharmin S, Kamruzzaman M, 2017, Meta-Analysis of the Relationships Between Space Syntax Measures and Pedestrian Movement. Transport Reviews, 2017(38): 524–550. https://doi.org/10.1080/01441647.2017.1365101

[7] Pafka E, Dovey K, Aschwanden GDPA, 2018, Limits of space syntax for urban design: Axiality, scale and sinuosity. Environment and Planning B: Urban Analytics and City Science, 2018(47): 508–522. https://doi.

org/10.1177/2399808318786512

[8] Rashid M, 2022, On Spatial Mechanisms of Social Equity: Exploring the Associations Between Street Networks, Urban Compactness, and Social Equity. Urban Science, 6(3): 52. https://doi.org/10.3390/urbansci6030052

[9] Li Q, Cui C, Liu F, et al., 2021, Multidimensional Urban Vitality on Streets: Spatial Patterns and Influence Factor Identification Using Multisource Urban Data. ISPRS International Journal of Geo-Information, 11(1): 2. https://doi.org/10.3390/ijgi11010002

[10] Sun G, Webster C, Zhang X, 2019, Connecting the city: A three-dimensional pedestrian network of Hong Kong. Environment and Planning B: Urban Analytics and City Science, 2019(48): 60–75. https://doi.org/10.1177/2399808319847204

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Construction Project Management and Construction Quality Control Strategy

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Abstract: With the gradual acceleration of the urbanization process, the construction industry has been developing rapidly. As the key link to ensure the quality and safety of the project, construction management and construction quality control are of great significance to enhance the competitiveness of construction enterprises and realize sustainable development. In this paper, the effective strategy of construction management and the effective strategy of construction quality control will be discussed in depth, aiming at providing useful management and quality control strategies for construction enterprises.

Keywords: Construction engineering management; Construction quality control; Strategy; Quality control point

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1. Introduction

Construction project management is an important means to ensure the smooth progress of engineering projects and improve engineering quality and safety. With the continuous development of the construction industry, the scale and complexity of construction projects are gradually increasing, which puts forward higher requirements for construction project management. Furthermore, construction quality control, as a key factor in ensuring the quality of construction projects, is of great significance in achieving the objectives of engineering projects. Therefore, it is of great practical significance and theoretical value to discuss construction management and construction quality control strategy.

2. Effective strategies for construction project management

2.1. Preliminary planning and design management

Project feasibility study is an important basis for project decision-making, and it ensures the smooth implementation of the project and the realization of expected benefits through a comprehensive evaluation of the technical, economic, and social aspects of the project [1]. Enterprises should use scientific methods and means, from the technical, economic, social, humanistic, ecological, and other aspects of the project to carry out a comprehensive feasibility study analysis and economic evaluation. The “three controls, two management and one coordination" of feasibility study and construction period should be incorporated into the core content of project management simultaneously to ensure that the project does not produce negative effects and obtains the best economic and social benefits [2]. The review and modification of the design scheme is the key link to ensuring design quality and improving the design level. The competent construction department should strengthen the monitoring of the optimization of the design work, formulate the evaluation standards and specific implementation rules for the optimization of the design scheme, and increase the staffing and review of professional and technical personnel. To conduct a comprehensive review of the design results at each stage, both to review the technical feasibility, but also to review the economic rationality, and strengthen the management of the design market, strictly through the qualification management, personnel registration, design bidding, drawing review, and other links to regulate the design market, and strive to reduce unlicensed design and design beyond the level.

2.2. Management of construction preparation phase

Collect and check design and construction drawings, project contracts, construction schemes, technical specifications, laws and regulations, and other documents. After careful inspection and analysis, determine the basis for the preparation of the construction organization design, fully consider the characteristics of the project and the actual situation, and ensure the scientific rationality of the program. The contents of preparation include a construction organization design book, construction flow chart, construction organization diagram, construction safety technical measures, etc., and each link and detail is carefully considered and planned [3]. Ensure that the quality of materials and equipment meets the design, technical specifications and standards, shall not purchase fake and shoddy products, and obtain legal property rights certificates and product quality certificates according to law. According to the characteristics and needs of the construction, materials, and equipment are reviewed and deployed to ensure that the supply of materials and equipment in the construction process is sufficient to avoid affecting the construction progress. Reasonable staffing and optimized organizational structure can ensure the coordinated operation of the construction team, equipped with the appropriate number of professional and technical personnel, conduct corresponding training according to the professional and technical requirements of the construction team, improve the technical quality and operational ability of the construction team, ensure the effective implementation of safety measures during the construction process, and reduce the occurrence of construction accidents. Cultivate the team consciousness and cooperation ability of the construction team, improve the communication and cooperation ability, and strengthen the team cohesion.

2.3. Construction process management

Clarify safety responsibilities at all levels and ensure that every worker understands and fulfills their safety responsibilities [4]. Establish a safety production leadership organization headed by the project manager, responsible for organizing and carrying out safety management activities. Conduct entrance education and safety training for new workers to ensure they understand and comply with safety regulations. Organize regular safety inspections and drills to improve workers' safety awareness and ability to respond to emergencies. Monitor construction progress in real-time with daily, weekly, and monthly progress reports. Modern information technology means, such as Building Information Modeling (BIM), are used to simulate and predict construction progress [5]. When there is a deviation between the actual progress and the planned progress, the reasons should be analyzed in time and measures should be taken to adjust, increase resource investment, optimize the construction plan, etc., to ensure the timely completion of the project. Clear quality standards and quality requirements, and develop a detailed quality management plan, which should include quality control points, inspection batches, and acceptance standards. Side supervision of key processes and key parts is conducted to ensure effective quality control [6]. When quality problems are found, analyze the causes in time and take measures to deal with them, record and summarize the quality problems, and prevent similar problems from happening again. According to the actual situation of the project and contract requirements, make a detailed construction cost budget, which should include labor costs, materials costs, machinery costs, and other costs. Through the cost accounting system, real-time tracking and recording of various expenses, comparative analysis with the budget, timely detection of cost deviations, and taking measures to control. Reduce construction costs through material management, equipment maintenance, and human resource allocation. Introduce advanced cost management ideas and methods to improve cost control levels.

2.4. Late acceptance and delivery management

In the later acceptance, we must first clarify the acceptance standards and procedures to ensure that each project content meets the design requirements and quality standards. In the acceptance process, strict quality inspection methods should be adopted to carefully inspect key parts and hidden projects to ensure that there are no hidden dangers. Establish a rectification and reinspection mechanism, and rectify and re-accept the problems found in time to ensure that the problems are completely solved. In terms of delivery management, it is necessary to formulate a detailed delivery plan, specify the time, place and method of delivery, etc., to ensure the orderly delivery process [7]. Strengthen communication and coordination with the owners, timely understand the needs and feedback of the owners, and ensure that the delivery results meet the expectations of the owners. In the delivery process, we should pay attention to details to ensure that engineering data, equipment, and facilities are complete and intact to provide convenience for the owner. To improve customer satisfaction, companies should also focus on the quality of service after delivery. For example, to provide owners with necessary operation training, equipment maintenance, and other services to ensure the continuous and stable operation of the project, establish a customer service feedback mechanism, timely understand customer satisfaction and demand, and provide reference and improvement direction for the enterprise's future engineering projects [8]. Late acceptance and delivery management is an indispensable part of construction project management. Only by developing effective management strategies and conscientiously implementing them, can we ensure project quality and customer satisfaction, and win a good reputation and credibility for the enterprise.

2.5. Information management strategy

By integrating all kinds of information resources, a unified information management platform is established to realize centralized management, unified scheduling, and efficient use of information. Sensors, Radio-Frequency Identification (RFID), and other technical means are used to collect all kinds of data on the construction site in real-time, and data analysis software is used to process and analyze it, providing data support for management decision-making [9]. With the help of artificial intelligence technology, the progress, quality, cost, and other aspects of construction engineering are intelligently managed and controlled to improve management efficiency and accuracy. In the process of information management, we should pay attention to information security and take necessary security measures to ensure the integrity and confidentiality of information.

3. Effective strategies for construction quality control

3.1. Material quality control

Conduct a comprehensive assessment of suppliers, including their quality management system, production capacity, historical quality records, etc., to ensure the selection of reliable quality and reputable suppliers, establish long-term stable cooperative relations with high-quality suppliers, ensure the stability of material supply and quality consistency, and carry out strict inspection and acceptance of each batch of materials entering the construction site. Ensure material meets design requirements and quality standards [10]. Physical property testing, chemical composition analysis, microbial testing, and other methods are used to conduct comprehensive and detailed testing of materials, requiring suppliers to provide material certification and identification to ensure the reliability and traceability of material sources. Classified storage according to the nature and use of materials, avoid mixing and misuse, and take appropriate moisture-proof and anti-corrosion measures for materials that are susceptible to moisture and corrosion to ensure that the quality of materials is not damaged. Follow the principle of first in, first out to ensure that the material is used within the validity period, timely identification and treatment: once found nonconforming products, immediately isolate and identify, prevent misuse, and notify the supplier for return and replacement processing. Record and analyze nonconforming products, find out the causes and take appropriate corrective measures to prevent similar problems from happening again [11]. Establish a quality information feedback mechanism, collect and process quality information from the construction site in time, provide a basis for improving material quality control, regularly review and improve material quality control work, constantly optimize quality control strategies and methods, and improve construction quality.

3.2. Construction process control

According to the specific requirements and characteristics of the project, formulate detailed construction technology standards. These standards should cover the process, construction requirements, quality standards, etc., to ensure that every step of the construction process has clear guidance. Based on construction technology standards, the sequence and quality control points of each construction process are defined. Through the strict control of key processes and quality control points, assure the stability and controllability of the entire construction process. With the continuous progress of science and technology, new construction techniques and equipment continue to emerge. Hence, construction units should actively introduce advanced construction techniques and equipment to improve construction efficiency and quality. For example, the use of BIM technology for construction simulation and optimization can identify potential construction issues and formulate solutions beforehand [12]. Construction personnel is the key factor of construction process control, strengthen the training of construction personnel, and improve their professional skills and quality awareness, so that they can master the construction process standards and operating norms, to ensure the accuracy and standardization of the construction process. In the construction process, the whole process of monitoring is implemented to track and record all aspects of the construction process in real-time. This helps to find and correct problems in time, ensuring the accuracy and stability of the construction process. Conduct regular quality assessments on the implementation of construction technology, and make feedback and improvements according to the evaluation results. This is helpful to continuously improve the construction process standards and control strategies, and improve the stability and reliability of construction quality.

3.3. Construction quality inspection and acceptance

At the initial stage of the project, a detailed construction quality inspection and acceptance plan shall be formulated according to the characteristics and requirements of the project, in which key information such as the frequency, content, method, standard, and responsible person of inspection and acceptance shall be clearly defined. Regular quality inspection of the construction site shall be carried out according to the plan, including inspection of the construction process, construction technology, and material use [13]. Carry out special quality inspections for key processes and hidden works to ensure the construction quality of these key links.

Quantitative analysis and evaluation of building materials and construction quality are carried out by using special testing equipment and instruments such as measuring instruments and material testing equipment. Random selection of building materials, components, or samples in the construction process is used for testing to ensure that the quality of materials meets the requirements. Sampling testing should cover all kinds of materials and construction links to improve the comprehensiveness and accuracy of testing [14]. Review the technical documents of the construction project, including construction drawings, design specifications, construction schemes, etc., to ensure that they are reasonable, accurate, and in line with standards. Ensure that the construction of the building is carried out following the contract requirements, including foundation works, structural works, decorative works, etc. Evaluate the performance of the building during use, such as seismic performance, thermal insulation performance, ventilation performance, etc., and compare with relevant standards to judge its eligibility. According to the acceptance results, the acceptance report is written to explain the quality of the building in detail, point out the existing problems and areas for improvement, and commend the qualified parts [15]. According to the inspection and acceptance results, the construction quality should be continuously improved in time, and the improvement should be reported to the relevant departments and personnel. Organize regular summary meetings of construction quality inspection and acceptance, share experience and lessons, and enhance the overall team's level of construction quality control.

3.4. Quality management system construction

Define the quality objectives of the construction project and ensure that they are aligned with the overall organizational strategy. Formulate a clear quality policy, clarify the organization's commitment to quality and expectations, and establish quality awareness among all staff. Determine the organizational structure of the quality management department and clarify the responsibilities and authority of quality management personnel at all levels. Allocate human, material, and financial resources reasonably according to the requirements of the quality management system to ensure the effective implementation of quality activities. Develop a quality manual that defines the structure, processes, and procedures of the quality management system. Prepare procedure documents and work instructions to specify the specific operation methods of each quality management activity. Conduct quality management system training for all employees to ensure that they understand and comply with relevant requirements [16]. Conduct more in-depth professional training for key positions and quality management personnel to improve their quality management capabilities. The key process is strictly controlled to ensure the stability and reliability of construction quality. Continuously improve the effectiveness of the quality management system through data analysis, corrective action, and preventive action. Conduct regular internal audits to assess the conformity and effectiveness of the quality management system. The senior management shall conduct a comprehensive inspection and evaluation of the operation of the quality management system to ensure the continuous optimization of the system.

4. Closing remarks

Construction project management and construction quality control are the key links to ensure the quality and safety of the project. The efficiency and level of construction management can be improved through effective management strategies, and the stability and reliability of construction quality can be ensured through fine quality control. In the future, with the continuous development of the construction industry, construction project management and construction quality control strategies will continue to improve and innovate, providing a strong guarantee for the development of the construction industry.

Disclosure statement

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References

[1] Zhang S, 2022, Research on effective strategies to improve construction management and construction quality control. Chinese Science and Technology Journal Database (full-text Edition) Engineering and Technology, 2022(8): 137–140.

[2] Li J, 2023, Research on Optimization strategy of high-rise building project Management and construction quality control. China Kitchen and Bath, 22(6): 94–96.

[3] Shen J, Zhang H, Li W, 2023, Analysis on effective strategies to improve construction management and construction quality control. Architecture and Decoration, 2023(11): 70–72.

[4] Zhang Y, 2022, Construction project management and Construction quality control strategy. Chinese Science and Technology Journal Database (Full text) Engineering Technology, 2022(5): 4.

[5] Wang Y, Li S, 2022, Research on effective strategies of construction management and construction quality Control. Building Materials and Decoration, 18(9): 120–122.

[6] Huang Y, 2022, Analysis of effective strategies for construction project Management and Construction quality Control. Building Materials and Decoration, 2022(010): 018.

[7] Cai J, 2021, A brief discussion on effective strategies of construction project management and construction quality control. Real Estate World, 2021(22): 99–101.

[8] Ning W, Zhang B, 2022, Improving construction project management and construction quality control of effective strategies. Brick World, 2022(1): 145–147.

[9] Li M, 2023, Improving construction project management and construction quality control of effective countermeasures. Journal of architecture development, 7(4): 7–9.

[10] Li Y, 2022, Effective strategies for improving construction project management and construction quality control. Building Materials Development Orientation, 20(3): 67–69.

[11] Luo Q, 2023, Strategy analysis on construction project management and construction quality control. China Science and Technology Journal Database Industry A, 2023(3): 4–4.

[12] Cao J, 2023, Analysis of effective strategies for construction project management and construction quality control. Metallurgical Management, 2023(17): 3–5.

[13] Qin S, 2023, Effective strategies for improving construction management and construction quality control. Urban Information, 2023(18): 0232–0234.

[14] Sun M, Zhang J, 2023, Research on strategies to improve construction management and construction quality control. China Science and Technology Journal Database Industry A, 2023(4): 4–4.

[15] Wang X, 2023, Research on effective strategies to improve construction management and construction quality control. Building Materials Development Orientation, 21(17): 40–43.

[16] Li W, 2019, Research on Effective strategies for Improving construction project management and Construction quality control. Building Materials Development Orientation, 22(5): 25–27.

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Integrated Project Library Exploration in Landscape Design Teaching for Environmental Design Majors

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Abstract: To enhance our talent cultivation model through "school-enterprise cooperation and industry-teaching fusion", we aim to improve the "4321" Industry-Education Integration System. This includes actively promoting the use of case banks and project banks in teaching to develop students' practical engineering skills through hands-on application of professional knowledge. Additionally, landscape design courses emphasize practical learning experiences to implement the fundamental goal of "cultivating morality". Guided by enhancing students' practical skills, we ensure alignment with course objectives and professional training requirements, emphasizing the seamless integration of theory and practice.

Keywords: Integrated project library; Environmental design specialty; Teaching practice

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1. Introduction

To achieve Chongqing's vision of becoming a "beautiful place with clear water", we need to implement municipal policies aligned with the city government's "Three Major Battles" and the "Eight Action Plans". These efforts are part of the urban enhancement action plan, focusing on the central urban area known as "100 Kilometers of Two Rivers and Four Banks". This area aims to exemplify the city's brand as a "City of Mountains and Water–A Beautiful Place" where the harmony of "mountains, water, city, and bridges" showcases the city's unique beauty and identity [1].

2. Project source of landscape design for comprehensive project library

The project site is located in Chongqing City's north bank of the Yangtze River, specifically the Diaoyuzui Peninsula in the southeast corner of Dadukou District. Covering 7.92 square kilometers with a riverbank spanning 10.26 kilometers, this area is part of Chongqing's main urban zone and is recognized as the city's "second peninsula". The Diaoyuzui Peninsula location in the main city of Chongqing has a smaller degree of riverfront land development but good traffic accessibility and ecological environment status [2]. The waterfront public space design of Chongqing Diaoyuzui Peninsula Diaoyu Most Ferry Plot can effectively improve the quality of the landscape along the river, and at the same time can be used as a model of ecological area design in the upper reaches of the Yangtze River [3].

Based on this, the project will begin with the exploration of natural resources, history, and culture of the Diaoyuzui Peninsula. It will integrate these findings with the on-site research to focus on the ecological adaptive design of the area, effectively improving the urban-water disconnection issues and enhancing the landscape quality along the river.

3. Project use of landscape design for comprehensive project library

After the completion of this project, it will be used by students in the "Landscape Design Comprehensive Practical Training" course in their 7th semester. This course is for undergraduate majors in landscape design and construction direction of environmental design. After researching each plot on the site and drafting an initial plan, students will conceptualize the analysis covering traffic, functional, and landscape structures. The site layout, vertical design, and traffic system design are finalized from the initial draft concept. Subsequently, students will further refine their design approach, addressing identified issues to complete the site plan, detailed node design, local perspectives, and aerial views.

4. Reasons for the selection of landscape design for the comprehensive project library

"Landscape Design Comprehensive Practical Training" is a practical course for environmental design majors. The course takes the project as the carrier, which has the characteristics of strong comprehensiveness and practicability. The course takes outdoor public space landscape design as the research object and makes comprehensive use of the case study method, project practice method, and summary method to master the principles and methods of public space landscape design. Students are required to master the basic theoretical knowledge of landscape design including design techniques and steps. They should be able to independently develop public space landscape project ideas, conceptual designs, and project presentations. This lays the foundation for students to excel in their internships and employment later.

In the face of limited resources, serious environmental pollution, ecosystem degradation, and other serious problems, the 19th Communist Party of China (CPC) National Congress report proposed to accelerate the reform of the ecological civilization system and build a beautiful China. Recently, in the current context and disciplinary background, waterfront space has become an important issue in the field of architecture and planning research in China [4].

The "Chongqing Main City Two Rivers and Four Banks Governance Enhancement Program" aims to transform the Diaoyuzui Peninsula into the Yangtze River Cultural and Artistic Bay Area. The plan is under consideration by the Planning Bureau. Studying the vitality of the city's waterfront public spaces in ecological civilization construction aims to better meet people's needs for a higher quality of life and is crucial for creating a beautiful China. Looking at the above relevant policies, the topic has significance due to the weak support of the current actual project of the course. The riverfront space renewal project of Diaoyuzui Peninsula in Dadukou, Chongqing, has a high degree of matching with the practical course, which can guarantee the teaching effect and the construction of the project is fully justified.

5. Construction of the main content and implementation conditions

According to the general idea of Chongqing Municipality's long-term plan "Work for 5 Years, Watch for 10 Years, and Plan for 30 Years", the "two rivers and four banks" of the main urban zone will be transformed into a scenic ecological belt and three-dimensional urban landscape belt. This will align with Chongqing's status as a centrally-administered municipality, a national central city, and a modern metropolis. The area will feature convenient and shared recreation spaces and a humanistic style aiming to create a top-tier international waterfront area that embodies the spirit of the mountains and rivers. It will be designed for optimal living, working, and traveling. To achieve the "international first-class waterfront belt" standard, showcasing Chongqing as a "City of Landscape–Beautiful Place", it needs to ensure that the "two rivers and four banks" achieve "smooth river, clear water, green shore, beautiful scenery". This initiative is part of the broader "City of Mountains and Water–A Beautiful Place" vision [5]. This project is based on the process of the Riverfront Space Renewal Project of Diaoyuzui Peninsula in Dadukou, Chongqing, and based on the course design guidebook and practical task book, the specific project content system is constructed and divided into four practical modules. Generally, the construction content of the following project modules is mainly a course design guidebook, practical project materials, and supporting lesson plans and courseware.

5.1. Pre-analysis and design theme conception module

Through this module, students are trained in pre-program research ability and design conception ability to master the research method of waterfront landscape design. Specific contents include topography, landscape pattern, natural vegetation, internal traffic, and landscape view. Additionally, cultural resources, future traffic, peripheral industries, and regional positioning are considered. This involves urban spatial structure extension and preliminary analysis, focusing on site topography, resource characteristics, and cultural aspects. Natural landscapes are emphasized alongside the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for future development, drawing from relevant case studies to inform clear design concepts expressed through analysis diagrams [6]. The pre-analysis module includes:

(1) Determine the research object and objectives of the specific design plot, emphasizing water resource protection and expanded use.

(2) Overall landscape structure analysis: speculate the design concept, divide the functional zoning, sort out the landscape sequence, analyze the tour route, etc. In addition to landscape detail analysis: pavement type and composition analysis, plant type and landscaping analysis, site vertical design, infrastructure analysis, etc.

(3) Advantages and suggestions for improvement: summarize the design advantages and make design suggestions for the deficiencies (with schematic analysis). Analyze the functions and forms of the land layout around the riverfront, the skyline of the riverfront, and the berms. Make it clear that the riverfront urban design project can optimize the urban environment and enhance the cultural value of urban water bodies.

(4) Form your design concepts and program ideas by learning from the best design cases.

5.2. General plan design module

Through this module, students are trained in the method and ability to put forward the leading design ideas from the current situation of the site and the future development plan. This encourages them to present the conceptual sketch successfully. Specific contents are guided by the formation of the preliminary program, which is the first draft design. This is then combined with the enhancing cognitive restructuring and optimizing component layout of the integrated program, which is the second draft. Thus, the general plan design module consists of:

(1) Preliminary program (first draft design): traffic organization, function division, landscape sequence, etc.

(2) Excavate the site's topographical qualities: resource characteristics, humanities, and natural landscape, analysis of the SWOT of the superior planning and future development with relevant case studies as the source of design ideas, and clear expression of design ideas in the form of analytical diagrams.

(3) Integrate the advantages and disadvantages of the group members' programs and determine the development direction of the program: landscape design of the land within the green line on both sides of the riverfront, and urban design composed of the local and hinterland area along the riverfront. Followed by studying the status quo of the mudflat and the mountain, sorting out the corresponding problems, and putting forward the solution paths.

(4) In-depth program: starting from the general plan layout, vertical design, ecological design, traffic system, etc., to form a more reasonable and refined program.

5.3. Sectional elevation drawing and effect drawing design module

Through this module, students are trained on elevation or landscape unfolding surface, site section drawings, all kinds of effect drawing expression, and design methods and abilities. Specific contents are to analyze the diagram, general plan, and all kinds of effect drawing expression and design. This module includes:

(1) 1-2 bird's eye view, 1-2 elevation or landscape unfolding surface, and 1-2 site section.

(2) Several local perspectives and the location of the index map.

(3) Classify the elements of the overall design study according to their role in shaping the city's characteristics and the geographic environment properties, clarify the role of each element in the overall environment, urban operation, living conditions of residents, regional cultural characteristics, etc., and form a waterfront public space landscape design that can be carried out independently.

5.4. Project analysis report writing, results presentation, exhibition board design and production module

Through this module, students are trained to be good at integrating multi-dimensional modifications into spatial design and expression of drawings. Additionally, they are trained in oral presentation and reporting skills to express the team's design ideas and to improve their adaptability to future work. This allows them to put forward modification opinions and instructions to the group proposal from multiple perspectives, and practice the ability to sort out and integrate the main opinions. Specific contents include text writing of design specifications, the production and layout of display panels, and the production of PowerPoint for reporting and defense. This module consists of:

(1) Using Photoshop, Autodesk 3ds Max, or other software to express the results visually.

(2) Report the program's results by detailing the design concept, plan and space layout, and important node composition.

(3) Exhibition board or PowerPoint production that includes interpretation of the current situation (including but not limited to the upper planning, site traffic, the current land and buildings, topography, hydrology, vegetation, etc.), planning interpretation (traffic, land, industry, etc.), case study (excerpts from the cutting-edge theories, the desirability of a typical case for analysis, refinement, summary), design concepts (justification, analysis of diagrams for the form), general layout, design layout and design of the program, and so on. As well as the general plan, design description, economic and technical indicators (floor area, land area, green space rate, etc.), related analysis (functional analysis, traffic

analysis, landscape analysis, vertical analysis, barge analysis, etc.), elevation or landscape expansion, site section, bird's eye view, and local perspective.

6. Summary of implementation measures

This project design develops implementation countermeasures from two aspects of the characteristic theme and overall design strategy of the Diaoyuzui Peninsula riverfront area.

(1) According to the project design documents and related information, current norms, regulations, and relevant technical standards, research results, analysis and argumentation, problem excavation, and insight, conceptual program design to complete the overall program design, public space enhancing design and comprehensive performance design of the riverfront area of Diaoyuzui Peninsula Area in Dadukou District.

(2) Digging deep into the development limitations of the area and putting forward problem-oriented design proposals according to the objectives of the overall design, analyzing the basic situation of the current environment of the design site, and putting forward specific and clear research contents on the construction activities of the site.

(3) Consider the ecological sustainability of the site in depth, and refine the design to complete the waterfront landscape design of Diaoyuzui Peninsula Area in Dadukou District.

(4) Comprehensively utilize the current height difference and natural resources, and organically lay out the environmental relationship of the site.

(5) Effectively explore the ecological sustainable design intervention, design key paths, and effectively promote biodiversity.

(6) The main design strategy from the city's unique natural, historical, and cultural characteristics to present the theme of the waterfront landscape design of the Diaoyuzui Peninsula area in Dadukou District.

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References

[1] Li S, 2022, Landscape Design of Fading Zone Based on the Concept of Resilient City, thesis, Shijiazhuang Railway University.

[2] Chen H, 2023, Research on landscape design of art district under industrial heritage reuse, thesis, Xinjiang Art Institute.

[3] Mu K, Wu L, Liu Y, et al., 2024, Research on ecological restoration design of waterfront slopes along four banks of two rivers in Chongqing. Water Resources and Hydropower Express, 1–14.

[4] Lanny, 2018, Research on Ecological Resources Protection and Planning of Tourist Attractions in the Northern

Foothills of Qinling Mountain, thesis, Xi’an University of Technology.

[5] Jiang H, Lan N, Mao Y, 2021, Discussion on the Ecological Design Method of Urban Waterfront Landscape–Taking Chongqing urban waterfront landscape design as an example. Beauty and Age (city edition), 2021(11): 51–52.

[6] Dai D, 2010, A Preliminary Study of Urban Design Methodology Taking into Account Protection and Development–Taking “Chongqing Hechuan Diaocheng Peninsula Urban Design” as an Example. China Urban Planning Society, Chongqing Municipal People’s Government Planning Innovation: Proceedings of the 2010 China Urban Planning Annual Conference; Chongqing Institute of Planning and Design, 2010:10.

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Whole-Process Project Cost Management Based on Building Information Modeling (BIM)

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Abstract: The whole-process project cost management based on building information modeling (BIM) is a new management method, aiming to realize the comprehensive optimization and improvement of project cost management through the application of BIM technology. This paper summarizes and analyzes the whole-process project cost management based on BIM, aiming to explore its application and development prospects in the construction industry. Firstly, this paper introduces the role and advantages of BIM technology in engineering cost management, including information integration, data sharing, and collaborative work. Secondly, the paper analyzes the key technologies and methods of the whole-process project cost management based on BIM, including model construction, data management, and cost control. In addition, the paper also discusses the challenges and limitations of the whole-process BIM project cost management, such as the inconsistency of technical standards, personnel training, and consciousness change. Finally, the paper summarizes the advantages and development prospects of the whole-process project cost management based on BIM and puts forward the direction and suggestions for future research. Through the research of this paper, it can provide a reference for construction cost management and promote innovation and development in the construction industry.

Keywords: Building Information Modeling (BIM); Project cost management; Data integration; Information sharing; Cost control

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1. Research background

With the continuous development and application of science and technology, the construction industry is also constantly ushering in new changes. The traditional project cost management mode has been unable to meet the increasingly complex project demand and the pressure of market competition. In this context, whole-process engineering cost management based on BIM came into being [1].

BIM or Building Information Modeling is a digital technology that integrates architectural design, architectural construction, and operation management. By integrating all the links of the building project, it forms a unified information model and realizes the comprehensive coordination and data sharing in the process of architectural design, construction, and operation. Compared with traditional two-dimensional drawings and manual calculations, BIM can provide more comprehensive, accurate, and reliable building information, which provides a better foundation for project cost management.

The whole-process project cost management refers to the whole life cycle of the construction project, from the early budget preparation, cost control in the design stage, to the cost analysis and change management, and then in the construction stage, to the later completion final account and operation cost control, the comprehensive management and control of the project cost. This management approach emphasizes coordination and communication at all stages of the project, as well as overall control of costs.

The whole-process engineering cost management based on BIM combines BIM technology with engineering cost management to realize comprehensive information sharing and collaborative management [2]. Through BIM technology, a comprehensive visualization of building projects can be realized, including building structure, equipment layout, material selection, and other aspects. At the same time, BIM can also conduct simulation and analysis to help engineers and managers to better understand the cost composition and influencing factors of the project to make more accurate decisions.

Whole-process engineering cost management based on BIM can also improve engineering efficiency and quality. Through BIM technology, we can work together among various project participants, reduce the error of information transmission and communication, and improve work efficiency. Additionally, BIM can also simulate and optimize to help engineers find and solve possible problems in the design stage and improve the quality of the project [3].

To sum up, whole-process engineering cost management based on BIM is an important way for the construction industry to meet technological changes. By combining BIM technology with engineering cost management, it realizes the comprehensive sharing and collaborative management of information and improves the efficiency and quality of the project. In the future, whole-process engineering cost management based on BIM will continue to play an important role in providing better support for the sustainable development of the construction industry.

2. Application of BIM in the whole-process of engineering cost management

The whole-process project cost management refers to a method of effective management of the cost in the whole process of a project. It aims to conduct a comprehensive and systematic control and management of the cost of the project through scientific methods and technical means to maximize the economic benefits of the project [4].

The goal of the whole-process project cost management is to ensure that the cost of the project is controlled within a reasonable range, and can be effectively managed and monitored in all stages of the project. It involves all aspects of the project, including project approval, design, construction, completion, and later operation and maintenance and other links.

Firstly, in the project approval stage, the goal of the whole-process project cost management is to determine the project budget and cost target and formulate the corresponding control measures. Through the analysis and prediction of the project demand, the budget of the project can be reasonably determined, and the corresponding control measures can be formulated according to the budget to ensure that the cost of the project is within a controllable range.

Secondly, in the design stage, the goal of the whole-process project cost management is to reduce the cost of the project by optimizing the design scheme. Through the comparison and evaluation of different design schemes, we can find the most economical and reasonable design scheme to reduce the cost of the project.

Thirdly, in the construction stage, the goal of the whole-process project cost management is to ensure cost control and cost saving in the construction process. By making a detailed construction plan, and reasonably organizing the construction process, the construction cost is kept within a reasonable limit.

Fourthly, in the completion stage, the goal of the whole-process project cost management is to calculate and evaluate the actual cost of the project. Through the accounting and evaluation of the actual cost of the project, we can understand the cost structure and cost deviation of the project, and provide a reference for later project management.

Finally, in the later operation and maintenance stage of the project, the goal of the whole-process project cost management is to control and manage the operation cost of the project. This is achieved by making a reasonable operation and maintenance plan, reducing the operation cost, and maximizing the economic benefits of the project [5].

In short, the definition of the whole-process of engineering cost management is to carry out a comprehensive and systematic control and management of the cost of the project to achieve the maximum economic benefits of the project. Its goal is to ensure that the cost of the project is controlled within a reasonable range and that it can be effectively managed and monitored at all stages of the project. Through scientific methods and technical means, the whole-process of project cost management can improve the efficiency of the project, reduce the cost of the project, and provide strong support for the successful implementation of the project.

The whole-process of project cost management refers to the comprehensive and systematic management of the project cost through scientific methods and effective processes in the whole life cycle of the project. The goal of the whole-process project cost management is to realize the economic, efficient, controllable, and sustainable development of the project.

The whole process of process of project cost management can be divided into the following stages: preliminary preparation stage, design stage, bidding stage, construction stage, and completion acceptance stage. At each stage, there are corresponding management methods and tools to ensure reasonable control and management of the project cost [6,7].

In the preparatory stage, the focus of the whole-process project cost management is to evaluate and analyze the feasibility of the project and determine the project budget and cost target. At the same time, market research and risk assessment are also needed to provide a basis for subsequent decisions. At this stage, commonly used methods include cost-effectiveness analysis, risk management, and decision support systems, etc.

In the design stage, the task of the whole-process of engineering cost management is to control and optimize the cost of engineering design. This includes the economic evaluation and cost estimation of the design scheme, as well as the evaluation and decision-making of the design changes and optimization scheme. At this stage, commonly used methods include cost estimation model, value engineering, and cost control techniques.

In the bidding stage, the focus of the whole-process of project cost management is to review and compare the bidding documents to ensure the selection of suitable contractors and suppliers. This includes the analysis and verification of tender offers and the evaluation and selection of tender proposals. Common methods in this stage include a bid review model, cost comparison, and supplier evaluation.

In the construction stage, the task of the whole-process of project cost management is to control and supervise the construction process. This includes monitoring and evaluation of construction progress and quality, as well as handling and decision-making on construction changes and claims. Common methods include construction cost control technology, schedule management, and quality management.

In the completion acceptance stage, the focus of the whole-process project cost management is to summarize and evaluate the cost of the project to ensure that the goal of the project is achieved. This includes the accounting and settlement of the project cost, as well as the evaluation and feedback of the project quality and customer satisfaction. At this stage, the common methods include the project cost accounting model, performance evaluation customer survey, etc.

In general, the process and method of the whole-process of engineering cost management is a system engineering, which requires a comprehensive use of various management technologies and tools. Through scientific methods and effective processes, the whole-process of engineering cost management can realize the economic, efficient, controllable, and sustainable development of the project. This is of great significance in improving the competitiveness and market value of engineering projects.

The purpose of the BIM technology application scheme is to utilize the characteristics of integration, accuracy, and compatibility as guidance for participating parties in cost control to realize the value-added of the project. In this regard, to leverage the strengths of BIM technology and achieve the implementation points, the following principles and ideas are put forward.

According to the goal of construction project cost control, the characteristics of BIM technology, and the differences among various parties, the application scheme of BIM technology in construction project cost control should follow the principle of project value-added, the principle of full participation and the principle of effective information [8]. Project value-added principle: the goal of construction project cost control is to realize the project value-added to the maximum extent, which is affected by the cost control effect of each stage and the degree of cooperation of all parties involved. The application of BIM technology is conducive to strengthening the control of the uncertainty in cost control and optimizing the allocation of project resources. To utilize the benefits, the application of BIM technology must align with the needs of all parties, prioritizing aspects that enhance project value. It encourages considering costs across the entire lifespan to achieve added project value. Principle of full participation: the longitudinal scope of the construction project cost control covers the investment decision of the construction project to all stages of the implementation, and the horizontal scope involves all elements and participants affecting the cost of the construction project. The application of BIM technology is conducive to solving the communication barriers promoting coordination between the parties, and assisting them to complete the corresponding cost control task according to the division of responsibilities. To fully exploit the benefits, it is necessary to build a five-dimensional building information modeling (BIM5D) management platform for all parties to share and provide information within the scope of authority. It is also necessary to adjust the cost control process and improve the cooperative working mechanism and participation of each party involved. Principle of effective information: the cost control of construction projects is accompanied by the generation and processing of a large amount of information and data, which has high requirements on the real-time, security, integrity, and accuracy of information. The application of BIM technology is conducive to improving the reliability of the decision-making basis, strengthening vertical multi-party communication, and realizing dynamic cost control. To capitalize on the advantages, it is necessary to build a BIM5D management platform to reduce the loss of horizontal information, feedback on the progress of project entities in real time, and avoid the problems of information redundancy and information isolation caused by repeated modeling and software differences.

The application level of BIM technology depends on the degree of meeting the needs of all parties and also determines the effectiveness of cost control. Therefore, the purpose of the BIM technology application scheme is to achieve demand transformation with the help of the technology, form value attraction to promote the active cooperation of all parties in cost control, and provide a direction for the realization of value-added projects [9]. According to the priorities, content, and attributes of different requirements, BIM technology is applied to solve them in different ways. According to the analysis of BIM technology and requirements, optimize the application of BIM technology in construction engineering cost control based on the principles of project value-added, full participation, and effective information. Specifically, build a BIM5D management platform to solve technical problems and meet the needs of function expansion and technical upgrading, such as strengthening visualization and analog features, improving graphic recognition rate, and supporting data linkage to ensure the effectiveness of information. Moreover, adjusting the cost control process to solve the problems of the organization and management level, and meet the needs of multiple cooperation and coordination, such as obtaining information according to authority, ensuring information security, and ensuring full participation. Among them, the BIM5D management platform is the basis for improving the cost control process, and the cost control process is a means to play the value of the BIM5D management platform, both of which are value-added services for the project.

BIM plays an important role in engineering cost estimation. It provides more accurate and reliable data, provides more efficient and visual tools, and can also provide a more comprehensive and sustainable analysis. However, its application still faces some challenges and limitations. Therefore, we need to further promote the development and application of BIM technology, strengthen training and education, and establish relevant standards and norms, in order to realize the maximum potential of BIM in engineering cost estimation. Only in this way can we make better use of BIM technology, improve the efficiency and quality of engineering projects, and promote the development of the construction industry [10].

Firstly, BIM technology can provide three-dimensional models of building projects, which provides intuitive and visual tools for project cost analysis. Through the BIM model, engineers and cost engineers can have a clearer understanding of the various parts of the construction project, including the structure, equipment, materials, etc. This allows them to more accurately assess the cost of the project and predict and adjust at different stages of the project. Simultaneously, the BIM model can also be integrated with other software, such as architectural design software and construction management software, to realize data sharing and collaborative work, and improve the efficiency and accuracy of project cost analysis.

Secondly, BIM technology can realize the information sharing and collaborative work of construction projects. Project cost analysis needs to involve many related parties, including architects, structural engineers, equipment engineers, suppliers, and so on. Traditional cost analysis often requires the exchange and sharing of information through paper documents or spreadsheets, which is easy to lead to inaccurate and incomplete information. BIM technology can realize the centralized management and sharing of building project information, and each relevant party can input and view the data on the same platform, thus reducing the error and time cost of information transmission. This makes the project cost analysis to more accurately reflect the actual situation of the project and provides a more reliable basis for the project decision-making.

Thirdly, BIM technology can also realize the simulation and optimization of building projects. In the project cost analysis, it is necessary to evaluate and compare the various schemes of the construction project to determine the most economical and reasonable scheme. Traditional cost analysis often requires manual calculation and hypothetical scenarios, which is cumbersome and error-prone. BIM technology can digitally simulate and optimize different schemes by building models and applying simulation software to quickly get the best scheme. This not only improves the efficiency of the project cost analysis but also reduces the impact of human factors on the results, making the decision-making more scientific and reliable.

In general, BIM technology plays an important role in engineering cost analysis. By providing an intuitive and visual three-dimensional model, it realizes the comprehensive and accurate project cost analysis. Furthermore, it improves the efficiency and accuracy of the project cost analysis through information sharing and collaborative work. Simulation and optimization of building projects produce a more scientific and reliable cost analysis. With the continuous development and application of BIM technology, it is believed that it will play a more important role in the future of engineering cost analysis.

3. Conclusion

The conclusion of whole-process engineering cost management based on BIM is based on the management and control of the whole-process of project cost based on the building information modeling (BIM). BIM is an integrated digital technology that enables information to be shared and work coherently during architectural design, construction, and operation. The whole-process of project cost management refers to the process of comprehensive management and control of the cost in the whole life cycle of the project. Through the whole-process project cost management based on BIM, the accurate prediction, efficient control and optimized management of the project cost can be realized. This management mode can improve the efficiency and accuracy of project cost management, and reduce the risk and cost of the project. Therefore, the whole-process engineering cost management conclusion based on BIM has practical significance and research value. Through the application and case study of the actual engineering project, this conclusion can be further verified and improved, and provide a scientific basis and guidance for the practice of project cost management.

Disclosure statement

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References

[1] Luo M, 2016, Analysis of the applicability of BIM in construction project cost management. Information construction, 2016(6): 134–135.

[2] Liu Y, 2021, Based on the applicability analysis of BIM in the construction project cost management. Smart Building and Smart City, 2021(4): 111–114.

[3] Yu-Mei W, 2019, Analysis of the applicability of BIM in construction project cost Management. Bohai Rim economy, 2019(7): 82–83.

[4] Chao M, 2019, Research on the application of BIM technology in the whole-process engineering cost management projects. Residence, 2019(35): 145.

[5] Ruan X, 2018, Discussion on the application of BIM technology to the whole-process engineering cost management. Engineering Technology Research, 2018(11): 32–33.

[6] Sha X, 2020, Discussion on the application of BIM technology in Construction engineering cost management. Brick and tile, 2020(5): 137 + 139.

[7] Sun D, 2020, Discussion on the application of BIM technology in Construction engineering cost management. Brick and tile, 2020(5): 129–130.

[8] Hu Z, Sun S, 2022, Application of BIM technology in the whole-process management of construction engineering. Construction and Budget, 2022(4): 1–3.

[9] Yu Y, 2021, Whole-process engineering cost management based on BIM. Residence, 2021(36): 130–132.

[10] Deng X, 2021, on the application of BIM technology in the whole-process of cost management. Equipment Engineering of China, 2021(24): 244–245.

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Cost Management and Cost Control of Photovoltaic Projects

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Abstract: With the rapid development of the photovoltaic (PV) industry and policy support, photovoltaic engineering has attracted much attention as a clean energy project. However, the complexity and huge investment scale of photovoltaic projects make cost management and cost control the key to project success. The purpose of this paper is to discuss the cost management and cost control strategies of photovoltaic projects, analyze their importance and challenges in the process of project implementation, and discuss the common cost control methods and techniques in photovoltaic projects, to improve cost management and cost control in photovoltaic projects, and to provide a reference for the sustainable development of the industry.

Keywords: Photovoltaic engineering; Cost management; Cost control

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1. Introduction

Photovoltaic engineering project investment is characterized by a shorter construction period and a larger total investment compared with other engineering construction, which needs to be rapidly constructed and put into use within a limited time [1]. The whole process of cost management has become an important way of cost control in modern engineering construction, and effective measures must be taken in the decision-making, designing, bidding and purchasing, construction, and completion stages of the project to strengthen the control of key factors affecting the investment to achieve the coordination and unity of organizational management, technical management, and economic management. Therefore, in photovoltaic engineering projects, it is crucial to manage costs and control investment risks in a timely and effective manner to improve the efficiency of project execution and management levels. As a clean, safe, and sustainable energy source, photovoltaic power generation has been rapidly developed in recent years. However, the high cost of PV projects has been one of the main bottlenecks restricting its large-scale application. Therefore, strengthening the cost management and cost control of PV projects is of great significance in promoting the healthy development of the PV industry.

2. Status and background of photovoltaic power generation project

The continuous progress of PV power generation technology and the rapid decrease of cost are the main driving force for the development of PV market. With the continuous maturity and large-scale application of PV power generation technology, the cost of PV power generation will be further reduced, and the future development potential is huge. Photovoltaic engineering is a technology that utilizes photovoltaic cells to directly convert solar energy into electricity. Currently, a variety of high-efficiency PV materials and technologies, such as monocrystalline silicon, polycrystalline silicon, copper-zinc-tin-sulfur, and chalcogenide, are being developed and utilized, which significantly enhance the efficiency of PV power generation. The application areas of PV engineering cover a wide range of residential, commercial, and industrial applications. Driven by policy encouragement and market demand, more PV power plant construction projects have been launched globally, especially in countries such as China, the United States, and Germany. For example, China, as a large country in the PV industry, is not only experiencing a rapid increase in installed PV capacity in its domestic market but also exporting the PV products it produces to all parts of the world. Although PV technology has great potential for development, it still faces challenges such as cost, technology storage, and weather dependence. Future research is likely to focus on reducing costs, improving conversion efficiency, and developing more reliable energy storage systems. In addition, with the global pursuit of reducing carbon emissions and alienating fossil energy sources, PV engineering is expected to be promoted and applied on a larger scale.

3. Whole process cost management of PV engineering

The costs of a photovoltaic project mainly include equipment costs, installation costs, other costs of engineering and construction, and financial costs. Among them, equipment cost is the main component of PV project cost, accounting for more than 70%. Installation costs include PV module installation, inverter installation, racking system installation, electrical equipment installation, and so on. Other costs of project construction include land costs, design costs, supervision costs, grid connection costs, etc. The financial cost mainly refers to the interest on the project loan.

3.1. Cost management in the investment decision-making stage

3.1.1. Selection of plant site

In the investment decision-making stage of the photovoltaic project, the choice of plant site is one of the important factors affecting the investment benefit of the photovoltaic project. When selecting the plant site, factors such as favorable geographic location, suitable climatic conditions, low land use costs, and convenient power supply should be fully considered to provide favorable conditions for the subsequent construction and operation of the project [2].

3.1.2. Selection of equipment and materials

The selection of equipment and materials is directly related to the quality and performance of the project. The quality of equipment such as photovoltaic modules, inverters and transformers directly affects the project. Therefore, it is necessary to choose reliable big brands to ensure that the equipment is good and stable to improve the project quality and power generation efficiency.

3.1.3. Selection of racking

The bracket system plays an important role in supporting and fixing PV modules in PV projects, which directly affects the stability and life of the system. When selecting the bracket, it is necessary to make comprehensive considerations according to the geographic conditions of the project, power limitation, bidding rules, and so on. It is important to select the bracket model suitable for the actual needs of the project so that the bracket system meets the engineering design requirements and can effectively support and fix the PV modules. This ensures the stability and reliability of the construction and operation of the project.

3.2. Cost management in the design stage

The whole process of cost management in the design stage is critical to the successful implementation of the project. In the design stage, the following three points are key cost management measures.

3.2.1. Design bidding by introducing a competitive mechanism

In the design bidding stage, through the introduction of a competitive mechanism, can prompt the design schemes to compete with each other and finally select the best design scheme. During the bidding process, the design solutions will be comprehensively evaluated in terms of safety, practicality, aesthetics, and economic rationality to ensure that the final selected design solution meets the needs of the project and has a high cost-effectiveness.

3.2.2. Introduction of design supervision

The introduction of design supervision is crucial to the construction drawing design process, and its main responsibilities include: reviewing whether the design is consistent with the preliminary scheme and norms and standards, providing rationalization suggestions on equipment selection, new materials, and new techniques, and coordinating multi-departmental cooperation to prevent changes in demand to ensure the consistency and quality level of the design scheme.

3.2.3. Implement limit optimization design and strictly control design changes

The project design stage should focus on cost control, strive to optimize the design scheme under the premise of meeting the functional requirements, and strictly control the design changes, especially the major changes that may increase the project cost. Avoid unreasonable changes, keep the investment strictly within the budget, and ensure the economic benefits and financial sustainability of the project.

3.3. Cost management in the evaluation stage of the feasibility study report

In the feasibility study report evaluation stage, cost management is a key link to ensure the economic feasibility of the project and investment efficiency. The following are the key points of cost management that need to be paid attention to at this stage:

3.3.1. Attention to rate standards

The importance of reviewing the rate system is self-evident in the review of the feasibility study. Rates, as the pillar of comprehensive cost accounting of the project, comprehensively cover many areas including the cost of measures, incidental expenditures, profit expectations, and tax expenditures, and are customarily presented in the form of a percentage [3]. During the evaluation process, it is important to focus on and review the reasonableness and accuracy of the rate standards to ensure that the rates are set following the actual situation and to avoid deviations and risks in the cost estimation. Only by confirming the accuracy and reasonableness of the rates can the uncertainty of the cost be effectively reduced, providing a more reliable guarantee for the successful implementation of the project and investment benefits.

3.3.2. Attention to related cost items

In the evaluation stage of the feasibility study report, special attention should be paid to related cost items, including equipment cost, equipment supervision cost, and production preparation cost. Equipment costs cover transportation and miscellaneous fees, transportation insurance fees, procurement and storage fees, and many more which must be verified in detail during the evaluation to ensure the accuracy of the calculation and avoid cost estimation errors. Equipment supervision costs are usually calculated together with the construction supervision costs, which should not be double-calculated, and its reasonableness needs to be confirmed. The calculation standard of production preparation costs needs to be carefully reviewed and calculated according to the percentage of the equipment costs to ensure that the calculation method is justifiable, and coordinated with other related costs. Through careful review and confirmation of relevant cost items, the project cost can be effectively managed and controlled, and the economic efficiency and return on investment of the project can be improved under the premise of ensuring the accuracy of the cost calculation, to lay a solid foundation for the smooth implementation and successful operation of the project.

3.3.3. Pay attention to the quantity and price of major equipment and materials

The evaluation should make a detailed assessment of the quantity and price of equipment and materials to ensure the accuracy and reasonableness of the estimate. When the feasibility study and general contracting are both handled by the same company for Engineering, Procurement, and Construction (EPC), special attention should be paid to the reliability of the data and prices to avoid bias and overblown costs. Only by carefully assessing and checking the volume and price of major equipment and materials can we ensure the truthfulness and reliability of the project cost estimation and avoid additional costs and risks caused by distorted data [4].

3.4. Cost management in the implementation stage

3.4.1. Reasonable control of material dosage and material price

In the cost composition of the photovoltaic power plant, the proportion of equipment and material expenditures is quite high, most of the time it will occupy the range of 60% to 80%. The price of PV modules, more conspicuously occupies at least half of this huge cost. This high proportion of material and equipment prices has a decisive impact on the overall cost of the project. Because the core of the photovoltaic power generation project lies in the utilization of solar modules, the cost of these components accounts for a large proportion of the overall project cost, directly affecting the project’s economy and profitability.

3.4.2. Strengthen project budget audit and settlement according to the quota

In addition to the common EPC general contracting mode, some of the fragmented projects in the photovoltaic power generation project will also use comprehensive unit pricing. Through the strict audit and review of the quota, the cost of the project can be effectively controlled to ensure the accuracy and reasonableness of the project investment. Projects using the comprehensive unit pricing mode can more accurately control the cost of each construction element and ensure the accuracy of the project budget.

4. Cost control program for the whole process of photovoltaic project

4.1. Cost management in the project establishment stage

In the bidding process of the design unit, the owner needs to carefully prepare the bidding documents to clarify the project requirements and technical principles, such as the project scale and access voltage level, to provide clear guidelines for the design unit to carry out its work. This helps ensure that the design unit understands the specific requirements of the project and improves the quality and efficiency of the design [5]. At the same time, clear requirements and technical guidance help reduce the risk of changes and additional costs in the later design phase. Additionally, investment estimation is an integral part of the project establishment phase. Through investment estimation, the owner can better understand the overall cost of the project, laying a foundation for subsequent budget control and cost management. This not only helps to plan capital expenditure but also provides important reference information for the project's financial plan and investment strategy. Based on determining the scale of project investment, the owner can better grasp the economic feasibility of the project and provide a basis for subsequent project promotion and management.

4.2. Cost Management in project design and bidding stage

4.2.1. Bidding process of EPC enterprises

Cost management is extremely important in the project bidding process and needs to follow the "one center, two basic points" principle. Among them, "one center" is to focus on the preparation of bidding documents to ensure the project needs and requirements. The "two basic points" are the key operation in the bid evaluation process where one aspect focuses on the total price to ensure that the overall cost of the project is controllable while the other aspect focuses on the unit price, carefully analyzing the cost of each element of the construction to ensure that the cost of each specification is reasonable [6]. By strictly controlling these two basic points, project costs can be effectively managed to ensure the economic feasibility and sustainability of the project.

4.2.2. Design phase

(1) Full preparedness: Insufficient design or inadequate preparation is a common problem in many projects. Therefore, in the initial stage of project initiation, the owner should abandon the tendency to prioritize speed and shorten the construction cycle, and should instead reserve sufficient time for the design phase to ensure the depth and quality of the design, thereby laying a solid foundation for the project's success.

(2) Typical design: Typical design is based on the rich experience of designers and scientific research results, and combined with the design model that has been proven effective in practice. This design method can significantly improve the quality and efficiency, and provide a solid foundation for the smooth implementation of the project.

(3) Design of limits: In the control design phase, the focus is on managing the cost of specific engineering components, such as the inverter room, booster room, comprehensive building, distribution room, and other individual structures, to ensure that the planning is completed within the budget constraints. By setting separate limits for each part, the cost of each project can be effectively managed and controlled to guarantee that the project operates stably within the budget. This fine-limit design method can help the project team better monitor and manage the cost of each building, thus securing the project's economy and sustainability.

(4) Value engineering and optimized design: Through value engineering, costs can be reduced and efficiency improved without compromising the quality of the project. Optimization design, on the other hand, is to continuously optimize the solution during the design process to achieve the best design effect and economy. All these methods help to improve the design level of the project and guarantee that the project runs smoothly and achieves the expected results. The organizational chart of the design phase in shown in **Figure 1**.

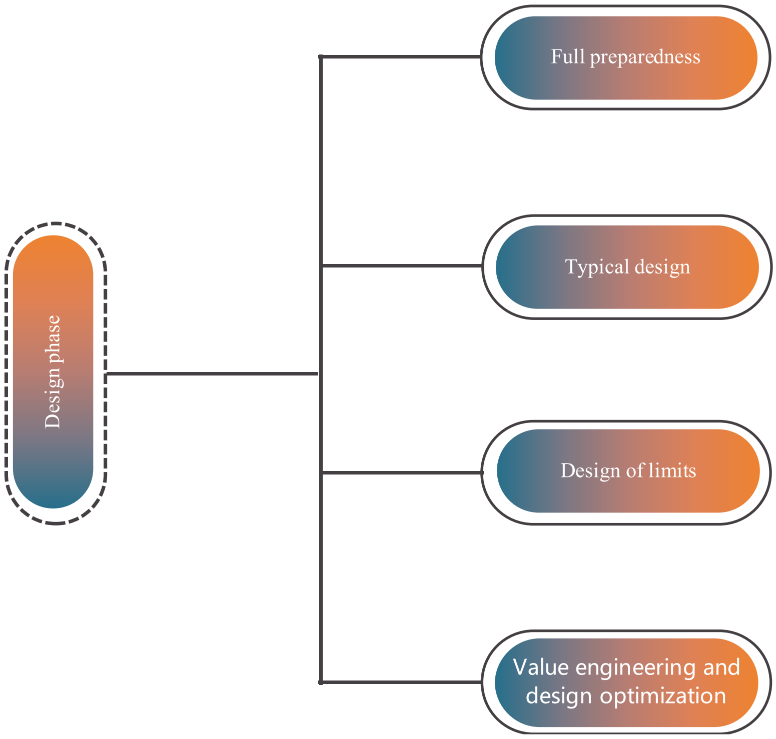

Figure 1. Organizational chart for the design phase

4.2.3. Procurement phase

(1) Optimize supplier relationship: Establish a win-win relationship, promote communication, and ensure a stable supply of resources.

(2) Specialized procurement: Hire experts, formulate precise strategies, and optimize the procurement process to ensure high quality and high efficiency.

(3) Strengthen internal audit: Establish a comprehensive audit system to monitor the procurement process, ensure compliance and efficiency, improve the quality of supplier services, reduce costs, and improve project efficiency. The establishment of a sound audit system can effectively supervise and manage the procurement activities of the project, assuring the compliance and transparency of the procurement process, and helping reduce the procurement risks and costs.

4.3. Cost control in the construction phase of the project

4.3.1. Progress control

In PV project construction management, the owner's precise management throughout the pre-construction, mid-construction, and post-construction stages is crucial. During the preparatory stage of construction, the owner has to clearly set the project progress target and specifically agree with the contractor on the construction tasks and key time points. To effectively monitor the progress of the project, it is necessary to exhaustively plan the phasing of construction and the expected completion time. During the construction process, due to the complexity of the work processes, the progress of the project should be dynamically monitored, and strategies should be adjusted on time to keep the construction running smoothly and to quickly respond to and deal with any problems that arise [7]. Simultaneously, potential risks, such as delays in the provision of design drawings, design errors, delays in supplier deliveries, inefficiency of the construction team, and the impact of inclement weather, needs to be considered in all aspects, and solutions should be formulated in advance to ensure the smooth progress of the project. Precise management, flexible scheduling, and risk prevention are the keys to a smooth PV project. To prevent these risks, the project team needs to be prepared for possible problems in advance and formulate corresponding risk response strategies to guarantee the normal progress of the project.

4.3.2. Cost control

To control project costs, the first thing to do is to clarify the spending targets for each stage. This requires the development of a detailed cost plan, which lists the projected spending for each phase so that we can monitor and adjust it at any time. Followed by paying close attention to the gap between the actual spending and the plan. Once overspending is detected, the reasons should be analyzed immediately and measures should be taken to correct it to ensure that the project cost will not be out of control. By formulating a reasonable cost plan and taking corrective measures in time, we can effectively control the project cost and ensure that the project is carried out smoothly.

4.4. Acceptance stage cost control

In the project acceptance stage, the focus of cost management is to accurately complete the project settlement. To ensure a smooth settlement process, it is necessary to set a fair contract pricing mechanism, implement practical and effective settlement strategies, and establish a reliable dispute-handling program [8].

(1) Determine a reasonable contract pricing method: The contract pricing method should be able to accurately reflect the project cost and comply with the provisions of the contract. Through the reasonable pricing method, the accuracy and reasonableness of the settlement can be ensured, and the cost deviation caused by the improper pricing method can be avoided.

(2) Implementation of practical settlement measures: When carrying out the completion of the settlement work, it is necessary to develop a detailed settlement program to clarify the basis for the calculation of the costs and the settlement provisions. This ensures that the settlement process is based on evidence to avoid confusion and loopholes.

(3) Establish effective dispute resolution: In the settlement process, some disputes may arise, so it is necessary to develop a clear dispute resolution mechanism. Timely handling and resolution of disputes will help guarantee the smooth progress of the settlement work and ensure that the cost control objectives of the project can be realized.

5. Conclusion and prospects

The cost management and cost control of photovoltaic projects is a key link to ensure the successful completion of the project. Through reasonable budgeting, strict cost accounting, and effective cost control, the cost of the project can be effectively managed to ensure that the project is balanced in terms of quality, time, and cost. In the future, with the continuous development of the PV industry and technological innovation, the cost management and cost control of PV projects will face new challenges and opportunities, and it is necessary to continuously improve the management level and introduce new cost control techniques and concepts to adapt to the changes in the market and the industry. This guarantees a future where PV projects can be implemented and completed efficiently and sustainably.

Disclosure statement

The author declares no conflict of interest.

References

[1] Huang L, 2023, Cost Management and Cost Control of Photovoltaic Project. Engineering Construction and Design, 2023(23): 262–264.

[2] Wang Q, Wang H, 2022, The Whole Process Cost Management of Photovoltaic Power Generation Project. China Power Enterprise Management, 2022(27): 72–73.

[3] Chen Z, Li L, Yu L, 2022, Main Influencing Factors and Control of Centralized Photovoltaic Project Development Cost in Post Parity era. Sichuan Hydropower, 41(06): 112–115.

[4] Song X, 2022, Cost Control of the Whole Process of Photovoltaic Power Generation Project. Value Engineering, 41(30): 7–9.

[5] Wang K, 2011, Research on the Application of Project Management in the Whole Process of Photovoltaic Power Generation Project, thesis, North China Electric Power University.

[6] Li M, Dai C, Que W, et al., 2018, Whole Process Cost Control of Photovoltaic Power Generation Construction Project. Housing and Real Estate, 2018(15): 27 + 33.

[7] Jiang J, 2010, Analysis of the Necessity of Supervision Work in the Design Stage. Science and technology economic market, 2010(02): 39.

[8] An T, 2020, The Application of Cost Control in Photovoltaic Project. Modern Economic Information, 2020(05): 25 + 27.

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Research Progress and Prospect of Road Dust Suppressants

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Abstract: Road dust has great adverse effects on traffic quality, traffic safety, atmospheric environment quality, and human health. Therefore, with the continuous development of modern science and technology, the research of road dust suppressants is also progressing. To promote the rational application and development of road dust suppressants, the research progress and prospects of them are analyzed in this paper. It includes a basic overview of road dust suppressants, the main types, the usage and precautions, and the main development direction. It is hoped that this analysis can provide some reference for further research and development of road dust suppressants.

Keywords: Road dust suppressant; Main types; Precautions; Development direction

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1. Preface

The 12th Five-Year Plan puts forward the requirements of control and monitoring technology for Particulate Matter with a Diameter of 2.5 Micrometers or less (PM2.5). As a crucial method for controlling PM2.5, the development and improvement of chemical dust suppressants and road dust suppressants are becoming increasingly urgent. From the point of view of hygiene and environmental protection, road dust not only seriously harms the physical and mental health of mining personnel, but also pollutes the environment around the mining area and destroys the ecological balance. From the technical and economic point of view, serious road dust pollution will cause greater economic losses, high road dust concentration, and visibility decline, not only will the driving speed be limited, but the vehicle spacing will increase, resulting in a significant reduction in the transportation capacity of dump trucks, but also may lead to vicious crashes and other accidents. Therefore, dust emission control is of great significance for curbing the generation of haze weather, improving the atmospheric environmental conditions in China, and suppressing the occurrence of respiratory diseases, especially pneumoconiosis.

2. Basic overview of road dust suppressant

2.1. Brief introduction

Road dust suppressant is a chemical substance designed to inhibit dust on road surfaces. Its primary goal is to reduce the generation and dispersion of dust, preventing significant amounts from escaping into the atmosphere. This helps to protect traffic safety, the atmospheric environment, and human health.

2.2. Mechanism and core

In terms of the current road dust suppressant, there are three main dust control mechanisms which are solidification, wetting, and coagulation, and its core content is as follows:

(1) The core of solidification is to make the road have greater strength so that it will not be damaged under the shear friction of the moving object, dynamic pressure, tensile condensation, and other effects.

(2) The core of wetting is to keep the moisture of the road between 10% and 40% so that the dust has a greater density, which can reduce the rate of decline and achieve good dust suppression [1].

(3) The core of coagulation is to ensure the dust generated by the road wear layer has a particle size of more than 80 mesh, so that the dust has a settling speed of more than 0.1 m/s, and finally the dust is effectively suppressed.

2.3. Application advantages

Road dust suppressant is reasonably applied in road projects, and its application advantages can be shown in the following aspects:

(1) This substance can form a protective layer on the road surface, binding the small sand and dust particles to prevent them from being lifted by the wind, thereby reducing air pollution and minimizing human health hazards.

(2) The protective layer formed by this substance has effective oil-proof and waterproof properties, which can protect the road surface from erosion caused by oil and rainwater, thus further extending the service life of the road [2].

(3) The protective layer formed by this substance can effectively reduce the friction coefficient between the road surface and the vehicle, so that the vehicle can move more smoothly and steadily, thus reducing the wear and tear of the vehicle and improving the driving experience.

(4) The substance does not contain any toxic, harmful, or polluting components, with good environmental performance [3]. With these advantages, road dust suppressants have been more widely used in the field of modern road engineering dust suppression. The application and development of such substances have become the focus of relevant researchers in recent years.

3. The main types of road dust suppressants at present

In terms of the commonly used road dust suppressants, there are four main types: wetting road dust suppressant, bonding road dust suppressant, cohesive road dust suppressant, and composite road dust suppressant. The following is an analysis of the basic situation and research on these four main types of road surface dust suppressants.

3.1. Wetting road dust suppressant

The main components of wetting road dust suppressants include surfactants and some inorganic salts. The main role of the surfactants is to reduce the surface tension of the solvent system to achieve good foaming, emulsification, wetting, penetration, and other application effects. The main role of inorganic salts is to make up for the lack of surfactants in water retention and moisture absorption so that their role is better played. This kind of road surface dust suppressant is more applicable in the field of coal dust suppression nowadays, and it is more often used in the front-line field of coal mine comprehensive mining surface and atmospheric dust reduction. In recent years, the road surface dust suppressant and the existing road surface dust removal devices have realized a well-integrated application, which can further improve the road surface PM2.5 removal efficiency [2]. In the subsequent research and development, researchers began to devote themselves to the research of more inexpensive wetting-type road dust suppressants.

3.2. Adhesive road dust suppressant

Binder-type road dust suppressants can be further subdivided into two types according to different raw materials. The first one is organic chemical bonded road dust suppressants, whose main components are polymers, resins, carbon cellulose filter media, lignin derivatives, bio-oil residues, olive oil residues, asphalt, cinder oil, paraffin oil, petroleum residue oil, crude oil, and some other organic substances. At the same time, such dust suppressants can be divided into four families, including synthetic resin, lignin, cellulose, and starch. Its main advantage is that the raw materials are easy to obtain and inexpensive, and the preparation technology is relatively mature. After practical research and application, it can be seen that most of the cellulose and lignin organic chemical bonding road dust suppressant bioaffinity and its hydrophilicity are very good. It can play an effective inhibition of industrial waste gas and heavy metal dust and has good pressure resistance and cold resistance [4]. At the same time, this kind of road dust suppressant also has better biodegradability than other road dust suppressants, especially lignin road dust suppressants, which have significant performance advantages.

The second is the inorganic chemical bonding type dust suppressant, whose main components are acid, kaolin, gypsum, clay, fly ash, calcium oxide, and halide. After practical research and application, it is found that this kind of road dust suppressant has a better dust-fixing effect in road engineering, but its emulsification performance is relatively low. To make better use of the raw materials, in the subsequent study, the researchers need to achieve a multifunctional composite effect by adding better additives, to further improve its application performance.

At present, the bonded road dust suppressant has been widely used in the fields of dust suppression on bare ground, in open dumps, in construction sites, and on roads. Simultaneously, it has demonstrated improved performance in practical applications. It is believed that in the subsequent continuous research and development, this kind of road surface dust suppressant will play a higher application value in the field of road engineering.

3.3. Condensed road dust suppressant

Cohesive road dust suppressant belongs to a kind of chemical hygroscopic inorganic salt form of cohesive agent. For this kind of road dust suppressant, the current domestic and foreign research is mainly concentrated in the field of calcium oxide (CaO), calcium dichloride ($CaCl_2$), magnesium dichloride ($MgCl_2$), and sodium chloride (NaCl), and other inorganic salts with high water absorption. In 1963, the former Soviet Union reported for the first time that $CaCl_2$ with strong hygroscopicity was uniformly sprayed in the amount of 0.6 kg/m^2 on the mine road with high relative air humidity, which could effectively inhibit the dusty situation of the road, and the effective period of dust prevention could reach 45–90 d [5]. Regarding CaO, $MgCl_2$, and NaCl, scholars, such as Wang and others, found through research that these inorganic salt materials have better moisture absorption properties under natural environmental conditions, but compared with the other two inorganic salts, the moisture absorption and dust suppression effect of NaCl can only be well played under high humidity conditions [6]. With the advantages of good hygroscopicity and evaporation resistance, cohesive road dust suppressants have been widely used in the field of road dust control in the early stages. However, in the subsequent application, it was found that the moisture-absorbing effect of this kind of road surface dust suppressant was easily affected by the temperature or the salinity of the land so the road surface dust-suppressing effect played in the actual application was not stable. With the continuous development of cohesive road dust suppressant preparation technology, many snow-melting agent-type cohesive road dust suppressants began to be widely used in road projects, and its application effect is more prominent than the traditional inorganic salt type cohesive road dust suppressant.

3.4. Compound road dust suppressant

With the research and development and application of various new materials in recent years, as well as the continuous improvement of the actual application demand of road dust suppressants, composite road dust suppressants began to realize faster development in the field of road engineering. Especially in complex, harsh, and changing environments of road engineering conditions, to avoid failures with single road dust suppressants, researchers conducted an in-depth study of composite dust suppressants tailored to local conditions. Through relevant studies, it is found that the development of compound road dust suppressants by coupling various synthetic technologies is very effective, and it is also a main development direction of road dust suppressants in the future. Usually, the main preparation techniques of composite road dust suppressants include solubilization, emulsification, ion chelation, coordination and copolymerization, and other coupling. However, due to the relatively short development time of this technology, the coupling mechanism is not mature enough, so the development and preparation of this type of road dust suppressant is still difficult. To effectively solve this problem, researchers also need to carry out in-depth research on the coupling mechanism of such road dust suppressants.

4. Methods and precautions of road dust suppressant

4.1. Methods

In the practical application of road dust suppressants, reasonable control of the usage method is the key to ensuring its dust suppression effect. It is known from the established practical application and research summary that, usually, the road dust suppressant can be used according to the following methods:

(1) Dilution: According to the proportion determined in the study, the road dust suppressor was diluted with water to form a solution.

(2) Preparation of spraying equipment: Sprayers or spray guns are used as spraying equipment for the road dust suppressant, and the equipment should be clean enough so that no residue of pollutants or other substances could affect the application performance of the road dust suppressant.

(3) Spraying: The prepared spraying equipment should be used to spray the diluted road dust suppressor onto the road surface that needs to be treated with dust suppression. The spraying distance and spraying angle should be controlled strictly according to the research and design standards [7].

(4) Maintenance: After completing the spraying treatment of the road surface dust suppressant, the staff needs to regularly do the inspection and maintenance of the road surface in the dust suppression area according to the actual situation, and when the dust is found to rise, the road surface dust suppressant needs to be sprayed again [8].

4.2. Precautions

To give full play to the application effect of road dust suppressant and meet the actual demand of modern road engineering, it is necessary to pay attention to some precautions in the application process. The precautions in the application of road dust suppressant mainly include the following aspects:

(1) Before use, its basic chemical properties and safe operating procedures should be fully defined, and the operation should be carried out in strict accordance with the recommendations in the manual.

(2) During the spraying process, the staff must do a good job of their protection, such as wearing protective clothing and goggles to avoid road dust suppressant getting in contact with their skin and eyes [9].

(3) Road dust suppressant and other chemical agents should not be mixed, so as not to impair the effect of dust suppression or produce toxic and harmful substances to pollute the environment.

(4) The road dust suppressant should be stored in an area away from open fire and high temperatures to avoid unnecessary accidents. This way, not only can the dust suppression effect of the road dust suppressant be better utilized, but also can further ensure the safety of its application.

5. The main development direction of road dust suppressant

With the increasing awareness of ecological and environmental protection in modern society, the application requirements of road dust suppressants are also constantly improving. The existing road dust suppressants are also non-toxic, harmless, and have good ecological and environmental performance since most of these substances are synthetic chemical substances. However, in practical applications, if the environment is more complex or contains some other chemical components, under the joint action of various factors, the road dust suppressants will inevitably have a chemical reaction and produce toxic and harmful substances. Based on this, biodegradable road dust suppressants with high ecological and environmental performance have become the main development direction of such substances [10].

To meet this development goal of road dust suppressants, researchers need to make more effort to research new ecological and environmental protection materials and adopt more advanced biological technology to prepare corresponding biodegradable suppressants, so that their performance can be adjusted according to the actual environmental changes. Additionally, researchers can also combine the actual situation of highway engineering and its specific application needs, multi-functional composite road dust suppressant, and special road dust suppressant research. In this way, the road dust suppressant used in the project can achieve better performance in dust suppression and provide greater ecological and environmental protection. It helps avoid reactions with other chemicals that could produce toxic pollutants, ensuring a safer and more reliable application.

6. Conclusion

To summarize, road dust suppressant is one of the most critical dust suppressants in the field of road engineering. To make the road dust suppressant play a better effect of dust suppression, its formula and preparation process are becoming more complex and diverse. Multifunctional composite dust suppressants and special dust suppressants have become the main direction of the current research. However, due to the current research on the mechanism of multifunctional composite dust suppressors is still in the initial stages, in future research, researchers need to establish a complete set of performance characterization methods and analysis methods. Based on the comprehensive understanding of the principle of the existing preparation technology, the mechanism of the coupling preparation technology of compound dust suppressors was discussed by selecting suitable materials, so that more excellent road dust suppressors could be brought to the market.

Disclosure statement

The author declares no conflict of interest.

References

[1] Liu Y, Zhang Y, Meng D, et al., 2024, Progress of Research and Application of Road Dust Suppressant. Environmental Protection and Circular Economy, 2024(4): 36–39.

[2] Zhang W, Zhu B, Wang Y, et al., 2024, Research on the Application of Compound Dust Suppressant in Road Construction Site. Modern transportation technology, 2024(2): 38–44.

[3] Zhang D, Zhang Y, Zhang W, et al., 2024, Progress of Chemical Control Technology of Construction Site Dust. Environmental Science and Management, 2024(3): 112–117.

[4] Chen H, Lin Y, Shi Y, 2024, Research on the Development Status of Infrastructure Dust Suppressants. Environmental Protection Frontier, 2024(2): 367–371.

[5] Wei Q, Gao G, Xu Y, 2023, Research Status and Prospect of Coal Mine Dust Suppressants in China. Modern Mining Industry, 2023(9): 49–53.

[6] Wang H, Wu C, 1996, Study on the Anti-Evaporation Property of Hygroscopic Inorganic Salt-Water System. Gold, 17(12): 28–31.

[7] Liu J, Wu C, Chen Z, et al., 2022, Optimization of the Formulation and Performance Test of the Foam Dust Suppressant for Transportation Road Surface in Open Pit Mines. China Production Safety Science and Technology, 18(5): 163–169.

[8] Zhao X, Du J, Xia S, et al., 2024, Development and Industrial Test of a Moisturizing Dust Suppressant for Truck Roads in North Surface Coal Mines. Journal of Environmental Engineering Technology, 14(2): 446–454.

[9] Zhang S, 2022, Application and Research of Dust Suppressants. Cleaning the World, 38(9): 51–53.

[10] Liu L, Lu W, Chen Y, 2024, Study on the Synergistic Wetting Effect of Gel-Forming Dust Suppressants on Coal Bodies. Safety, 45(1): 31–36.

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Research on Planning and Design of Multi-Story Prefabricated Electric Bicycle Charging Parking Lot in Urban and Rural Areas

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Abstract: In recent years, disorderly parking and difficult charging of electric bicycles have been challenges in urban management. The rapid growth of electric bicycles is in contradiction with the lack of dedicated parking spaces and charging service facilities in towns and villages. To solve the issue of parking and charging electric bicycles in limited urban and rural spaces, prefabricated building technology is applied to the design of a multi-story electric bicycle parking lot. The multi-story prefabricated electric bicycle parking lot is utilized in urban and rural planning and design to upgrade parking facilities in old urban areas, land-constrained commercial areas, as well as counties, towns, and rural areas with inadequate municipal facilities. Multi-story prefabricated electric bicycle parking lots are the application exploration of industrial buildings, and promote the high-quality development planning and construction of towns and counties and villages. Compared with the single-story metal charging station, the multi-story assembled electric bicycle parking lot has the characteristics of integrating parking and charging, being more durable and safer in structure, accommodating a large number of vehicles, and improving the space utilization rate.

Keywords: Prefabricated building; Electric bicycle; Parking lot

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1. Introduction

Since 2022, the number of electric bicycle sales in China has grown exponentially after governments around the country relaxed their policies on electric bicycle driving. China is currently the world's largest electric bicycle production and sales country, and now electric bicycles have gradually become the main means of transportation for people to commute. According to statistics, at present, there are nearly 400 million electric bicycles in China, but the existing urban and rural construction planning lacks special parking spaces for electric bicycles, charging facilities, and parking lots, which leads to indiscriminate parking of electric bicycles and illegal occupation of municipal roads and urban public space, affecting residents' daily traffic. Random charging causes fire and explosion, causing safety hazards to society. Therefore, to solve the parking and charging problems of electric bicycles in towns and villages, the design of a multi-story prefabricated electric bicycle charging parking lot is conceived [1].

2. Policy background, theoretical analysis, and research hypothesis

According to the statistics of the National Fire and Rescue Service from 2022–2023, there were 18,000 fires caused by electric bicycles nationwide in 2022, and 21,000 similar fire accidents in 2023, an increase of 17.4% [2]. The popularity of electric bicycles does not adapt to the original urban planning, causing a series of problems in society. When residents use electric bicycles daily, there is a lack of specified parking spaces in urban and rural areas, whether in residential areas or towns.

Due to the increasing number of battery-induced fires caused by improper use of electric bicycles, more local governments and residential property management companies prohibit residents from bringing electric bicycles into the house to charge batteries. Some even prohibit residents from parking electric bicycles in residential areas and buildings. This has caused conflicts between the government, property management companies, and electric bicycle users [3]. The parking, charging, and safety management of electric bicycles have become a difficult problem for local governments. More cities, towns, and villages have tried to solve the problems of residents using electric bicycles, such as “parking difficulties, charging difficulties, management difficulties,” and introduce management methods for electric bicycle charging and parking, hoping to alleviate the problem of electric bicycles becoming a fire hazard in towns and villages. Local street and residential property management companies are also trying to find some relatively independent safe areas in the limited space of the city, and simply transform these areas to set up temporary parking spots for electric bicycles, equipped with charging facilities to centralize management of electric bicycles. At present, the recommended electric bicycle parking shed on the market is mainly open-air, single-story side parking, and the structure is a very simple welded metal steel bar. However, the number of parking lots is small, the structure is not durable, and the fire resistance is poor. Based on the above analysis, this paper proposes three hypotheses to solve the parking problem of electric bicycles in the long run:

(1) The existing space (comprising of the original parking lot and garage) of the urban residential area is transformed to enhance its utilization rate and establish a multi-story three-dimensional electric bicycle parking lot to fulfill the residents’ demand for parking nearby.

(2) During the planning and construction of counties, towns, and villages, enhance the planning and design of municipal roads, the allocation of public parking lots and charging facilities. Utilize the limited land to construct multi-story charging parking lots for electric bicycles and raise awareness of orderly and standardized parking and charging among residents in counties and villages.

(3) Using the structural characteristics of prefabricated buildings to design and construct multi-story electric bicycle parking lots, to achieve the requirements of a fast construction period, saving space, accommodating a large number of parking spaces, and simple facility configuration.

3. Current status of electric bicycle parking

3.1. Urban and rural planning lagging behind the demand for electric bicycle use

3.1.1. Analysis of urban parking of electric bicycles

Firstly, the existing non-motor vehicle parking spaces in society are planned according to the size of bicycles, the number of bicycles owned by each family, and the previous usage habits [4]. In the existing urban space, most of these parking spaces have been parked with bicycles and urban shared bicycles. As a result, the remaining parking spaces for non-motor vehicles can no longer accommodate the increasing number of electric bicycles.

Secondly, although the electric bicycle is mostly classified as a non-motor vehicle with its size (1,700 mm × 500 mm × 1,100 mm) being closer to the motorcycle (1,890 mm × 250 mm × 940 mm). The parking area is 1.2–1.8 times that of the ordinary bicycle, so the required parking space is larger. With the surge in the number of electric bicycle users in recent years, the existing non-motor vehicle parking spaces are difficult to meet the parking needs of electric bicycles, resulting in no designated areas to park, thus users park wherever they please. This results in various chaotic situations (**Figure 1**).

This leads to a few problems. Firstly, indiscriminate parking. Many electric bicycles do not comply with the required parking areas, causing issues like occupying pedestrian pathways and other vehicle parking spaces. Secondly, illegal occupation. Some electric bicycles are parked in areas where parking is prohibited, such as fire passages, residential corridor spaces, and various public spaces in cities, which bring hidden dangers to evacuation and emergency paths during emergencies. Thirdly, non-standard parking. Some electric bicycles are not placed neatly and are stacked too high when parked, resulting in blocked vision, traffic obstacles, and safety hazards.

Figure 1. Electric bicycles and other vehicles occupy parking spaces on urban roads (Source: Beijing News, 2024-04-11)

3.1.2. Analysis of parking electric bicycles in counties, towns, and villages

With the improvement of the living standards of residents in counties, towns, and villages, the number of cars and electric bicycles owned by residents has increased year by year. The demand for vehicle parking is in contradiction with the current situation that the road system planning of counties and villages has not been perfected for a long time (**Table 1**). For example, the roads in villages and towns are narrow and curved, the mountain roads have ups and downs, and some roads are not equipped with pedestrians and non-motorized lanes, parking lines, or parking spaces. This mixed traffic of people and vehicles causes daily safety hazards for "residents. Additionally, there are more broken roads and fewer pedestrian bridges. Residential buildings are mainly single-story or multi-story self-built "handshake buildings" with dense spacing. Once these buildings lack parking spaces, only a few have motor vehicle parking garages inside the first floor, which is shared with the living room. The population density of towns and villages is high but there is a lack of planning and construction of large underground and above-ground public parking lots, as well as a serious shortage of public facilities such as charging stations. The per capita income of township residents is not high, and their educational level and quality are limited. Most people are not accustomed to paying for parking, so families with many electric vehicles often charge them directly in self-built houses or park them outside (**Figure 2**). Additionally, there is a lack of property management units in counties, towns, and villages, and many migrants live there. To facilitate charging and parking, disorderly parking and charging of electric bicycles is common, increasing the fire risk compared to cities.

Figure 2. Dongguan Street Village self-built hall corridor electric bicycle parking (Source: China Industrial Network, 2024-01-03)

Table 1. Analysis of current planning problems of municipal road system in towns and villages

Status quo	Results in	Solution measure
Urban planning is backward and management approval lagging behind	The construction of self-built houses is not humanized, the space is small, and the distribution is dense	Improve the planning system, adjust and standardize the follow-up construction
The municipal system is not well-planned	The roads are narrow and winding, and people and cars are mixed	Widen the road and install non-motorized lanes
Municipal land planning is inadequate, and some roads are not equipped with pedestrian and non-motorized lanes	There are more broken roads, fewer pedestrian bridges, and fewer traffic green belts and buffer zones	Open up the broken road, set up pedestrian bridges, green belts, buffer areas, and increase the municipal transport land
Regional financial funds and non-agricultural land are tight, and there is a lack of public support facilities	There is no parking spaces, few public parking lots, and no charging facilities for electric bicycles	Increase the number of parking spaces, build parking lots in villages, and make more use of three-dimensional parking lots

3.2. Random charging of electric bicycles is dangerous and has caused many fires

At present, most electric bicycles in China use lead-acid batteries, with a small portion using lithium batteries. Lead-acid battery-powered electric vehicles require non-removable charging. Therefore, electric bicycle parking facilities need to have charging functions to ensure battery life. Electric bicycle manufacturers recommend that users maintain the battery charge between 20% and 90% as much as possible. Users should charge their bicycles promptly after daily use. The optimal time to charge is when 50%–70% of the driving distance has been used, with a full charge generally taking 6–10 hours [5]. Since there are small numbers of slow charging facilities on the market, users will save trouble by bringing the batteries or electric vehicles to residential buildings to charge and risking accidental fires by randomly connecting wires to charge. Since 2022, there have been more than 10,000 electric bicycle fires across the country, causing casualties. Illegal parking and charging of electric bicycles bring danger to the living environment. Accidents occur in old cities, urban villages, counties, towns and villages, and other areas. These densely populated and built-up areas are at high risk. Once a fire starts due to wire aging, it can quickly spread to surrounding buildings, easily causing casualties.

4. Overview of project research

4.1. Design introduction

Prefabricated concrete modular building technology is a new type of building technology that has been applied to a certain extent in the domestic market in recent years. In addition to the application of prefabricated buildings in residential and public buildings, its application scope can be further expanded to the design and construction of parking lot buildings [6]. The design of the multi-story prefabricated electric bicycle charging parking lot combines with the requirements of "sunshade, rainproof and safe non-motor vehicle parking lot and facilities should be set according to the local bicycle infrastructure construction" when the existing buildings in Shanghai are renovated [7]. As well as the latest requirements of the Notice on Issuing the Regulations on the Allocation of Parking Spaces for Construction Projects in Guangzhou issued by the Guangzhou Municipal Bureau of Planning and Natural Resources in July 2023, the allocation of parking spaces are 100% construction of charging facilities to meet the needs of direct meter installation and power connection and to address the parking and charging of electric bicycles as design purposes. The whole parking lot is assembled and constructed by prefabricated high-performance concrete panels and prefabricated staircases at the site of the project. There are a few production module components that can be modified and customized according to different space sizes and required layers. The space between the existing buildings is transformed to build an electric bicycle parking place with a charging function. It is suitable for old urban areas, commercial areas with land shortages, and counties, towns, and rural areas with insufficient municipal facilities [8].

4.2. Design site selection and analysis

Electric bicycles are the daily means of transportation used by residents. **Table 2** shows the statistics and analysis of residents' current parking status and usage of electric bicycles. Ease of use is the primary requirement, followed by the number of parking spaces, charging facilities, fire resistance, safety management issues, etc. Parking requirements close to home result in residents parking electric bicycles in a "haptic parking" manner. This is also the key to the subsequent series of contradictions. Electric bicycle parking space should be as close to the residence as possible. **Figure 3** shows the location of parking spaces for electric bicycles. The parking problem of electric bicycles is more related to the transformation of the existing building community [9]. At present, many local governments, such as Longyan City, Xiamen City, and Qingyuan City in Fujian Province, have issued policies to include centralized electric bicycle parking and charging fields in the renovation of old residential areas [10–12].

Table 2. Electric bicycle parking status and residents' demand statistics

Current state	Design requirement
Lack of space to park, parking scattered	Close to the residence
The existing parking is inconvenient and the number of parking spaces is small	Enough parking space, centralized parking, easy to take and place
Lack of charging stations, fire risk, lighting, and other facilities	The parking space is fully equipped with charging stations, fire protection, shading, rain protection, lightning protection, lighting, drainage and monitoring facilities
Causing safety hazards, space occupancy, and fire problems	Safe parking space, centralized parking
The contradiction between government, property management, and users	Property companies and residential district business committees, village committees can assist management
The outdoor space is disorderly and the supporting facilities are insufficient	Interior space with sufficient facilities
Urban planning and current policies lagging behind	Rational planning and people-oriented

The overhead floor of connected residential buildings is taken as the design site. As shown in **Figure 4**, bicycles can only be placed in a single layer in the original space, and they are placed in a disorderly manner.

The tenants' electric bicycles lack space to be placed, and can only be placed in various odd spaces of the community, which affects the entry and exit of other residents and cause security risks. Therefore, the utilization rate of the space is explored, the number of parking spaces are increased, and the space is transformed into a prefabricated three-story electric bicycle charging parking lot in the form of a three-dimensional parking garage. The parking lot has 3 stories above ground, with a length of 1,620 mm and a width of 9,000 mm. Each level is 2,200 mm, with a net height of 1,900 mm and a total height of 6,800 mm. The total construction area is 437.4 m^2. The parking lot is divided into 3 rows, creating 3 charging parking areas on each floor, with an average of 20 charging parking spaces per area and 53 charging parking spaces per floor, as shown in **Figure 5**. Each parking space is 1.02 m^2, each parking area is 145.8 m^2, and the total number of parking spaces across the 3 layers is 159. The facility also features a "car-electric separation and sharing power change mode." Additionally, there are 2 smart charging cabinets, each capable of charging 12 electric bicycle batteries. Based on the assumption that each family owns 1 electric bicycle, the parking lot can accommodate the charging and parking needs of up to 183 households [13].

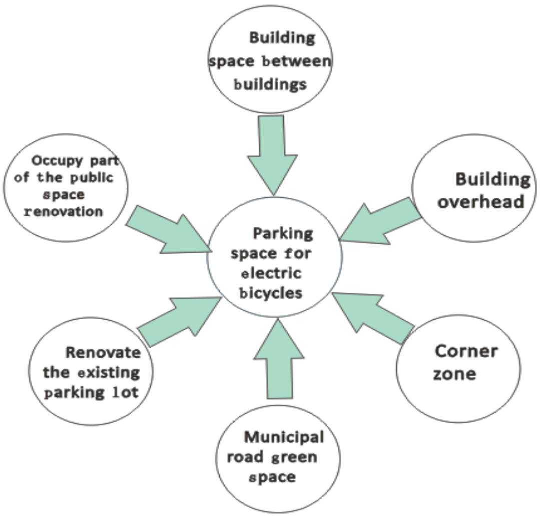

Figure 3. Electric bicycle parking space analysis diagram (based on **Table 2**)

Figure 4. Status of non-motor vehicle parking in building space of a residential district (Source: Photo by Liya Fang)

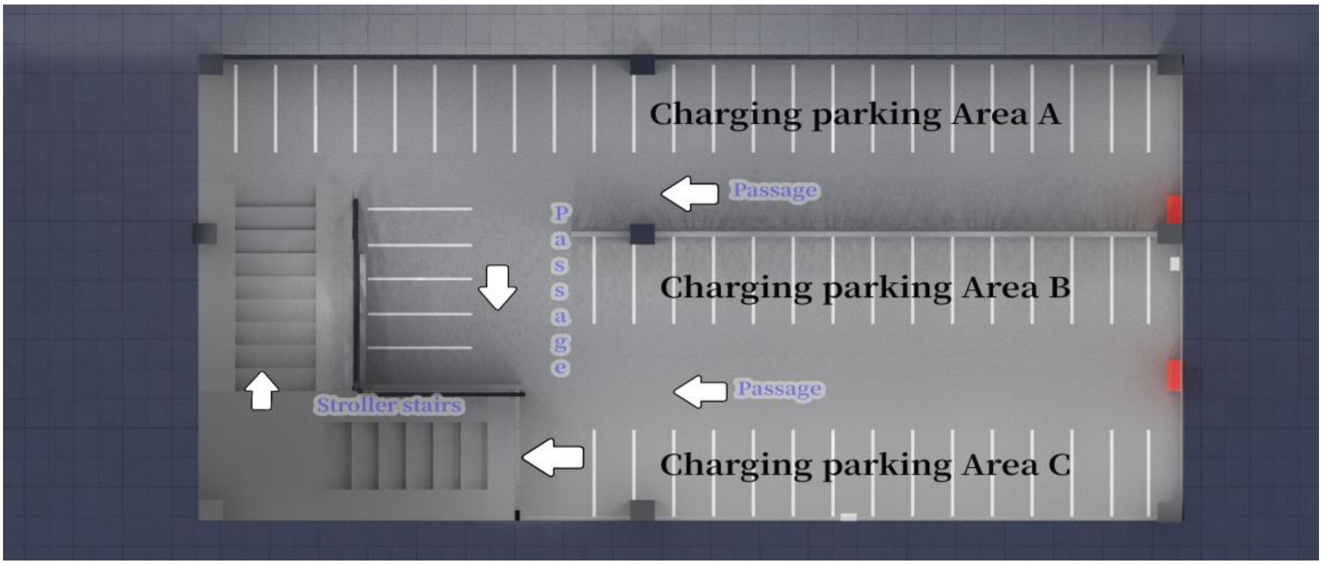

Figure 5. The second-floor layout of the prefabricated multi-story electric bicycle parking lot (Source: Design by Liya Fang)

Figure 6. 3D design of multi-story assembled electric bicycle charging parking lot at multiple angles (Source: Design by Liya Fang)

4.3. Design model of a multi-story prefabricated electric bicycle charging parking lot

The prefabricated electric bicycle parking lot as shown in **Figure 6** is an integral frame structure [14]. The load-bearing design of the main parts is based on live load, with either an independent or raft foundation used depending on site conditions. Most parking lot buildings adopt prefabricated construction technology, with both external and internal walls being clean walls. The main precast concrete components are floor slabs (composite slabs with embedded pipelines), vertical wall slabs (composite slabs with embedded pipelines), frame columns, composite beams, and staircases [15]. Secondary accessories include metal railings, stair railings, control boxes, main electricity meters, explosion-proof lighting fixtures, lightning protection grounding facilities, surveillance cameras, charging sockets, metering meters, and barrier-free facilities. Fire equipment accessories include fire extinguishers and smoke alarms. Using C35 concrete, HRB400 rebar, a 400 × 400 mm wall column, with the minimum thickness of each prefabricated floor is 120 mm and the thickness of the vertical wall panel is 60 mm. The thickness of cast-in-place is not less than the prefabricated part, and the surface of the prefabricated board is made into a rough surface [16]. The span of the laminated floor is designed according to the standard mode of the actual situation. The prefabricated staircase is anchored directly into the cast-in-place portion of the laminated slab through steel bars to form a strong connection to the main body. The concrete members of the exterior wall frame of the parking lot are fixed by connecting them to the existing wall of the building with the connecting parts. The prefabricated components used to assemble the multi-story parking are attached with material information, clearly indicating the installation position and size, and a two-dimensional code sticker is attached to facilitate the construction workers to check the construction method of the components by scanning the code with their mobile phones. The precast concrete component wall panel is embedded in the hydropower pipeline according to the design drawings, and the pipeline layout is ensured to meet the safety distance. The first floor of the parking lot is equipped with a general distribution box, and each floor must be equipped with explosion-proof lighting fixtures, drainage pipes, and lightning protection grounding facilities. Continuous drains should be set up around the first-floor plate to discharge rainwater to the nearest municipal pipe well, to ensure that parked electric bicycles can be charged normally even in thunderstorm weather. The top floor of the parking lot can be equipped with solar panels or photovoltaic panels to collect environmentally friendly energy as the supplementary power supply of the parking lot [17].

The parking lot is an open environment, the parking method of vehicles is vertical, and each parking space is 1,700 mm × 600 mm. The channels width is 1,700 mm, the two-stage stairs are used with the staircase width at 2,500 mm, and the two sides of the tread are provided with 600 mm wide up-and-down push lanes. Users can walk a few steps from the residential building to the first-floor entrance of the prefabricated multi-story building to enter the parking lot. Each floor of the parking lot is divided into three charging areas, A, B, and C. Each charging area is equipped with an intelligent charging meter, to achieve a multi-control machine that can jointly control 20 outputs and charge 20 vehicles at the same time. In the future, users will be able to use the shared parking mode, and each parking lot will be equipped with parking markings and charging sockets [18]. Users can connect the charging plug of electric bicycles at the parking lot, and charge them by swiping bank cards or scanning the QR code with the WeChat program. The smart meter has a current detection function. When the smart meter detects that the electric bicycle in the parking position is fully charged or the load power is too large, the socket will automatically turn off power as protection to prevent safety hazards caused by overload and short circuits. The smart charging meter installed will charge according to the charging time, which is convenient to use.

4.4. Project benefits

4.4.1. More durable and safe structure

Most of the existing electric bicycle charging stations on the market are single-story iron-made charging sheds (**Figure 7**). This kind of charging station is generally located next to municipal roads or in open spaces of urban blocks. Several galvanized square pipes are used as structural supports, and colored steel plates are simply welded and coated with anti-rust paint as the ceiling, built-in with a charging meter and electrical socket. The temperature has a great impact on the battery, and the battery should be stored in an environment of 0℃ ~ 20℃ and no higher than 40℃ [5]. Poor battery quality, short circuits of wires, high temperature, or overcharge will damage the battery, and cause combustion or explosion. Once it burns up, the fire spreads fast, the duration is long with high temperatures. It is not easy to extinguish, resulting in a large number of toxic fumes leading to emergency escape difficulties, which is easy to cause casualties. In 2024, there were several fire accidents caused by the charging or spontaneous combustion of electric bicycles in electric bicycle sheds in Guangzhou (**Figure 8**). In many cases, the fire is caused by electric bicycle batteries. The time taken from the start of the fire to the explosion took only 40 s and produced a lot of smoke. Within three minutes, the temperature reached 1,200℃, causing the ambient temperature to exceed 660℃. This high temperature can burn people near the iron-made charging station and cause the structure to melt and collapse, forcing people to escape. The prefabricated multi-story electric bicycle charging parking lot uses concrete and steel as main component materials, the wire tube is embedded in the concrete module, the circuit design is more standardized, and has lightning protection and grounding facilities. With waterproof, lightning protection, and high-temperature resistance characteristics, the service life can reach up to 10–20 years which is more durable and safe than the iron-made charging station. **Table 3** shows the parking forms and comparative analysis of electric bicycle parks.

Figure 7. Metal electric bicycle charging shed (Source: Photo by Liya Fang)

Figure 8. An electric bicycle shed fire in Haizhu district, Guangzhou (Source: The Paper, 2024-07-05)

Table 3. Electric bicycle parking form and comparative analysis

Form	Advantage	Shortcoming
Single-deck type	Simple construction, short cycle, low cost, short life, less car storage, scattered	The number of vehicles accommodation is small
Outdoor	Simple construction, flexible use of the site, weak vehicle protection, quick depreciation of facilities, large parking lot numbers, and scattered distribution	Electric vehicle failure from sun and rain: battery overheating from sun, short circuit from rain
Elevated indoor	Effectively shade from the sun and rain, generally single-story parking, easy to use, more concentrated distribution	Lack of lightning protection and fire protection facilities, battery-induced fire can easily spread to other vehicles and surrounding buildings
Multi-story indoor structure	A large number of vehicle accommodations, shade from the sun and rain with lightning protection, vehicle protective wall, easy-to-support charging facilities, convenient centralized access, long building life	Construction requires a larger space, higher cost than other forms

4.4.2. Meeting the number of vehicles, simultaneous parking and charging, saving time and cost

The current electric bicycle charging station only has a single-story structure, and can only charge 10–20 vehicles at the same time. The user must calculate their electric bicycle charging time, and park the vehicle in other areas after charging. This mode of separation of parking and charging does not meet the needs of users. The multi-story assembly electric bicycle charging parking lot not only meets the needs of users to charge and park simultaneously but also uses the principle of three-dimensional space. By overlapping the assembly plate in the city, counties, towns, and villages, from single-story to multi-story, the number of electric bicycle parking charging stations increased several times, and the location outside the parking space is equipped with an intelligent charging cabinet. This provides users with the function of a battery charging cabinet to meet the requirements of unified charging, unified management, and storage. After the parking lot is completed, the electric bicycle charging power supply for residential use will have an electricity unit price of ¥0.59, which is lower than the average unit price of ¥0.9/kWh (¥0.50 for electricity and ¥0.40 for service fee per hour) at commercial charging stations. Reducing user charging costs supports the sustainable development of green power vehicles [19].

4.4.3. Flexible site selection and smaller use of space for construction

Because of its higher safety, the prefabricated parking lot can be set up closer to residents with flexible and diverse locations. It can not only be built in the public space of cities, counties, towns, and villages, but also in the elevated floors of residential buildings, podium buildings, and the space in between buildings. The building facade wall panels can be easily built in the factory through molds. It includes the texture of fair-faced concrete, decorative brick, stone, and various textures of decorative concrete, which are integrated into the original residential areas as public service facilities [20]. Prefabricated components are adopted, and most of its components are produced in the factory. After the component materials are transported to the site, the assembly construction can be completed using the original site space of the residential area. The construction period is short by avoiding the large area of on-site material processing sites, office facilities, and temporary facilities. Moreover, as a structure, the construction procedure of the parking lot is simple thus construction costs are more economical.

4.4.4. Example analysis

In 2011, the United States has adopted the prefabricated building technology to build parking lots. The Green Square parking lot building developed by the government in downtown Raleigh, United States, adopts the precast concrete frame structure inside, which can accommodate 900 parking spaces. The external wall of the building uses solar blades as the energy supply for the whole building (**Figure 9**) [21]. China's Jinan city built the country's first prefabricated multi-story underground civil air defense garage in 2023, and Wuhan is also building the country's largest assembled integrated parking building. The external wall of the building uses solar blades as the energy supply for the whole building (**Figure 10**) [22,23]. In recent years, with the development of three-dimensional parking equipment technology, intelligent information systems, and charging equipment, the form of a mechanical three-dimensional garage has made a qualitative leap. The form of the parking frame not only has a simple lifting, pit, horizontal, and lifting platform, but the overall structure has also developed from the past simple open-air steel frame type to the current combined with the building frame parking building. Various forms of three-dimensional bicycle parking racks have also appeared in the market. In the renovation of the old city, in the face of limited space, developers choose the combination of mechanical three-dimensional garages and an intelligent parking system to improve space utilization. For example, Yangtao Square, 1906

Science Park, located in Zhongshan Seventh Road, Liwan District, Guangzhou, formerly known as the old factory of Guangzhou Cigarette Factory, will be revitalized and transformed into a food experience park in 2023 as an old city industrial park. The developer has built two large intelligent mechanical three-dimensional garages, which greatly solves the problem of parking difficulties around the old city [24]. In addition, the parking garage combines electric vehicle charging pile technology, integrating parking and charging, and users can utilize license plate recognition and intelligent parking management services by pressing the button according to the operation prompt on the first floor of the parking garage (**Figure 10**). All these cases provide the technical basis for the design and research of a multi-story prefabricated electric bicycle charging parking lot.

Figure 9. USA Green Square parking lot (Source: Construction Network)

Figure 10. 1906 Science Park Yang Tao 3D Square parking lot (Source: Photo by Liya Fang)

5. Preparations before construction

Before the on-site construction of the multi-story prefabricated electric bicycle charging parking lot, the stacking site of prefabricated components should be a hardened site to ensure smooth drainage around the site and consider factors such as lifting capacity limitations [25]. During the construction of the parking lot, the push and place positions of the components should be designed and separated according to the structural requirements and lifting capacity, the transport approach of the prefabricated components, the placement points of the lifting equipment, the lifting and stacking routes should be calculated, and the installation and construction plan should be prepared to meet the lifting and installation of each component [26].

5.1. Technical control point of the construction process

The pre-buried casing or reserved hole at the wall and floor of the pipeline should be reserved in place on the prefabricated component at one time, the specifications should meet the requirements, and the coordinates and elevations should be correct. The production unit of prefabricated components should formulate production plans according to the site use requirements, design, and construction requirements of the user. After the precast concrete is poured, it should be operated and maintained promptly according to the provisions of the state concrete maintenance. After the precast member reaches 75% of the design value of the concrete compressive strength, and the cube compressive strength is not less than 15 N/mm, it can be demolded. The joint surface of all precast members and cast-in-place concrete should be rough, and the roughness should meet the requirements of JGJ1-2014, Technical Specification for Prefabricated Concrete Structures, while the convex of exposed coarse aggregate should be uniformly and continuously distributed along the entire assembly joint surface.

Mold requirements and inspection of prefabricated components are crucial to ensure the quality of final products. Firstly, the materials selected for the mold should have quality certificates or inspection reports. After the mold assembly is completed, it is necessary to carry out hair removal, rust removal, slag cleaning, and other work. The surface of the steel mold in direct contact with the concrete of the component should be evenly coated with a release agent. Secondly, for components with higher appearance requirements, special attention must be given to the splicing of templates, particularly at the junctions of the side and bottom molds. To prevent leakage that could negatively impact the component's appearance, it is essential to use sealing materials such as water sealing strips. Finally, the permissible size deviations and the methods for inspecting the prefabricated component mold must comply with the Technical Specification for Prefabricated Concrete Structure JGJ1-2014 [27]. Adhering to these specifications ensures that the prefabricated components meet the required standards of quality and precision.

The power switch, charging and billing equipment, fire hydrant box, and fire extinguishing equipment in the parking lot should be open-mounted. Also, the equipment should be placed clearly and easily, and assigned to check and maintain regularly.

6. Feasibility of urban and township electric vehicle parking lot planning transformation

6.1. Latest measures to standardize the parking management of electric bicycles across the country

Sanyanli Village, Baiyun District, Guangzhou is one of the urban villages in Guangzhou. There, in May 2024, an electric bicycle fire broke out at an outdoor charging point, causing several electric bicycles, shops, and outdoor billboards nearby to burn. After the fire, the government at all levels in Guangzhou organized personnel to investigate the illegal parking and charging problems of electric bicycles and adopted a series of fire prevention management measures. Sanyuanli Village and many other villages in Guangzhou prohibit electric bicycles from being parked in villages and residential areas [28]. The implementation of permits and parking registration for residents' electric bicycles, along with strict monitoring of vehicle parking status, involves regional urban management personnel working with the village committee and street office for extensive inspection of parking practices. Additionally, several simple electric bicycle charging booths and parking points have been constructed outside the area. While these measures may help reduce the risk of fires caused by electric bicycles, they do not address the fundamental issue of insufficient parking for electric bicycles at the source (**Figure 11**).

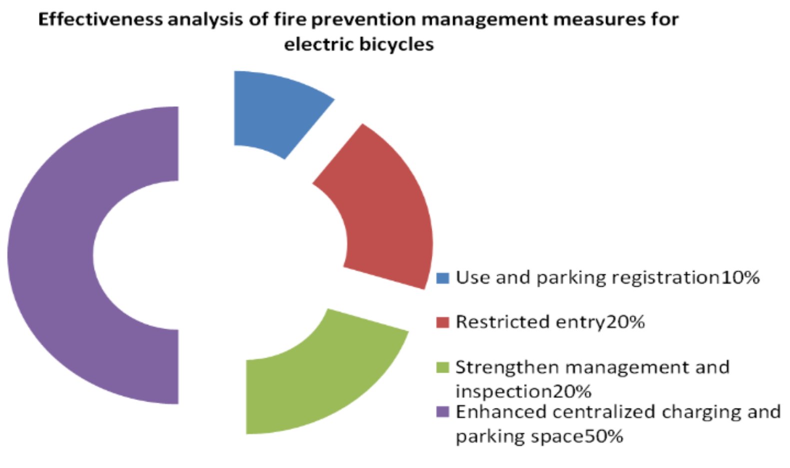

Figure 11. Effectiveness analysis of fire prevention management measures for electric bicycles (based on statistical analysis of questionnaires)

6.2. Feasibility analysis of urban electric bicycle three-dimensional parking planning

Given the large urban floating population and relatively well-developed road structure and parking facilities, the issue of electric bicycle charging and parking can be addressed through a multifaceted approach. This includes transforming the urban village environment, improving block environments and passenger stations, and undertaking urban renewal projects. By focusing on these areas, it is possible to increase the availability of multi-story parking lots and charging spaces, thereby solving the challenges associated with electric bicycle parking and charging.

6.3. Feasibility analysis of three-dimensional parking planning for electric bicycles in counties and villages

Counties, towns, and villages often face tight financial constraints and have limited non-agricultural land available. Therefore, the planning and design of multi-story electric bicycle charging parking lots should align with social management principles and local conditions, leveraging initiatives such as the "Beautiful Village Project," "Rural Revitalization Project," and the upgrading of tourist attractions. This approach should also encompass the development of village government squares, bus stations, cultural venues, public health stations, and other service facilities. For example, Baojing County in western Hunan has built 235 village parking lots through the "Rural Revitalization Project" in the past two years and plans to build 1,000 public parking lots in the next three years to solve the problem of rural parking difficulties [29]. At the same time, it is essential to promote daily education among residents to standardize vehicle parking practices and enhance fire safety awareness, thereby gradually improving the quality of life for township villagers.

7. Conclusion

How to solve the issue of charging and parking of electric bicycles has become a hot topic of livelihood in the current society. A prefabricated multi-story electric bicycle parking lot is not only an attempt to open up new fields of prefabricated building technology, but it is also suitable for supporting and complementing existing residential public facilities. It is a small project with fewer types of production components, a simple process, minimal construction waste, and the capability for customization and scalable mass production aligning with the requirements of green building and building industrialization. It also addresses the shortcomings of metal charging stations, offering a safer and more durable structure. Analysis of various domestic and international prefabricated parking lot planning in many governments' urban planning, township planning, and renovation of old residential areas, supports the hypothesis of this paper. The conclusion drawn is that the policy of applying multi-story assembled electric bicycle parking lots to the transformation of old residential areas is feasible, with an existing technical foundation available.

The design of the prefabricated multi-story electric bicycle charging and parking lot integrates both parking and charging functions simultaneously. It features a high parking capacity and low charging costs, offering a model for towns and villages to address the standardized charging and parking issues of electric bicycles effectively. This design is practical and promotes the high-quality development and planning of towns, counties, and villages, presenting significant market value. As technology advances, future developments are expected to enhance the construction of multi-story prefabricated electric bicycle parking lots with features such as clean water wall aesthetics, mechanical parking systems, automatic fire suppression, intelligent parking solutions, and photovoltaic power generation, making the parking lots even more advanced and efficient.

Disclosure statement

The author declares no conflict of interest.

References

[1] Xinhua News Agency, 2019, The Number of Bicycles in China Ranks First in the World with Nearly 400 million. Baidu Baijiahao, published November 22, 2019. https://baijiahao.baidu.com/s?id=1650897405422180337&wfr=spider&for=pc

[2] Jimu News, 2024, 21,000 Cases a Year, Electric Vehicle Fire Incidents Frequent! It is Difficult to Crack Down on Them. Experts Suggest Setting Up a QR Code to Track Battery Information. Yoojia, published February 24, 2024. https://www.yoojia.com/article/10022531572192664124.html

[3] Qilu One Point, 2024, Can Electric Bicycles Enter the Community? Expert: The Key is to Solve Parking and Charging Needs. Baidu Baijiahao, published March 29, 2024. https://baijiahao.baidu.com/s?id=1794373665149252505&wfr=spider&for=pc

[4] Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2015, Code for Design of Parking Garage Building. China Architecture Publishing, Beijing, 2015: 18–21.

[5] Xia X, 2017, How to Maintain the Lithium Battery of Smart Electric Vehicles? Baidu Experience, published January 19, 2017. https://jingyan.baidu.com/article/6fb756ec62db21241858fb07.html

[6] Li Z, 2020, Introduction to Building Industrialization. China Machine Press, Beijing, 2020: 35–60.

[7] SRIBS, 2021, Technical Standard for Green Retrofitting of Existing Building. Tongji Press, Shanghai, 2021: 12–13.

[8] Bao S, Lin J, Fang S, et al., 2019, Development and Design of Electric Bicycle Stereo Garage. Family Life Guide, 2019(02): 52–53.

[9] Xiao H, 2024, "Place" Electric Bicycles, These Communities Have a Trick. Guangzhou Daily, published March 21, 2024.

[10] Xinluo District People's Government of Longyan City, 2021, Notice of the Office of the People's Government of Xinluo District, Longyan City on Issuing the Implementation Plan for the Construction of Centralized Parking and Charging Places for Electric Bicycles in Xinluo District. Xinluo District People's Government Administrative Normative Documents Database, published November 10, 2021. http://www.fjxinluo.gov.cn/xxgk/zfxxgkzl/zc/xzgfxwj/2021/202308/t20230821_2027960.htm

[11] Xiamen Xiang'an District People's Government, 2022, Notice of Xiamen Xiang'an District Construction and Transportation Bureau on Issuing the Implementation Plan for the construction of centralized Parking and Charging Places for Electric Bicycles in Xiang'an District in 2022. Xiamen Xiang'an District People's Government Network, published July 7, 2022. http://www.xiangan.gov.cn/zfxxgk/qrmzfjgzb/XM06114/zfxxgkml/03/06/202207/t20220714_855900.htm

[12] Qingxin District Urban Management and Comprehensive Law Enforcement Bureau, Qingyuan City, 2022, Qingyuan Qingxin District Public Area Electric Bicycle Charging Pile Construction Project Implementation Plan. Qingyuan City: Fresh Qingyuan City District Urban Management and Comprehensive Law Enforcement Bureau, published December 22, 2022. https://www.qingxin.gov.cn

[13] Wang G, 2019, Practical Technology of Parking System Engineering. China Railway Publishing, Beijing.

[14] Wang X, Liu L, 2020, Construction Technology and Case Analysis of Prefabricated Steel Structure. Machinery Industry Press, Beijing, 2020: 12–14.

[15] Wang X, Zhao T, 2020, Construction Technology and Management of Prefabricated Concrete Structure. Machinery Industry Press, Beijing, 2020: 41–43.

[16] Xie J, 2021, Guidebook for Quality Acceptance of Assembled Buildings with Concrete Structure. China Building

Industry Press, Beijing, 2021: 19–20.

[17] Liang J, 2022, Old Building Space Renovation and Renewal Design. Jilin Publishing Group Co., LTD, Changchun, 2022: 127–131.

[18] Chen J, 2018, Demand Characteristics and Sharing Optimization Method of Urban Typical Land Allocation Parking Facilities. People's Communications Press, Beijing, 2018: 183–195.

[19] Zhao L, 2021, Low Energy Consumption Renovation of Existing Residential Buildings. China Architecture Publishing, Beijing, 2021: 8–9.

[20] Zhang Y, 2020, Prefabricated Concrete Building. Machinery Industry Press, Beijing, 2020: 95–96.

[21] Prefabricated Building Network, 2024, Prefabricated Parking Lot Collection Prefabrication. Construction Network, published July 31, 2024. http://www.precast.com.cn

[22] Poster News Network, 2023, The First One in The Country! See How "Tide" This Prefabricated Multi-Story Underground Civil Air Defense Garage in Jinan. Baidu Baijiahao, published May 29, 2023. https://baijiahao.baidu.com/s?id=1767215284806126511&wfr=spider&for=pc

[23] Liu Y, Liu K, 2023, On-Site Observation of the "Three Construction" Scientific and Technological Innovation Consortium for the Construction of the Largest Prefabricated Parking Building in Wuhan. Hubei Daily.

[24] Guangzhou "Double Happiness"—1906 Yangtao Technology Square Three-Dimensional Garage, Parking is Not Closed. Static Traffic Network, published May 7, 2024. https://mp.weixin.qq.com/s?__biz=MzI3OTQwNDE3Nw==&mid=2247523936&idx=1&sn=7dc9736e4318f9bb39ca0f404fdc63ca&chksm=ea75e5855d655f974b24dd692d851754a652ad9ed5176ed99a6b3c5499acee585ae53682e491&scene=27

[25] Hou J, 2015, Prefabricated Concrete Housing Construction Manual. China Architecture Publishing, Beijing, 2015: 82–105.

[26] Liu Q, Ma X, Chen B, 2021, Prefabricated Construction Technology. Beijing Institute of Technology Press, 2021: 185–188.

[27] Tao L, 2019, Guidebook for Quality Acceptance of Assembled Buildings with Concrete Structure. China Architecture Publishing, Beijing, 2019: 4.

[28] Southern Plus, 2024, A Probe into Sanyuanli Village in Guangzhou under the "Electric Chicken" Ban: Motorcycles are Parked around the Village, and Delivery Vehicles are Registered. Baidu Baijiahao, published May 17, 2024. https://baijiahao.baidu.com/s?id=1799116382600110860&wfr=spider&for=pc

[29] Peng Z, Peng K, Zhang Q, 2024, The "Voice" of the Masses Becomes "Applause". Baojing County Actively Promotes the Construction of Village Parking Lots to Solve the Parking Problem in Rural Areas. Xiangxi Autonomous Prefecture Transport Bureau Network, published March 1, 2024. https://jtj.xxz.gov.cn/xsjt/202401/t20240103_2113895.html

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Application of Digital Technology in Road and Bridge Design

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Abstract: With the development and progress of science and technology, road and bridge design has experienced rapid development, from the initial manual drawing design to the popularity of Computer-Aided Design (CAD), and then to today's digital software design era. Early designers relied on hand-drawn paper design forms which was time-consuming and error-prone. Digital support for road and bridge design not only saves the design time but the design quality has also achieved a qualitative leap. This paper engages in the application of digital technology in road and bridge design, to provide technical reference for China's road and bridge engineering design units, to promote the popularity of Civil3D and other advanced design software in the field of engineering design and development, ultimately contributing to the sustainable development of China's road and bridge engineering.

Keywords: Road and bridge design; Digital technology; Civil3D; Modelling; Three-dimensional view; Earth calculation

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1. Introduction

Under the background of further technological innovation, the current digital design has become the mainstream of the road and bridge design field, Autodesk's Civil3D, Bentley's MicroStation, CARD and HintCAD, and other software integration of multidisciplinary information, three-dimensional models can further enhance the level of integration of design and construction. Designs can be based on comprehensive design and analysis tools, effectively improving the automation level of road and bridge engineering design and collaboration efficiency. Comprehensive analysis and digital design software not only improve the quality of road and bridge design but also provide significant support for the subsequent project construction and management. It can be seen that digital technology drives the road and bridge engineering design industry to take off.

2. Road and bridge design requirements in the new era

2.1. Balancing functionality and economy

In the new era, road and bridge design must take into account both functionality and economy. In the context of social and economic development, when traffic demand increases, roads and bridges not only need to meet the basic function but also need to have a high level of service. This requires designers to fully consider traffic flow, service level, user experience, and other multi-dimensional factors in the program planning to ensure that the design meets the functional requirements. Simultaneously, in the market trend of rising construction costs, the design should meet the functional requirements based on optimizing resource allocation and cost control to ensure that the project has a high degree of economic feasibility.

2.2. Safety and environmental protection

Road and bridge design must take into account safety and environmental protection. For safety, designers need to fully consider the road and bridge structural stability, seismic performance, and durability to ensure that the project is always in a safe operating state in a variety of extreme conditions. As for environmental protection in modern road and bridge engineering, minimize the negative impact on the environment, and maximize the protection of ecological balance where the design stage needs to give priority to the use of environmentally friendly materials, and processes, and reduce pollution and energy consumption.

2.3. Long-term benefits and sustainable development

The road and bridge design in the new era needs to pay great attention to long-term benefits and sustainable development. Compared to the traditional design, modern road and bridge design, other than focusing on short-term construction and use costs, pays more attention to long-term maintenance and operational benefits. Additionally, designers also need to comprehensively consider the long-term impact of the project on society, the economy, and the environment, and adopt sustainable design ideas and methods to ensure that road and bridge projects obtain good comprehensive benefits in the whole life cycle [1].

3. The application value of digital technology in road and bridge design

3.1. Enhance the design efficiency

The traditional manual design, two-dimensional CAD design, often needs to spend a lot of time dealing with complex engineering data and drawings. With the support of digital technology, using advanced three-dimensional (3D) design software such as Civil3D and Bentley, designers can quickly generate and modify 3D models, and achieve dynamic adjustment of design through parametric design, which not only saves design time but also ensures accuracy, consistency, and standard of design.

3.2. Optimize resource management

Through digital tools, designers can comprehensively manage the whole life cycle information of roads and bridges, including design, construction, maintenance, and other stages. This makes the integration and sharing of data from various disciplines more efficient and eliminates a large number of wasteful resource problems caused by lagging and inaccurate information.

3.3. Enhance the ability of collaboration between various professions

Modern road and bridge design projects usually involve multidisciplinary and collaborative work, such as structural engineering, traffic engineering, environmental engineering, and so on.

The digital design platform can provide a unified and collaborative information sharing and collaboration environment for each profession. The professional team in the design stage of road and bridge engineering can view, edit, and update the design data on the same platform, based on the realization of data sharing to reduce the information transfer error, and time delay, and to break the barrier of information silos [2].

4. Research on the application of digital technology in road and bridge design

4.1. Technology overview

Civil3D, developed by Autodesk, belongs to a design and documentation software, which is mainly used in the field of civil engineering. This technology can be based on the construction, the use of three-dimensional models, and the use of parametric design combined with dynamic analysis to achieve efficient design, management, and optimization of civil engineering projects. In terms of technical principles, Civil3D mainly uses construction together with road and bridge engineering information modeling technology to create detailed 3D digital models, which cover all the infrastructures under the project, such as roads, bridges, and drainage systems. Concurrently, Civil3D also supports terrain modeling, surface analysis, and longitudinal and cross-section generation, which can ensure the deep integration of high-precision geographic data and engineering data during the design phase.

4.2. Data management and modeling

4.2.1. Terrain model creation

The terrain model is an important part of Civil3D-based road and bridge design, and the accuracy of the terrain model is directly related to the accuracy and feasibility of the subsequent structure design. During the creation of the terrain model, firstly, the system carries out data collection, using Light Detection and Ranging (LiDAR) scanning, aerial images, traditional ground surveying, and other channels to achieve the collection of geological data of the project site for data format conversion and preliminary processing of the data.

Secondly, using the Surface-Terrain Surface tool in Civil3D, the processed elevation point data is imported into the function module. The Surface module then generates a terrain surface model using the Triangulated Irregular Network (TIN) method. During this process, the designer must set the coordinate system to ensure the geographic information aligns correctly. Finally, the generated terrain model needs to be checked and corrected. At this stage, the designer can quickly identify the matching error by comparing the measured data, and then manually adjust the wrong area, adding and supplementing measurements to improve the accuracy of the terrain model. **Figure 1** shows the schematic diagram of the Civil3D-based terrain model design.

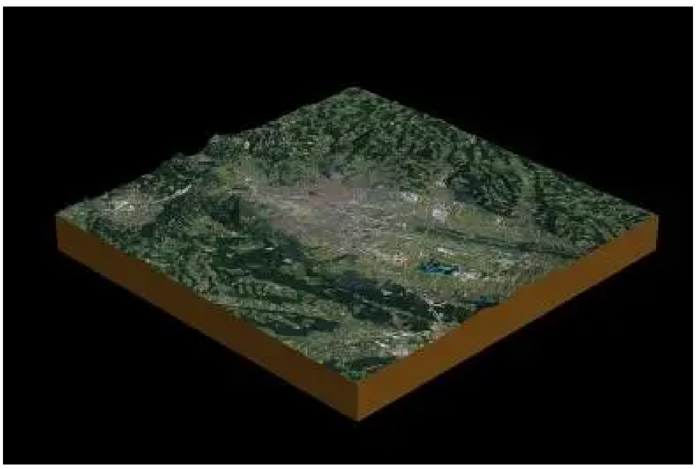

Figure 1. Illustration of Civil3D-based terrain model design

4.2.2. 3D view and simulation

3D view and simulation are a key part of Civil3D software for comprehensively displaying and evaluating design solutions. Based on the switching of different angles and viewpoints in Civil3D, road and bridge engineering designers can comprehensively review the terrain and the design structure. In the design stage, firstly, Civil3D is used for accurate geometric modeling and parametric design of roads, bridges, and ancillary facilities. Simultaneously, the engineering structure is organically combined with the terrain model to ensure that the design scheme is reasonable, feasible, and well-matched with the terrain conditions.

For road design, based on the Assembly tool module to create road and bridge section templates, define the road and bridge cross-section structure level. This step needs to cover the shoulder, road surface, drainage facilities, and other basic parts. Next, use the Corridor function to complete the setting of the cross-section template, along the center line and the longitudinal section of the stretch, forming a preliminary complete three-dimensional model of the road project. During the bridge design phase, the bridge module under Civil3D is used to model the OCT structure, covering the piers, abutments, main bridge structure, and ancillary facilities. The bridge model is integrated into the 3D model of the road to ensure that the bridge location and the road connection are reasonable and smooth and the process can be gradually adjusted and optimized through the "Bridge Integration Tool" of Civil3D. The process can be gradually adjusted and optimized by Civil3D's "Bridge Integration Tool" [3]. **Figure 2** shows the schematic diagram of the bridge 3D model based on Civil3D.

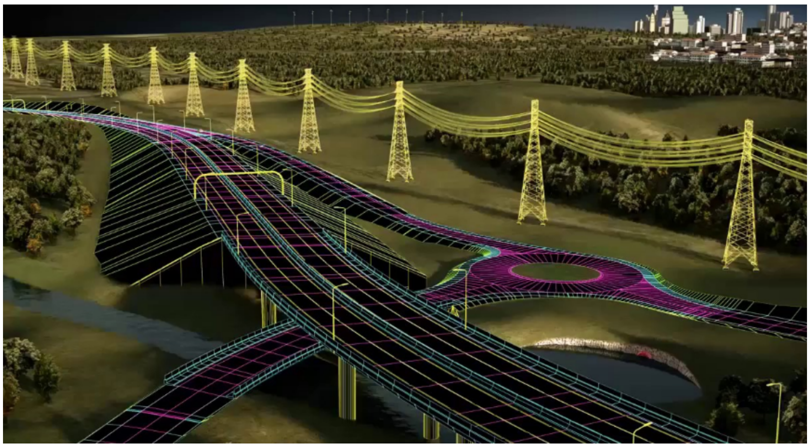

Figure 2. Schematic diagram of the bridge 3D model based on Civil3D

Secondly, the simulation analysis and optimization are carried out. This process requires a line-of-sight analysis, which uses Civil3D's line-of-sight analysis tool to check whether the roads and bridges have a good line-of-sight and to check all possible line-of-sight obstacles. It then carries out the traffic flow simulation and the bridge load capacity simulation based on the "Analysis Function" under the bridge module, to ensure that the design results meet the requirements for use. Afterwards, traffic flow simulation and bridge load capacity simulation are carried out based on the "Analysis Function" under the bridge module to ensure that the design results meet the usage requirements. Finally, the Civil3D's "View Control" function module is used to render the 3D model of the road and bridge from different angles and viewpoints, to display the design results in an all-round way [4].

4.3. Preliminary route optimization adjustment

After the construction and simulation of the 3D model of road and bridge engineering, Civil3D can optimize and adjust the preliminary route based on intelligent algorithms and automated tools.

4.3.1. Route plane optimization

During route plan optimization, parametric adjustment is one approach where Civil3D automatically optimizes the route layout based on preset design rules. In this process, the designer adjusts parameters such as curve radius, straight segment length, and intersection locations, while Civil3D automatically implements these adjustments to ensure the route achieves the optimal path while meeting engineering specifications. Additionally, by integrating terrain and existing facilities data, Civil3D uses obstacle avoidance algorithms (such as Voronoi) to automatically adjust the route, avoiding terrain obstacles, buildings, and other infrastructure.

4.3.2. Longitudinal section optimization

For longitudinal section optimization, the Civil3D software can optimize the longitudinal section slope and elevation information by automatically analyzing the terrain relief. Using linear programming and curve fitting algorithms, Civil3D will automatically adjust the design line to reduce the construction difficulty as well as the amount of earthwork [5]. Concurrently, the system under this process will automatically adjust the route elevation according to the theory of the center of gravity, making the fill and excavation reach a high degree of balance, reducing the amount of engineering earthwork deployment and further compressing the construction cost.

4.3.3. Cross-section optimization

During the cross-section optimization, Civil3D will automatically select and match the best cross-section templates based on multi-template matching the cross-section design standard [6]. At this stage, designers can preset multiple template schemes within Civil3D and the system automatically switches templates based on project topography and design requirements to achieve refined design. For road and bridge slopes, the slope rate and shape of the roadside can be optimized based on the dynamic adjustment function of Civil3D, which improves the stability and safety of the slopes and reduces the amount of slope protection work in the later construction stage.

4.3.4. Conflict detection and adjustment

Civil3D has an automatic conflict detection function. After the 3D model is generated and initially optimized, Civil3D can automatically check whether there are potential conflict points between the route and other facilities (bridges, pipelines, buildings) around the selected site. Under this process, the system provides intelligent adjustment suggestions for road and bridge engineering designers based on the conflict detection results, and automatically makes adjustments, such as modifying the route alignment, adjusting the route elevation, and optimizing the structural design of roads and bridges [7].

4.4. Earthwork calculation and measurement

4.4.1. Accurate earthwork calculation

For the calculation of earthwork volume, after realizing route optimization, the system automatically divides the boundary of the design area and generates the tuning plane at the same time. It then applies volume calculation methods such as "the prism method" and "grid method" followed by calculating the earthwork volume by comparing the ground model (the original terrain) and the design model (the improved terrain). By comparing the difference between the ground model and the design model, the volume of excavation and filling can be determined [8]. Civil3D software has a built-in earthwork calculation tool, which can quickly output a detailed earthwork volume report to the designer.

4.4.2. Construction material estimation

The estimation of construction materials mainly involves the accurate prediction of the quantity and specification of various types of construction materials required in road and bridge projects, the specific steps are as follows.

(1) Set up the material types and requirements. According to the design standards and specifications, the designer inputs the types of construction materials (steel reinforcement, concrete, etc.) and the unit dosage standards in Civil3D software.

(2) Civil3D automatically extracts the length, width, bridge span, bridge height, and other geometric features of the structural elements from the completed 3D model. Based on the original geometric features of the design combined with the standard of material usage per unit volume of the road and bridge project, it automatically calculates the total demand for various materials.

(3) The system automatically generates a detailed list of construction materials, which shows the specifications, quantities, and total amount of different materials in detail, providing a reference basis for subsequent construction preparation. This is shown in **Figure 3**.

Volume Report

Project: C:\Civil3D 2020\AutoCAD 2020\C3D\Help\Civil Tutorials\Drawings\Earthworks-1.dwg

Alignment: Centerline (1)
Sample Line Group: SLG-1
Start Sta: 0+00.000
End Sta: 17+29.049

Station	Cut Area (Sq.ft.)	Cut Volume (Cu.yd.)	Reusable Volume (Cu.yd.)	Fill Area (Sq.ft.)	Fill Volume (Cu.yd.)	Cum. Cut Vol. (Cu.yd.)	Cum. Reusable Vol. (Cu.yd.)	Cum. Fill Vol. (Cu.yd.)	Cum. Net Vol. (Cu.yd.)
0+00.000	2376.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0+25.000	2746.32	2371.82	2371.82	0.00	0.00	2371.82	2371.82	0.00	2371.82
0+50.000	3109.56	2711.05	2711.05	0.00	0.00	5082.87	5082.87	0.00	5082.87
0+75.000	3466.40	3044.42	3044.42	0.00	0.00	8127.29	8127.29	0.00	8127.29
1+00.000	3694.66	3315.30	3315.30	0.42	0.19	11442.59	11442.59	0.19	11442.40
1+25.000	4015.53	3569.53	3569.53	0.13	0.25	15012.13	15012.13	0.44	15011.68
1+50.000	4321.17	3859.59	3859.59	0.00	0.06	18871.71	18871.71	0.50	18871.21
1+75.000	4606.35	4133.11	4133.11	0.00	0.00	23004.82	23004.82	0.50	23004.32
1+90.600	4770.94	2708.99	2708.99	0.00	0.00	25713.82	25713.82	0.50	25713.32
2+00.000	4852.97	1675.27	1675.27	0.00	0.00	27389.09	27389.09	0.50	27388.59
2+25.000	4958.52	4542.35	4542.35	0.00	0.00	31931.45	31931.45	0.50	31930.94
2+50.000	4959.53	4591.69	4591.69	0.00	0.00	36523.14	36523.14	0.50	36522.63
2+75.000	4872.57	4551.90	4551.90	0.00	0.00	41075.03	41075.03	0.50	41074.53
3+00.000	4765.96	4462.28	4462.28	0.00	0.00	45537.31	45537.31	0.50	45536.81
3+16.000	4699.52	2804.59	2804.59	0.16	0.05	48341.90	48341.90	0.55	48341.35
3+25.000	4622.10	1553.60	1553.60	0.40	0.09	49895.50	49895.50	0.65	49894.86
3+50.000	4431.74	4191.59	4191.59	0.00	0.19	54087.10	54087.10	0.83	54086.27
3+75.000	4338.18	4060.14	4060.14	0.00	0.00	58147.24	58147.24	0.83	58146.41
3+99.500	4075.33	3817.24	3817.24	0.00	0.00	61964.48	61964.48	0.83	61963.65
4+00.000	4070.09	75.42	75.42	0.00	0.00	62039.90	62039.90	0.83	62039.07
4+20.566	3855.00	3018.22	3018.22	0.00	0.00	65058.12	65058.12	0.83	65057.29
4+25.000	3809.45	629.40	629.40	0.00	0.00	65687.52	65687.52	0.83	65686.69
4+50.000	3561.58	3412.51	3412.51	0.00	0.00	69100.03	69100.03	0.83	69099.20
4+70.566	3369.05	2639.48	2639.48	0.00	0.00	71739.51	71739.51	0.83	71738.68
4+75.000	3328.87	550.03	550.03	0.00	0.00	72289.54	72289.54	0.83	72288.71

Figure 3. Civil3D-based bill of materials

4.5. Interactive design and review

4.5.1. Team collaboration and sharing

During the design of road and bridge projects, Civil3D provides powerful collaborative design and data-sharing functions. During design, design team members can collaborate in real-time on a unified platform. Through cloud-based data management and version control, designers from different disciplines can access and edit design files at the same time, and be able to use the latest version of design data. Simultaneously, Civil3D supports the direct sharing of Drawing (DWG) files, allowing team members to conveniently perform design and modifications in a CAD environment. This facilitates the interactive design through team collaboration and sharing, enhancing the scientific validity and feasibility of the design results.

4.5.2. Multi-party evaluation and feedback processing

After completing the design of a road and bridge project and entering the project evaluation stage, Civil3D's multi-party collaboration function can effectively integrate the opinions of different stakeholders and designers of different disciplines. During the review and feedback period, the chief designer can convene the client, the construction unit, the supervisor, and other related units to jointly carry out the design review based on the cloud platform and desktop application. During the multi-party review process, all parties can directly mark and comment on the model, and the feedback information will be recorded and updated by Civil3D in real-time. Through the interactive review, not only can the road and bridge engineering design problems be discovered and solved promptly, but also the design solutions can be continuously optimized to ensure that the design results meet the needs of all parties [9].

5. Conclusion

As analyzed above, this paper provides a detailed study of road and bridge engineering design supported by digital technology. After briefly reviewing the requirements of road and bridge design in the new era and the application value of digital technology, this paper uses Civil3D technology as an example to discuss how to achieve data management and modeling, route optimization and adjustment, earthwork calculation and measurement, and collaborative review in the design phase. Civil3D-based collaborative review helps road and bridge engineering design units to improve the efficiency and quality of their designs, laying a solid foundation for subsequent construction and contributing to the sustainable development of China's road and bridge engineering.

Disclosure statement

The author declares no conflict of interest.

References

[1] Lv X, 2021, Trial Analysis of the Application Mode of Digital Technology in Road and Bridge Design. Urban Construction, 2021(1): 120.

[2] Zhao X, 2021, Research on the Application of Digital Technology in Road and Bridge Design. Construction Engineering Technology and Design, 2021(34): 838–839.

[3] Chen L, Jiang H, 2023, Digital Practice and Application of Zhejiang Road and Bridge Overhaul Project. Urban Road and Bridge and Flood Defence, 2023(5): 232–235.

[4] Wang S, Luo T, Peng L, et al., 2023, BIM Co-Design of Bridges for the New Chengdu-Dazhou-Wanzhou Railway. Railway Standard Design, 67(10): 148–154.

[5] Huang J, 2023, Research on the Design and Key Technology of Highway Management and Maintenance Digital Twin System. Construction Machinery, 2023(6): 28–34.

[6] Pu S, 2024, Discussion on the Innovation and Practice of Intelligent Computer and BIM Technology in Road, Bridge and Tunnel Engineering. China Construction, 2024(18): 182–184.

[7] Ma N, 2024, Research on Optimisation of Highway Safety Facilities Layout Based on Digital Technology. Intelligent Building and Smart City, 2024(1): 48–50.

[8] Fang K, 2023, Research on Road and Bridge Route Design. Building Materials and Decoration, 19(31): 151–153.

[9] Yang L, Zhao X, Nie T, et al., 2023, An Overview of the Application of Digital Twin in Road Engineering. Traffic Engineering, 23(3): 107–114.

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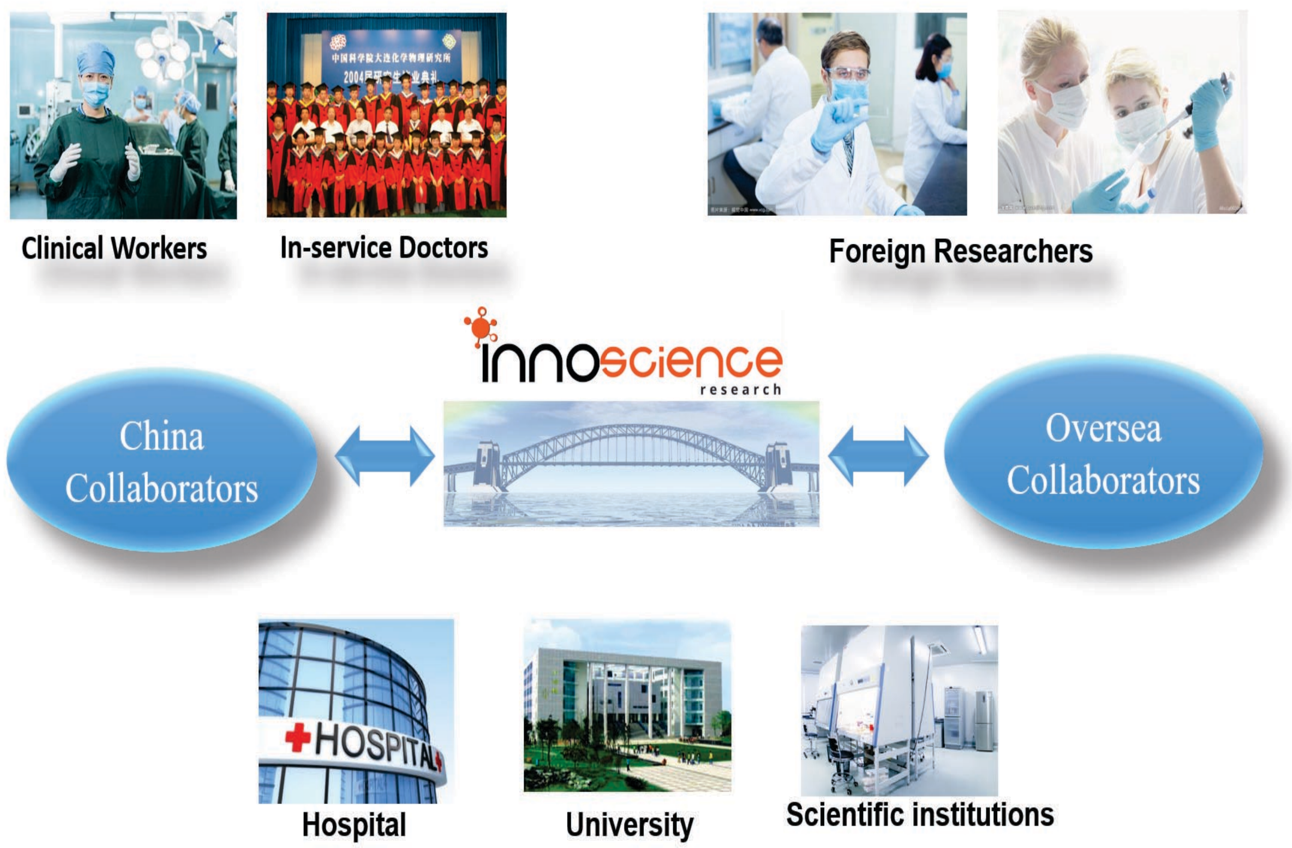

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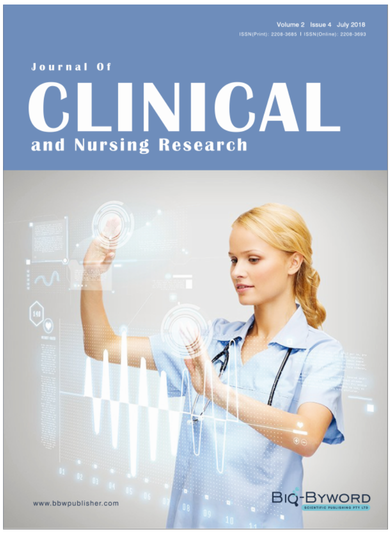

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