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Application Strategy of Green Transportation Concept in Urban Road Design

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Abstract: Urban traffic and urban environmental pollution are important issues that must be taken into account in the process of urbanization, especially in China. Modernization has enabled many developed countries in the west to carry out rational city traffic planning. At the same time, the concept of green transportation has also emerged, integrating low-energy consumption, low pollution, comfort, and safety into urban traffic to effectively solve issues pertaining to traffic and pollution. The concept of green transportation has been widely adopted in China and made popular in many cities, thereby promoting the sustainable development of cities.

Keywords: Green transportation concept; Urban road design; Public transport

Online publication: October 25, 2023

1. Introduction

The urban environment belongs to a complete ecosystem, in which both internal and external disturbances will affect its balance. Although the ecosystem has a certain capacity for self-regulation, there are limitations to it. If the external disturbance exceeds the capacity for adaptation, the balance will be broken. At present, the suburbanization of cities in China is expanding; thus, it is necessary to pay more attention to urban transportation. Although the development of urban transportation has brought greater economic benefits to the city, it has also brought about detrimental effects on the environment and increased energy consumption; the number of vehicles in the city has increased significantly, roads are continuously being widened, parking lot areas are gradually being expanded, and more and more natural resources are being consumed for urban transportation. Therefore, it is necessary to apply the concept of green transportation to the design and development of urban roads so that the issues pertaining to urban roads and urban environment can be addressed.

2. Concept of green transportation

Green transportation is a “green” method. The application of this “green” method can effectively alleviate urban traffic congestion, optimize the current urban road environment, and reduce the impact of exhaust emissions

from vehicles on the environment. Scientific and reasonable means are used to ease the pressure of urban traffic as much as possible in order to promote the mutual development of urban traffic and urban environment. The concept of green transportation includes the principle of bus priority, the design of a slow-moving traffic system, and the optimization of management needs.

2.1. Principle of bus priority

Transportation is an extremely important aspect in the process of urban development and also an impetus for promoting urban development [1]. Public transportation is the most fundamental aspect of the transportation system, in which its development status represents the actual development status and maturity of urban transportation. Public transportation is also a means of green travel. Therefore, in the process of urban development, it is necessary to optimize and improve the bus route, build a relatively complete bus system and network, prioritize buses as the main route in urban road design and planning, and increase the number of bus stops and other supporting facilities. Designers need to understand the essence of urban road development, promote the development of public transportation, and provide people with a good green travel environment, thereby reducing exhaust emissions from vehicles and pollution to the urban environment.

2.2. Design a slow-moving traffic system

A reasonable control of vehicle speed is also an important aspect of urban traffic development. Excessive vehicle speed may lead to traffic accidents, which will not only cause damage to infrastructures, but also threaten the safety of people [2]. Under the concept of green transportation, a slow-moving traffic system can be designed to cultivate the habit of driving at low speed. This system can also ensure seamless connections between urban roads, reduce the probability of traffic accidents, and improve traffic safety.

2.3. Optimization of management needs

With the rapid development of cities, the per capita purchase rate of automobiles has increased sharply. The increase in the number of cars will lead to serious environmental pollution. Exhaust gas emitted from automobiles during driving contains many harmful substances, such as sulfide and carbon dioxide. Under the concept of green transportation, it is necessary to continuously optimize management needs and improve the management and control of vehicles. Reasonable traffic restrictions can be implemented to alleviate urban road congestion and reduce environmental pollution. See **Table 1** for details.

Table 1. Comparison of different travel modes

Travel mode	Capacity (person/h)	Road area (m^2/person)	Speed (km/h)	Features
Subway	30,000–92,000	Does not occupy ground area	40–65	High cost and efficiency
Light rail transit	10,000–28,000	0.5	35–65	High cost and efficiency
Public transit	3,200–9,000	0.3	30–60	Environmental pollution, high consumption, Low emissions per capita
Car	3,000	2.4	35–65	High cost and consumption
Bicycle	1,800	1.5	10–16	Low cost, no pollution
Walking	1,200	0.4	3.8	Fitness, environmental protection, low cost

3. Concept of green transportation plays an important role in urban road design

Sustainable development policies have gradually gained significance in current social and urban development. At present, China has put forward higher requirements for urban road design under the concept of green transportation. The significance of applying the green transportation concept is mainly reflected in several aspects. First, through reasonable application of the concept, we can effectively control the construction cost of urban roads, reduce the input cost as much as possible, and maximize economic benefits [3]. The concept of green transportation emphasizes on making full use of various resources through scientific and reasonable means and addressing the material waste issue that has always existed in urban road design. New renewable energy sources, such as wind and solar energy, can be applied to urban road design. These new energy sources possess certain features, such as low cost, environmentally friendly, and the capacity to lower engineering construction costs [4]. Second, through the application of the concept, the overall urban road design level can be improved. Urban road design is a relatively complex task, which needs to be effectively integrated with the selection of management strategies consistent with the design content. Compared with traditional management concepts and policies, the concept of green transportation is more consistent with urban road design. The application can greatly improve the management effect of the project and also improve the overall construction level. Third, through the application of the concept, the consumption of resources can be controlled, and the effect of urban road design can be guaranteed.

4. Application strategy of green transportation concept in urban road design

4.1. Rational use of vacant land

Since most cities in China are developing in the direction of modernization, it is inevitable that there will be some abandoned and vacant lands. Although the area of each of these lands is insignificant, the total land area is relatively large. Some vacant lands are located in the center of the city, and the reason for this may be the small area, high planning cost, or serious pollution [5]. Therefore, in urban road design, designers need to make reasonable use of these vacant lands, which can be set up as bus stops, parking lots, *etc*., so as to continuously improve the utilization rate of urban lands [6]. We must determine the actual state of each piece of land, including the reasons for vacancy, and carry out reasonable planning for these lands so as to effectively improve the regional planning and design level, reduce land development costs, and increase economic benefits.

4.2. Improving bus routes

Public transportation is an important part of urban transportation and an important manifestation of the green transportation concept. Travelling by public transportation is more economical and environmentally friendly than travelling by car. Therefore, public transportation is a key component in urban road design [7]. Optimizing and improving bus routes can alleviate road congestion, ease urban traffic pressure, and shorten residents' travel time. Therefore, we should design special lanes for public transportation, integrate the concept of green transportation into it, and comprehensively consider various factors when designing urban roads to ensure smooth traffic flow [8]. In addition, setting up special signs in lanes dedicated to public transport may prevent vehicles from occupying these lanes. Regular maintenance and repairs of these special lanes should also be carried out to keep the road clean and ensure that they are in good condition. When utilizing these special lanes, it is necessary to ensure that the management work is done well, improve supervision and management, and reduce the probability of traffic accidents as much as possible. There are several specific measures that should be considered. First, improve the bus lines. As the urban transportation network develops with time, it

is impossible to make large-scale route changes over a short period of time. However, with the development of various areas in the city and the travel patterns of passengers, the bus lines can be arranged or planned in such a way that the rationality of the lines and convenience for travel are guaranteed. Second, improve the transfer system. Designing a transfer system is not an easy task. During the design process, it is not only necessary to ensure that the location of the transfer station is convenient for people, but also essential to consider the connection of the transfer stations. Transfer points can be set up in areas with a large flow of people to shorten the distance between transfer stations and ensure convenience for bus transfers [9].

4.3. Implementing traffic stabilization and purification measures

Optimizing the road environment is an important aspect in urban road design. Therefore, under the concept of green transportation, it is necessary to realize harmonious development between traffic and nature as much as possible and create a city with good traffic and environment for people [10]. At present, the residential areas adjacent to roads are faced with serious noise pollution, which has a serious impact on the residents' daily life. Moreover, the large amount of exhaust emissions may damage the ecological environment of the city and affect the ecology as a whole. Therefore, in urban road design, it is necessary to integrate the concept of green transportation and implement traffic stabilization and purification measures. Relevant practice and research have shown that these measures can improve safety and people's quality of life by reducing pollution from exhaust gas, alleviating the noise problem, and providing people with a good living environment [11]. The main measures include the following: (i) construction of traffic island flower beds; building traffic islands in the center of large intersections will not only improve road traffic safety and reduce potential safety hazards, but also enhance aesthetics; (ii) installation of speed bumps; the speed of vehicles can be controlled by installing speed bumps on the road, which would also improve safety; (iii) construction of S-shaped lanes; the curbs on both sides of the road can be extended to build S-shaped lanes so as to alleviate the noise problem.

5. Conclusion

Generally speaking, in recent years, China has gained a deeper understanding of the concept of green transportation and gradually strengthened its emphasis on this concept. By applying this concept to urban road design, the effect of the design can be optimized, the costs can be reasonably controlled, and urban environmental problems and road congestions can be solved. Moreover, through the application of the green transportation concept, we can make full use of the lands in a city, improve the overall effect of the design, and promote urban development.

Disclosure statement

The authors declare no conflict of interest.

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The Application of Trenchless Piping in Sandbar Drainage Network Renovation Projects

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Abstract: In this study, the research progress of trenchless piping technology for pipes with a large diameter was reviewed. The geological conditions of the sandbar in Xiangyang were taken into account in this study. This paper highlights the construction process management of the pipeline network project in Yuliangzhou Starting Area of Xiangyang City. Research was carried out in the aspects of optimizing mud ratio, controlling pipeline elevations, pipeline welding, and trenchless pipeline construction in limited spaces, stable support during pit excavation, and controlling the spacing between the junctions of two pipe segments. The research resulted in excellent outcomes and ensured safe construction, and the quality requirements were also met.

Keywords: High water level; Sandbar; Trenchless piping

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1. Introduction

Despite the rapid development of cities, many sewer systems in the old urban areas are still combined sewer systems [1]. As the city progressed, the sewage pressure increased sharply. Besides, many old pipelines did not undergo regular maintenance, which resulted in many problems like misalignment, disconnection, water seepage, rupture, root infiltration, and pockmarked surface. This led to poor drainage, which caused water accumulation and flooding. Environmental pollution, noise pollution, traffic congestion, and adjacent pipeline damage caused by excavation have also been major issues in this city. Therefore, there is an urgent need to employ non-excavation trenchless construction methods for the construction of such large-diameter, well-sealed pipeline projects. This article takes the Xiangyang Yuliangzhou starter district pipeline network project as an example and discusses the research and application of non-excavation large-diameter pipeline construction technology. It also provides insights and references for similar projects in the future.

2. Project overview

The Phase I renovation project of the drainage pipeline network in Yuliangzhou Starting Area, Xiangyang

City, was located on the western side of Yuliangzhou, extending from the west to the Han River, east to Haoran Road, north to First Road, and south to Oasis Avenue. The total area covered approximately 2.4 square kilometers. This project involved converting the original combined sewage system into a separated sewage system. The new sewage pipeline network had a total length of 15.233 km, with pipe diameters ranging from 600 mm to 400 mm. Additionally, a new integrated sewage lift pump station with a capacity of 0.2 m^3/s was constructed [2].

The geological structure of Yuliangzhou belongs to the Quaternary Holocene formation (Q4al+pl), characterized by layers of sand, gravel, and silt deposits, with an upper section of marl on the bedrock [2]. The geological drilling data showed that at depths of 5 to 12.8 meters, there was fine sand (classified as type III), and at depths of 12.8 to 14.2 meters, there were rounded gravels (classified as type V to VI). Below 35 meters, there was tertiary clay, marl, and sandstone (classified as type V). The non-rock soil cover layer was not very deep, and there were no severe soft layers encountered. The underground utility networks crossed at depths ranging from 5 to 12.8 meters within the fine sand layer (**Figure 1**).



Figure 1. Overview of Yuliangzhou

3. Important and difficult points in the construction of trenchless pipelines at sandbars

3.1. Difficulties in controlling pipeline elevation

Due to the layered composition of sand and silt in the underground soil at this project site, coupled with a high water table, the pipeline, which had a lower density than the slurry, consistently remained suspended near the upper part of the borehole. This resulted in excessive drag forces and elevation deviations that exceeded regulatory requirements.

3.2. Difficulties in foundation pit support and dewatering

According to the design specifications, this project utilized wellpoint dewatering and FSP-IV Larson steel sheet pile support for the excavation and receiving pits in the pipeline installation area. However, due to the project's location in the Yuliangzhou Economic Development Zone, surrounded by the Han River, and with a high water table and challenging geological conditions, the excavation support and dewatering were particularly difficult (**Figure 2**).



Figure 2. Support and groundwater level diagram

3.3. Serious pipe scratches

The project was located near a residential area, which is densely populated. The long-distance pipeline dragging process could significantly disrupt traffic. Additionally, limited space for welding and transportation will result in considerable bending and abrasion damage to the pipeline during transfer (**Figure 3**).



Figure 3. Construction process

3.4. Borehole collapse during the dragging process

The construction area had soil composed of silty clay, which made it challenging to control the pipeline dragging process manually. This difficulty in maintaining a stable mud wall during dragging resulted in borehole collapses, generated pressure, and subsequently led to road surface subsidence (**Figure 4**)



Figure 4. Collapse and grouting

3.5. Pipeline fracture

After the mud wall was damaged, borehole collapses occurred. This was followed by direct contact between the dragged pipes and the underground sandy soil, causing an increase in friction during the dragging process. The frictional forces exceeded the maximum dragging capacity of the original pipes, resulting in pipeline fractures and subsequently causing an interruption in the dragging process, which had an impact on the project's progress.

3.6. Challenges in controlling pipe end misalignment

After dragging and connecting two adjacent pipe sections, significant eccentricity, and misalignment issues occurred at the horizontal joint due to the interference from inclined sections. This necessitated the expansion of the well chamber, which further complicated well support and dewatering efforts. As a result, it exacerbated the damage to the existing road surface (**Figure 5**).



Figure 5. Pipe end misalignment

4. Countermeasures

4.1. Construction scheme of well chamber support structure

To support the well chamber during pipe dragging, a closed support system is employed [3]. This system included cement mixing piles installed at the pipe ends, aligned along the width of the two sidewalls of the well chamber where the pipe passed through. These cement mixing piles served to solidify loose sandy soil. Additionally, surrounding the well chamber except for the pipe's location, several Larson steel sheet piles were placed in a radial arrangement. The two types of support structures intersected to create a closed support system, forming a watertight enclosure that effectively prevented water ingress, reduced the risk of well chamber collapse, and avoided roadbed erosion. In the cement mixing pile components, a pair of parallel transverse struts was placed above or below the pipe, with their ends securely fixed to the side walls of the cement mixing pile components using positioning bar clips. The ends of the transverse struts were secured in grooves on the ends of the Larson steel sheet piles on either side of the pipe. This enhanced the safety and stability of the cement mixing pile components, ensuring the safety and stability of the overall support structure. The cement mixing piles in the well chamber support structure not only formed a stable closed structure but also effectively controlled the elevation of the pipe ends and prevented damage to the overlapping panel beams of the roadbed (**Figure 6**).



Figure 6. Closed support system of the foundation pit

For longer pipe sections with significant resistance where pipeline breakage was a concern, a well chamber support structure that facilitated pushing was employed. This structure utilized non-excavation, top-supported, and pipe-dragging well chamber support structures. The end-pulling groove piles were positioned on both sides of the well chamber support structure at the pipe ends, with both ends connecting to the steel sheet pile support structure. The groove-type blade feet were oriented downward, with the groove openings facing upward, and were placed horizontally between the end-pulling groove piles. The H-shaped joint groove slots were secured at the upper and lower edges of the prefabricated stopboard and were placed horizontally between the end-pulling groove piles. The prefabricated stopboard consisted of endplate boards and fixed boards, with the endplate boards situated at the pipe end openings, and the prefabricated stopboard positioned between the H-shaped joint groove slots and groove-type blade feet, and between the H-shaped joint groove slots. The open side of the

endplate board was fitted with sealing membranes facing the soil, and the well chamber surface was fitted with locking covers. The T-shaped clip bars were inserted at the joints of the prefabricated stop boards and the soil. Grouting was used to strengthen the gaps between the prefabricated stopboard and the soil, forming a stable support structure that allowed the use of pushing equipment for assistance. This effectively addressed issues related to non-excavation, top-supported, and pipe-dragging well chamber support, including the inability to seal the openings, the instability of the soil around the pipe openings, the failure to form a stable backrest surface, and the non-standardized recycling of support structure measures. This approach offered distinct advantages, including evident hole-locking effects, structural stability, simple construction procedures, and cost-effectiveness (**Figure 7**).

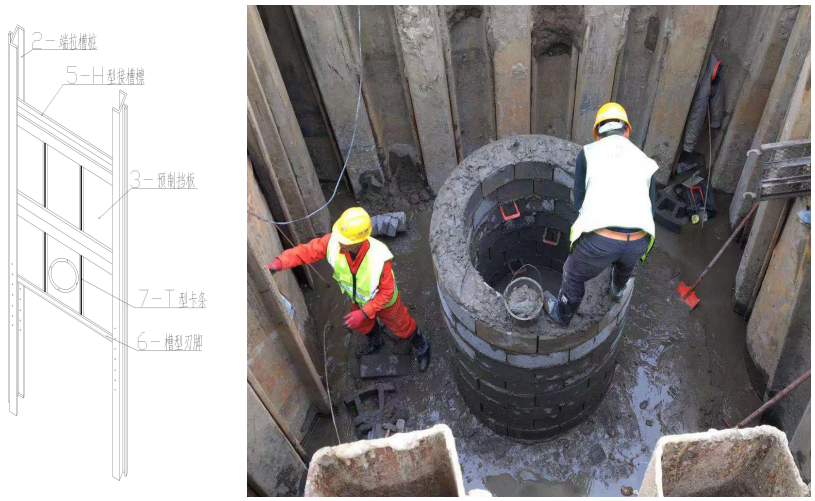


Figure 7. Schematic diagram of well chamber support structure

4.2. Pipe body reinforcement scheme

The slurry involved adjusting the amount of bentonite to be 2.5 to 3 times the original soil quantity. Additionally, inorganic water-hardening agents, primarily consisting of CaO, active Al_2O_3, and SiO_2, were added. The recommended additive blending ratio for bentonite ranged from 2% to 8%. The technical process involved a composite mineral design and chemical activation. The basic composition included 50% cement, 25% to 40% industrial waste materials rich in active Al_2O_3 and SiO_2 (such as slag, steel slag, fly ash, etc.), 1% to 5% surface modifiers (to enhance the surface activity and charge of soil particles), and 5% to 10% active activators (to promote the hydration reactions of cement and other minerals) [4].

The solidifier was mixed thoroughly with the soil and water. Through physical and chemical reactions between its components and the soil, this process significantly improved the soil's physical and mechanical properties, strength, water stability, and long-term volume stability. An experiment was conducted to determine the appropriate solidifier dosage, where comparative tests were performed with different types of solidifiers, varying dosages, and different slumps at the test site.

Simultaneously, during the pipe dragging process, further grouting and reinforcing of the pipe was achieved by installing grout ports on the pipe head. Alternatively, grout pipes were fixed around the pipe's circumference, and after the pipe dragging was completed, the secondary grouting was carried out by dragging the grout pipes. By combining these two methods, the stability of the sandy soil during the borehole expansion phase was ensured, and the pipeline was doubly reinforced by enveloping it with grout through these two reinforcing measures (**Figure 8**).



Figure 4.2 Mud ratio and construction drawing of tractor pipe

4.3. Dewatering and anti-floating plan for well chamber excavation

During the renovation work, external dewatering would have caused additional damage to the ground, leading to an expansion of the construction area for maintenance. Additionally, the residual dewatering piles would have resulted in wastage and left behind subsidence holes. Therefore, after some research a solution involving post-grouting piles, thus combining dewatering and anti-floating measures was implemented.

In the well chamber base, grout piles were installed, serving the purpose of dewatering in the initial phase and anti-floating measures in the later phase. The pile structure was established through mud wall drilling or borehole drilling using a jet grouting machine. An outer tube (permeable cement pipe) was placed into the borehole after drilling, and a certain amount of concrete was poured into the outer tube to seal the bottom. The reinforcement cage was constructed using grouting tubes as the main reinforcement, and an inner tube was securely positioned with inner supporting bars. After placing the outer tube, the reinforcement cage with the connected inner tube was centrally positioned. Then, the gap between the inner and outer tubes was filled with well-graded aggregate, sieving out particles smaller than 0.3 mm. Finally, using the grouting tube within the reinforcement cage as the main reinforcement, grouting was performed to form the pile structure. Throughout this process, it could be utilized as a dewatering well, and the grouting volume was easy to control. The resulting pile featured stability, a well-controlled steel reinforcement cover, a compact and stable structure formed through grouting, easy construction procedures, and cost-effectiveness (**Figure 9**).



Figure 9. Construction drawing of grouting pipe pile

4.4. Pipeline elevation control strategy

In addition to adding control points for pipeline elevation on the well chamber support structure, a pipeline elevation control device was utilized for backpressure at the pressure relief well. The well chamber's position was controlled using support piles formed with cement mixed piles, achieving multi-node elevation control.

The sandbar pipeline terminal elevation control device consisted of a semicircular limit steel cover plate with a straight section in the middle and flared curved sections at both ends. The cover plate included pulleys or elastic protective strips. The support truss was a combination of upper truss, standard section truss, and lower truss. The upper truss was connected to the top frame, and the standard section truss was connected to the upper and lower trusses to adjust the height. The lower truss was connected to the cover plate and the standard section truss using bolt connections. All trusses were welded using angle steel, and the top frame's main beam was made of shaped steel. The sleepers could be square timber or shaped steel with wedges (bricks or wooden blocks) underneath for adjusting the truss structure's height. The cushion plate could be made of steel or wood and served to cover the top frame, facilitating the loading of upper counter-pressure items. These counter-pressure items could include construction shovels, sandbags, concrete blocks, and so on. The use of this device increased the vertical pressure at the pipe end, reducing the risk of slope changes, difficulties in controlling the pipe end elevation, and the danger of the pipeline moving upwards due to buoyancy during pipeline dragging construction (**Figure 10**).



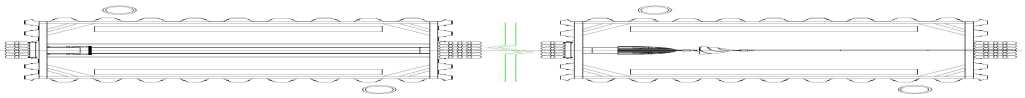
Figure 10. Sandbar pipeline dragging terminal elevation control device

4.5. Anti-scraping and anti-collapse roof and dragging scheme

The main construction process includes several steps: construction preparation → surveying and layout → excavation and construction of the well chamber foundation pit → equipment positioning and directional drilling → hole expansion and mud circulation → secondary hole expansion and hole cleaning → welding of pipes → auxiliary support and pipe-dragging → high-pressure grouting during pipe-dragging→ mud clearance → cutting pipes at the well entry point → transferring equipment → well chamber construction and pit backfilling [5].

The construction sequence followed the "upstream to downstream, mainline before lateral line" approach. In the upper end of the well chamber, a non-excavation top and towing pipe pit support structure were utilized. At the lower end, a cement mixing pile support structure was employed for sealing. This strategy enabled the construction of pipeline sections with a sequence of jacking from the upstream well chamber, followed by towing from the downstream well chamber. The welding of pipe segments occurred inside the pit, while

jacking and assistance took place simultaneously to prevent damage from friction during the dragging process on the road. Dual reaming was employed to stabilize the loose sandy soil into a cylindrical soil body in the first reaming, and the second reaming was used to remove the relatively moist core soil to create a stable borehole. The first reaming process compacted larger gravel and pebbles toward the outer layer, avoiding disturbance to the soil during the second reaming and cleaning processes, ensuring high construction quality. The grout pipe during dragging evenly injected slurry into the gap around the pipeline. The high pressure formed within the borehole due to the two reaming processes helped fill the gaps effectively. The slurry created a suspended pressure during the pipeline's dragging process and generated forward thrust using a reversed bending nozzle, reducing friction. Subsequently, the slurry solidified, reinforcing the pipeline body and enhancing its deformation resistance. This process formed a double-layer protection and reinforcement around the pipeline, effectively addressing the impact of temporary rising water levels on the pipeline's buoyancy and deformation resistance (**Figure 11**).



Jacking end Dragging end



Figure 11. Construction drawing of top and tow pipe

5. Implementation effect

The application of conventional non-excavation techniques, such as jacking construction, has been relatively slow to develop [1]. There is a lack of their application in the construction of long-distance, large-diameter sewage networks. Particularly in the sandy island environment, non-excavation construction methods have been scarce. Effective measures for controlling pipeline elevations, sealing support structures, and achieving precise and non-destructive pipeline connections have not been established, making it challenging to meet the on-site requirements.

Through research and exploration, the experience of drainage network jacking construction in favorable

geological environments has been leveraged. A combination of conventional techniques related to welding, slurry treatment, soil improvement, and support and dewatering methods has been utilized for research into jacking construction techniques for large-diameter pipelines in high-water sandy soil areas. This approach has successfully tackled the challenges of jacking construction for drainage networks in sandy island environments, resulting in favorable results and practical application.

Through on-site experiments, applications, and inspections, all indicators met the design and drawing requirements. This method achieved significant savings in terms of labor, machinery, materials, and more, including a 45% reduction in the construction period, a 25% decrease in labor costs, a 20% reduction in material expenses, and a 47% cut in equipment costs. It effectively addressed various challenges such as unstable mud walls due to a high groundwater level leading to hole collapse issues, difficulties in controlling pipeline elevation, serious damage during pipeline welding, and significant pipeline undulation. Non-excavation construction technology was more convenient and flexible, enabling the completion of pipeline installation in urban areas where traditional excavation techniques faced challenges. It allowed avoiding underground pipelines and obstacles and ensured precise pipeline installation at designated locations. This approach reduced the impact on urban traffic, shortened construction periods, minimized repeated road excavation, and delivered significant social and environmental benefits, contributing to an enhanced urban image and quality.

6. Conclusion

The article, using the Xiangyang Yuliangzhou project as an example, discusses the research and application of non-excavation large-diameter pipe-pulling construction technology in upgrading and renovating pipelines in high-water-level sandy areas. This technology effectively changes the traditional excavation and road construction methods, reducing the environmental impact around the construction site. It ensures stable and reliable operation of the pipeline network, contributes to resource conservation, and prevents secondary environmental pollution, aligning with national requirements for energy efficiency, environmental protection, and a low-carbon "ecological civilization." This approach has received recognition from various parties. It ensures the economic and safety aspects of project construction, reduces construction time, and significantly enhances the efficiency and results of pipeline network renovation, providing technical parameters and solution data for similar projects in the ecological construction of the Han River Basin, with wide prospects for application in domestic ecological civilization construction and related projects.

Disclosure statement

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Practical Strategies for Urban Rail Transit Loop Planning, Construction, and Operation

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Abstract: Urban rail transit loops are essential in urban rail transit systems and transportation networks. However, precise requirements and reference standards for rail transit loop design have yet to be established. There are certain areas for improvement in planning, construction, and operation. In the planning and design of urban rail transit loops, the scale of the city and the relationship between line operations should be considered to ensure that the line conforms to the city's operating traffic conditions and can effectively cater to peak passenger flow requirements. This article presents strategies for planning, constructing, and operating urban rail transit loops, laying the foundation for the healthy operation of urban rail transit.

Keywords: Urban rail; traffic line change; Planning and construction; Operation strategy

Online publication: October 25, 2023

1. Introduction

Urban rail transit lines are important traffic diversion corridors in urban development. Therefore, loops are a standard design model in the design of urban transportation lines. Currently, most cities in China adopt a circular-based transportation network layout for road networks. Compared to other line designs, urban traffic loops have specific differences in functional positioning and loop systems. Therefore, there needs to be a unified positioning in the design of urban rail transit loops. There are many types of urban rail transit loops. In the article, the structural role, planning, construction, and operation of urban rail transit networks are analyzed, and specific operational practice strategies are explored.

2. Functional analysis of urban rail transit loop lines

In the planning and construction of transportation lines, cities generally use the original rail transit to form a ray-like operation mode and use this as a basis to plan loop lines, which can realize the interception, diversion, and series connection of transportation lines. The urban transportation rail pattern design needs to play a leading role in the development of different urban areas from different transportation positioning. However,

the management of rail transit systems in most cities in China is discrete making it challenging to ensure the structural quality of central cities. The design of the loop system is conducive to integrating the city center lines with rail and ray transportation. If a ring system is built in the urban structure, the interception and diversion conditions and traffic functions along the line must be objectively evaluated. It is important to realize effective transfers between the city center and the external environment and prevent problems such as excessive passenger transfers and difficulty controlling the crowd during peak periods [1]. The function of the urban rail transit line-changing system needs to be integrated with urban planning and layout to improve the connection capacity during peak periods to avoid traffic congestion and make traveling easier.

3. Operation characteristics of urban rail transit loop lines

The characteristics of China's current urban rail transit loop operation and management can be analyzed from the following aspects:

First, the urban rail transit loop's passenger flow is relatively large, with a significant transfer volume during peak periods and high passenger flow throughout the day. Besides, the transportation distance of passengers during line operation is relatively short. Secondly, in terms of urban rail transit operation, the inner and outer loops are usually logarithmic, or different types of large and small intersections are used. Thirdly, the operation mode and organizational structure of urban rail transit loops are relatively flexible. The inner and outer lines of the loops generally operate independently allowing passengers to avoid returning to the starting point. This design ensures that the failure of one loop line does not disrupt one-way operations. This allows the line to operate more efficiently, ensures the line network's ability to handle evacuations, and improves the flexibility of transportation coordination. Furthermore, in the design of urban rail transit loop lines, there are typically several loop lines. When the line is long, it is common to include a parking facility along the line, and the track design often incorporates an eight-shaped configuration to facilitate train movements.

4. Key points in the planning and construction of urban rail transit loops

In the planning and construction of urban rail transit loop lines, the loop lines must be consistent with urban planning to ensure that the loop lines meet the long-term development requirements and the transportation needs of the city. Moreover, the station nodes should also be designed based on the people flow of the station's location and the construction requirements of various facilities to avoid crowd congestion and improve line operation efficiency while ensuring a safe and efficient travel experience.

4.1. The relationship between urban rail transit loops and urban planning

In planning urban rail transit loops, it is necessary to consider and analyze from the perspective of passenger flow to determine the relationship between loop design and urban functional layout. If the city's layout is a strong central form, the functional layout of the ring line needs to be evenly laid out to connect various groups. The loop design should encourage passenger flow and make traveling more convenient. Transportation planning of urban rail transit loops is different than ordinary radial planning, the passenger intensity index must be up to the passenger flow index of the largest one-way section [2]. In general, loop transportation covers relatively short distances, and the passenger flow capacity of individual sections is relatively low. Therefore, when establishing key passenger transportation indicators, passenger flow efficiency should be considered as an important criterion. For urban transport networks, it is essential to ensure an initial passenger flow of 10,000 passengers per kilometer per day and a long-term passenger flow intensity exceeding 10,000 passengers per kilometer per

day on the loop lines. This is crucial for achieving improved transportation operational efficiency.

4.2. The relationship between urban rail transit loops and radiation planning

The line should be designed based on ray series connection as much as possible. The number of rays should be more than 8, and over 50% of the stations should be transfer stations to efficiently handle passenger flow collection and evacuation. The radial area experiences the accumulation of passengers from multiple areas. The length ratio of radial lines inside and outside the ring line should be controlled at around 0.5. Therefore, the scale of the city must be large enough to ensure that it can hold a huge number of passengers. Besides, it is important to sort out the relationship between loop lines and transfer lines. First of all, the transfer lines must be adapted to the passenger flow to prevent the problem of having a huge accumulation of passengers at some points and having too few at others. Secondly, in the planning and designing of the ring line, avoid being located at the endpoint of the radial line to prevent passenger flow from being passive when transferring at the ring line location. In the design, a comprehensive transportation construction model with multiple parallel corridors between the loop and the outer ring can be formed, starting with landscape line planning.

4.3. The relationship between urban rail transit loops and combined loops

Various combined rings can be created in urban rail transit network design through the network structure. For instance, two lines can combine to create a loop. The “L”-shaped line can be inverted to generate a closed-loop line or a chessboard-like structure. Different line types can be used to construct various line combination rings [3]. The key is whether the lines can form a ring. In planning passenger flow, it is necessary to determine whether the route needs to be designed into the form of a ring. During the transfer between two lines, especially during peak transportation periods, the node design should guarantee that the passenger flow reaches over 50% of the cross-sectional passenger flow. When evaluating the line, it is crucial to comprehend the line’s ring structure. Moreover, construction inspection and assessment should cover aspects such as site selection and the feasibility of line sections.

5. Strategies for urban rail transit loop planning, construction, and operation

5.1. Setting up transfer stations

Construction and management are important aspects during the early stages of planning and operation of urban rail transit loop systems. In the planning and operation management of transfer stations, it is necessary to identify and predict the transfer channels’ safety factors accurately. Moreover, the passengers’ travel patterns, including travel distance, passenger flow at starting and ending points, and surrounding traffic operation rules, should be analyzed. The construction of transfer stations usually takes a long time. During the initial planning phases, it is essential to develop the preliminary plan considering building and construction conditions and analyze the plan data’s feasibility. Resource analysis should be carried out for multiple aspects, such as the ring system’s spatial configuration, geographical location, and construction conditions. The site setting and operation of transfer stations must meet surrounding traffic operation and travel requirements and comply with corresponding data indicators. Besides, it is important to minimize the impact of the construction of the rail network on surrounding industries and construction projects. Moreover, it is necessary to predict line density and passenger flow based on the long-term planning and structure of the central city to prevent vehicle transfer locations and line operation stability from being adversely affected [4].

5.2. Reasonable planning and operation base

The role of the urban rail transit vehicle base is to ensure that parking, maintenance, and other aspects of all operating vehicles can be carried out smoothly, which means that a large amount of space is required. Generally, the parking area of vehicles needs to include parking lines, car washing lines, maintenance lines, and other aspects. At the same time, there should also be control centers on-site. The planning work must be done based on both entry and exit lines. In the planning and operation of vehicle bases, the balance of the development of the vehicle's internal and external environments must be considered [5]. During the construction of the vehicle base, it is necessary to effectively control the pull-out and operating lines to ensure efficient vehicle dispatching. No other vehicles or people should be allowed to enter the construction areas, such as vehicle bases and parking lots, so a semi-enclosed design model should be adopted. The compatibility between vehicles and management personnel must be reflected in the systematic operation of areas such as vehicle bases and parking lots. During the acceptance and management of line vehicle bases, the line performance should be evaluated to prevent any impact on the central operation and dispatching of vehicles. In constructing the vehicle base, various software and hardware should be utilized to ensure the stable operation of the vehicles in the loop system.

5.3. Do a good job of coupling the ring traffic planning

The urban rail transit planning and design must be carried out in conjunction with the city's scale and development plan. During the construction and operation of the loop system network, a coupled network model must be constructed. This includes forming network integration and spatial support of multiple transportation lines, building a stable transportation hub structure, promoting the radiation of the transportation network grid, and promoting the coordinated development and planning of transportation lines [6]. The inner ring line in the city's central urban area should be designed to relieve the city's traffic pressure and realize the diversion of urban traffic. Therefore, the structure of different urban areas must be optimized from the perspective of overall coordinated development, and diversion and transfer should be reflected at different transfer points. Rail transit lines have become the key to the development of transportation connection capabilities in the current development of cities, which is also a key component of networked line coupling. However, in the rail transit design, it is necessary to predict and evaluate the growth trend of passenger flow from both the peripheral and internal aspects to prevent the flow rate at transfer points from exceeding the safety threshold. In addition, multiple loops can be formed in the urban rail transit planning system with a polycentric structure to lay the foundation for urban development. In the network coupling planning of urban rail transit, the development of different industrial centers in the city should be used to form a coordinated development target model and build a more stable urban traffic diversion and operation model [7].

5.4. The operating speed of urban rail outer ring lines

In the operation of transportation systems in cities of different sizes, the operating speed of circular lines is directly related to the planned scale and radiation of the lines. Therefore, before designing the rail transit loop, it is necessary to conduct a survey and analysis of the primary conditions of the line and site occupancy. At the same time, the outer ring passage lines and rail transportation should be built in accordance with the city's long-term development. The ring line's operating speed and operating conditions during different periods should be analyzed [8]. Currently, in most urban rail transit in China, the distance of a single ride is generally within half of the entire ring line. Therefore, the speed setting of the ring line operation is generally 38 km/h, which can meet the travel requirements of passengers. At the same time, the maximum speed setting for different distances between stations must meet different urban spatial structures and population changes. The goals of land development and construction project operations along the outer ring urban rail transit lines must be aligned in

building a multi-center network structure.

5.5. Guidance model for urban rail transit loop planning

In the design of urban rail transit, it is necessary to form an uplink and downlink operation mode. The route can be planned in the up and down directions, and the passengers do not need to deliberately distinguish between going up or down. They only need to know the train's endpoint [9]. However, ring lines are quite unique, so the traditional up-and-down operation method is not applicable. There are no definitive endpoints. However, it must be determined based on the inner and outer circles of the circular traffic and the clockwise and counterclockwise operation conditions. As a loop does not have clear starting and endpoints, it is important to have clear directories on the stations and incorporate multiple vehicle access stations along the line [10], and the passengers should be guided on the stations along the line. Optimizing the design of stations and carriage guidance systems will help passengers understand the operation of the circle line and choose the optimal travel routes. Circular route signs are also used to facilitate passengers to find routes and determine the direction of travel.

6. Conclusion

In summary, urban rail transit loops' construction, operation, and management are the key to large-scale urban transportation design. It is also a critical transportation line model to solve urban transportation problems and realize the series connection of transportation lines. Circular lines are different than conventional lines in terms of operation, station node design, and passenger flow calculation. Therefore, in the planning and operation practice of lines, it is necessary to combine the characteristics of the city, strengthen the optimization and innovation of line planning, and optimize operation management to avoid passenger congestion during peak periods, and to provide a better traveling experience for passengers.

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Discussion on Construction Technology and Welding Deformation of High-Rise Steel Frame Structure

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Abstract: Because of urbanization, land resources in China's cities has become increasingly scarce. Therefore, modern buildings are becoming taller, making high-rise steel frame structures the new favorite of the construction industry. However, the construction of high-rise steel frame structures requires advanced technology. If the construction technology is effectively implemented and the welding techniques of the construction personnel align with the requirements for high-rise steel frame structures, it can help mitigate deformations in the steel structure, thus preserving the overall construction quality of high-rise steel frame structures. To enhance the applicability of steel frame structures in high-rise buildings, this paper focuses on analyzing the optimization path for the construction process of high-rise steel frame structures. It introduces a tailored approach to control welding-induced deformations in steel frame structures, aiming to make a valuable contribution to the advancement of China's construction industry.

Keywords: High-rise steel frame structure; Construction technology; Welding deformation; Structural stability

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1. Introduction

The issue of urban land use in my country is progressively intensifying. The majority of ongoing construction projects are high-rise buildings to optimize land utilization efficiently. High-rise steel frame structure refers to buildings with six floors or more than 30 m, with steel as the primary material. The main frame structure is built using techniques like bolted connection, welding, and other forms. Compared to traditional buildings, high-rise steel frame structures are of lightweight, strong, and earthquake resistant, making it ideal for modern high-rise buildings. Besides, it drives the sustainable development of China's construction industry. Therefore, it is imminent to optimize the construction technology of high-rise steel frame structures and analyze the causes of welding deformation to quality of buildings.

2. Technological characteristics of high-rise steel frame structure

2.1. High precision requirements for measurement and setting-out

The high-rise steel frame serves as the central structural core of the building, forming the primary foundation for subsequent construction in high-rise buildings. If there is misalignment within the steel frame structure due to inaccurate measurements, it will cause the steel frame structure to dislocate. As a result, the stress structure of the steel frame is affected, which may lead to safety accidents during subsequent construction [1].

Surveying and setting out are necessary for the construction projects. Proper measurements can provide essential data support for the construction of engineering projects.

Compared to other construction types, high-rise steel frame structures require higher precision in measurement and layout, with limited room for error. Inaccuracies can lead to irreversible outcomes, resulting in material wastage and reduced construction efficiency. Therefore, the technological characteristics of high-rise steel frame structures First of all, the accuracy of measurement and setting-out is exceptionally high.

2.2. Easily affected by the weather and temperature

High-rise steel frame structures primarily consist of steel materials, including section steel and steel plates. A substantial amount of auxiliary work is needed during processing and construction to achieve the construction goals of high-rise steel frame structures. Consequently, the weather and temperature significantly impacts the construction outcome of such structures [2].

First, temperature significantly affects steel as the primary construction material of high-rise frame structures. Generally, the thermal expansion coefficient of steel is 1.2 10^{-5}/°C. Taking a 100-meter steel structure as an example, when the temperature rises by 1°C, its length will increase by 0.65mm. If thermal expansion and contraction is not considered during the connection and welding of high-rise steel frame structures, the overall performance of the structure will be affected, which in turn affecting the quality of the project construction. Secondly, the necessary equipment for the construction of high-rise frame structures, such as welding and steel-cutting equipment, will seriously impact the performance of the equipment under temperature changes. On the contrary, even burning down construction equipment in a low-temperature environment, it is impossible to weld, in general, Secondly, the equipment required for high-rise frame structure construction, like welding and steel-cutting tools, can be greatly affected by temperature fluctuations. In cold conditions, below 15°C, welding becomes impractical, and there is a risk of equipment malfunctions. Therefore, welding equipment should be pre-heated to above 15 ℃ [3].

Weather conditions are a critical factor in steel frame construction. To ensure high-quality construction of high-rise steel frames, it is essential to assess the overall impact of weather conditions, thus preventing construction quality issues linked to adverse weather..

2.3. High-performance requirements for supporting machinery and equipment

Steel as the primary material of high-rise steel frame structures. Hence, the performance of steel processing and welding equipment is the pivotal factor influencing high-rise steel frame structures.

First of all, the cutting tool is the primary equipment in steel blanking. The sharpness of the cutting tool's teeth and the degree of deviation between its tooth edge and the intended scale are pivotal factors. Any deficiency in these aspects can substantially compromise the quality of steel processing, leading to the presence of burrs, discrepancies in steel dimensions, and non-uniform steel incisions [4,5].

The second important equipment is the welding equipment. If the performance of the welding equipment is poor, the output power of the equipment will be unstable, the welding spots will be uneven, and the welding

effect will be seriously affected, which will eventually affect the overall construction of the steel frame structure.

Lastly, in the construction of steel frame structures, the utilization of steel as the primary construction material is indispensable. Given the substantial workload, any inadequacies in the quality of the equipment used can readily result in equipment failures or damage during prolonged operations, consequently impacting both construction quality and efficiency.

3. Welding deformation analysis of high-rise steel frame structure

3.1. Types of welding deformation

The types of welding deformation of high-rise steel frame structures mainly include linear, angular, bending, and torsional deformation [6].

3.2. Causes of welding deformation

There are three main reasons for welding deformation. (1) Insufficient structural rigidity: Structural rigidity is essential for high-rise steel frame structures to support building loads. If the chord section and cross-sectional dimensions do not meet the engineering requirements, it will cause longitudinal deformation. (2) Welding location: The welding location serves as the point of connection in high-rise steel frame structures and is crucial for maintaining the system's center of gravity. Any asymmetry in the welding location can disrupt the structural integrity of the steel frame, resulting in bending deformation. Furthermore, if the weld section's center is not at an ideal position, it may lead to a displacement of the structure's center of gravity, causing angular deformation. (3) Welding process: The welding process is the main factor affecting the welding quality of high-rise structures. If there is current fluctuation or that the quality of the welding rods is poor, the welding outcome will be impacted. Ultimately, this can result in an insufficient connection between the steel materials, unable to support the structural load adequately, and consequently leading to deformation [7].

4. Methods of controlling welding deformation of high-rise steel frame structure

4.1. Optimizing the welding process

The deformation caused by welding can be effectively reduced by optimizing the welding process. First, the welding current and voltage should be reasonably selected This ensures that the weld is deep and wide enough while avoiding excessive thermal deformation caused by overheating. Additionally, following a proper welding sequence, starting from the interior and proceeding outward, helps minimize heat accumulation and reduces the risk of structural deformation [8].

During the welding process, it is important to ensure the stability and consistency of welding parameters. For large high-rise steel frame structures, the temperature distribution during the welding process may be uneven, so real-time monitoring and control during the welding process is required to ensure the stability of the welding parameters. At the same time, selecting high-quality welding materials and equipment can also reduce the risk of welding deformation and improve the welded joints' quality.

In addition to optimizing the welding process, it is also crucial to set up appropriate supports. During the welding process, by setting appropriate supports, the free deformation of the structure can be reduced. However, when setting supports, care should be taken not to over-constrain to not cause internal stress concentration but to affect the structure's overall stability [9].

4.2. Controlling stake-out and unloading

Stake-out is the first step in constructing high-rise steel frame structures, which involves converting the geometric information of the structure from design drawings into specific part sizes and shapes. During the lofting process, the design requirements should be strictly followed to ensure that the size and position of each part are accurate. Especially for details of welded joints, shrinkage and deformation of the weld should be considered during the setting-out process, and appropriate margin and compensation should be used to ensure that the actual size after welding is consistent with the design size.

Blanking control is closely related to lofting, which involves cutting the lofted standard-size part from the raw material. Suitable cutting methods and equipment should be used to ensure the accuracy and quality of cutting. In addition, due to the thermal expansion coefficient and thermal conductivity of different materials, the thermal influence during cutting should be reasonably controlled to reduce the thermal deformation of the material [10].

The keys to stakeout and blanking control are precision and consistency. The lofting and blanking of each part should be carried out in strict accordance with the standard operating procedure to avoid dimensional deviation and error accumulation. At the same time, before lofting and blanking, the quality of raw materials should be carefully checked to ensure that they are up to standard to avoid problems in the subsequent welding process.

4.3. Mechanical correction method

In constructing high-rise steel frame structures, welding deformation will inevitably occur, especially in large and complex structures. The mechanical correction method is widely used in to control welding deformation effectively. This method relies on automated means to adjust and modify the welded structure to achieve the geometric shape and size required by the design [1 1].

When using the mechanical correction method, it is first necessary to measure and analyze the post-weld deformation to accurately understand the deformation of the structure. Then, the appropriate automated correction means and process are selected according to the type and degree of deformation. Standard mechanical correction methods include hydraulic correction, stretching, pressure correction, etc. These methods can make targeted structural adjustments and eliminate or reduce welding deformation.

It is important to take note of the following aspects when employing the mechanical correction method. Firstly, the correction strength and direction should be reasonably determined according to the actual situation and deformation characteristics of the structure to avoid new deformation or damage. Secondly, sufficient tests and simulation analyses should be carried out to ensure the safety and effectiveness of the correction process. Moreover, the deformation capacity of structural materials and the potential for material yield should also be taken into consideration [12].

4.4. Flame correction method

Controlling welding deformation has always been a critical issue in the construction of high-rise steel frame structures. In addition to the methods introduced earlier, the flame correction method is also widely used in practical engineering [13].

The flame correction method involves using a high-temperature flame to locally heat the welded structure to change the shape and size of the system, thereby reducing or eliminating welding deformation. This method is usually suitable for local correction of welding deformation, especially for bending and twisting deformations.

In the flame correction method, the heating position, temperature, and time needs to be determined

according to the actual situation of the structure. Besides, the heating temperature should be strictly controlled to avoid melting or scorching the materials. In addition, adequate experiments and simulation analysis are required to ensure the safety and effectiveness of the correction process [14].

4.5. Rigid correction method

When using the rigid correction method, it is first necessary to design appropriate support and constrain schemes according to the type and direction of deformation that may occur during the welding process. The supports that can be used include temporary welding fixtures, supporting frames, or steel plates, so as to ensure the stability of the structure during welding. Constrain can be achieved by setting temporary welds or embedded fixtures to limit the deformation of the structure.

When using the rigid correction method, it is important to pay attention to the following aspects. First, the thermal deformation caused by welding should be considered to ensure that the supports and fixations will not cause stress concentration or uneven deformation inside the structure. Second, the arrangement of supports and constraints should be reasonable, covering areas where deformation may occur and ensuring the quality of welded joints.

The advantage of the rigid correction method is that it is simple and practical. By adequately setting rigid supports and constraints, the deformation of the structure can be reduced during the welding process, and its geometric shape can be kept stable. However, the rigid correction method also has some limitations, as this method might not be effective for large and complex steel frame structures [15].

5. Conclusion

In conclusion, the high-rise steel frame structure is one of the main structures of current construction projects. To ensure the construction quality of the high-rise steel frame structure, the construction unit should pay attention to the construction process and formulate targeted preventive measures for welding deformation, so that the effect of the structure can be maximized.

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Research and Application of Excitation Method Optimization in Areas with Low Signal-to-Noise Ratio of Seismic Data

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Abstract: In areas with a low signal-to-noise ratio of seismic data, the continuity of the seismic reflection waves in the exploration target layer is very poor, which will reduce the imaging accuracy and make it impossible to solve certain geological tasks. This article suggests an approach to address the issue of seismic acquisition by optimizing excitation parameters. It involves conducting a detailed investigation of the surface structure, enhancing the observation system, increasing the coverage appropriately, and transitioning from combined-well excitation to single-well excitation. Additionally, the use of technical tools like qualitative evaluation of the observation system and forward modeling are employed to determine the final optimized seismic acquisition plan. The effectiveness of this approach is evident from the seismic profile obtained in an exploration area in Inner Mongolia.

Keywords: Optimization; Single-well excitation; Combined-well excitation; Coverage times; Forward illumination

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1. Problem statement

Due to the complex and volatile deep seismic geological conditions in the Longwantong (LWT) exploration area in Inner Mongolia, its seismic data has a low signal-noise ratio. This makes it difficult to obtain the desired information of the target layer. The deep target layer exhibits low reflection energy, and limited continuity in seismic reflection waves, resulting in poor seismic imaging accuracy. Subsequent data processing and interpretation face significant challenges with reduced accuracy and confidence. In order to solve geological tasks, the seismic acquisition parameters in this exploration area have been continuously strengthened, and the cost of data acquisition has increased sharply [1]. Therefore, it is crucial to improve the quality of seismic data, the signal-to-noise ratio of seismic data, and the imaging accuracy at the minimum cost.

In this study, we employed various techniques, such as three-dimensional modeling, forward illumination simulation, coverage number analysis, enhanced testing, qualitative evaluation of observation systems, and more, to conduct research and analysis on the optimization of excitation parameters. It identifies the shift

from combined-well configurations to single-well excitations, based on meticulous investigations of surface structures and increased excitation point density. These optimization plans were then assessed for feasibility and soundness, with the actual seismic profile outcomes used to verify their effectiveness [2].

2. Optimization scheme

2.1. The investigation of delicate surface structures provides the basis for selecting the optimal depth for well-blast stimulation

Surface structure investigation is not only the first step in seismic information collection, but also the basis for initiating optimization. To determine the optimal depth and lithology for stimulation, a thorough investigation of the three-dimensional surface structure was conducted at an enhanced density of 1/km². This process involved creating a detailed near-surface model. **Figure 1** illustrates the establishment of a three-dimensional surface model. Excitation parameters were meticulously designed point by point, ensuring that the explosions were triggered within the high-speed layer. Extensive excitation tests were performed in various media at depths ranging from 3–140 meters. These tests revealed that the best-optimized stimulation well depth was between 3–7 meters below the upper surface of the high-speed layer, and the most effective excitation lithology was water-bearing fine sand.

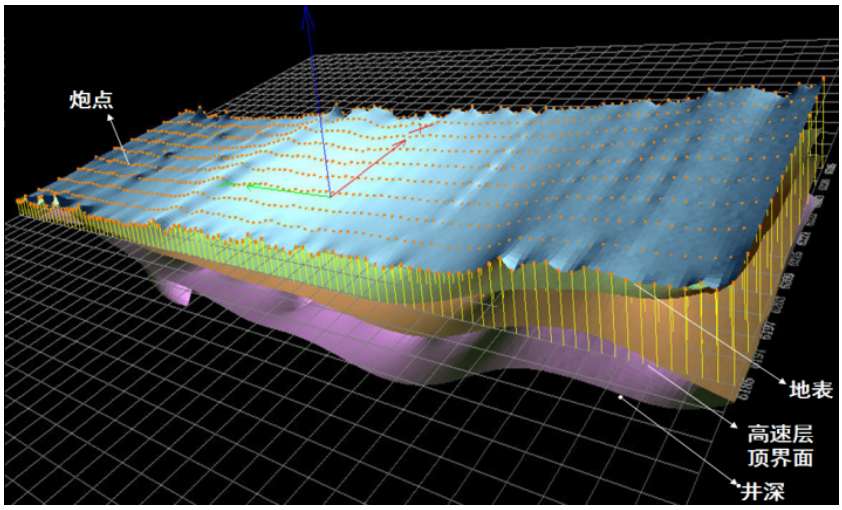


Figure 1. Accurate 3D-surface structure survey model. Translation (from left to right, from top to bottom): shot point, the surface of the earth, the top interface of high-velocity layer, well depth

2.2. Reasonably increasing the density of excitation points to increase the number of coverages

Choosing a reasonable number of coverages is the key to optimizing the excitation scheme. Superpositions have a suppressive effect on waves and random interference. Reasonably increasing the density of excitation points to increase the number of coverages can improve the signal-to-noise ratio of seismic data, thereby improving the quality of seismic processing profiles [1].

A theoretical curve can be obtained based on the relationship between the signal-to-noise ratio and the number of coverages [2] (**Figure 2**). **Figure 2** shows that before the number of coverages reached 36 times, the signal-to-noise ratio increased rapidly as the number of coverages increased. When the number of coverages was between 36 and 140 times, the signal-to-noise ratio increased rapidly and then slowly. In other words, the increase in the number of coverages will not result in significant effects after a certain number is reached.

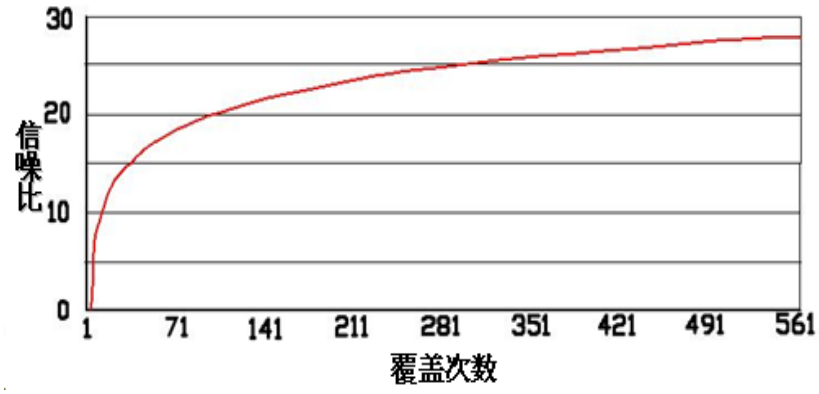


Figure 2. The theoretical curve between the fold and SNR. Note: The *x*-axis represents the number of coverages; *y*-axis represents the signal-to-noise ratio

We established a geophysical model of the area based on the geological data of the area, as shown in **Figure 3**, and conducted an analysis through a comparison of observation systems with different coverage times to determine reasonable optimization factors [1]. Observation systems of 25 m and 50 m away from the shot point were used for forward lighting simulation. The corresponding times of coverage of these two observation systems were 160 and 80 times, respectively. Other acquisition parameters were the same; the final acquisition parameters were determined based on the simulation results.

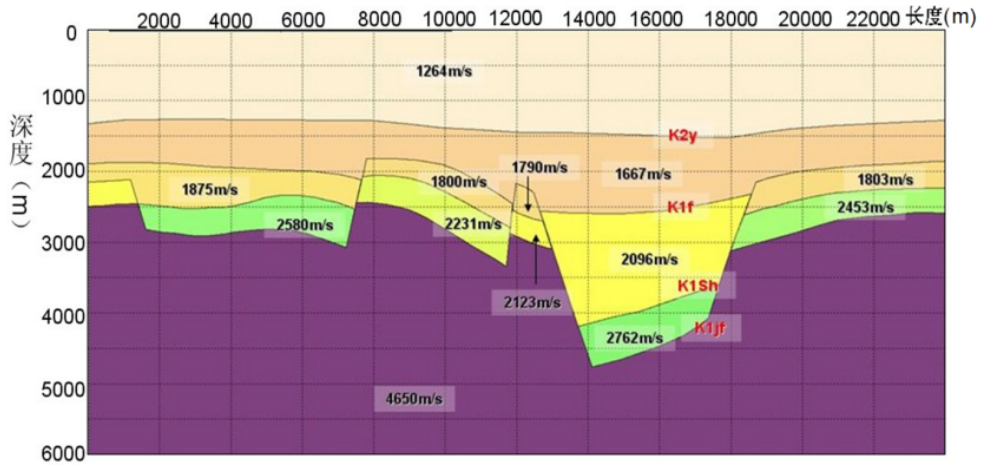


Figure 3. Geophysical model through well ZC3. Note: the *x*-axis represents length; the *y*-axis represents depth

Based on the model, forward illumination was used to generate single-shot records, and the superimposed profile was then obtained through further processing, as shown in **Figure 4**. Based on **Figure 4**, it is clear that the imaging of the main target layer of the stacked profile with 160 coverage times was more accurate and detailed than those of the pre-stack time migration profile with 80 coverage times.

The illumination analysis results were also consistent with the above-mentioned results. **Figure 5** shows the total illumination effects of 80 and 160 coverage times. The 160 coverage times had apparent advantages in terms of illumination intensity of the main target layer, especially in the deep layer. This shows that the excitation optimization scheme with a reasonable increase in coverage times effectively improves the signal-to-noise ratio and imaging accuracy of the exploration target layer in this area [3-7].

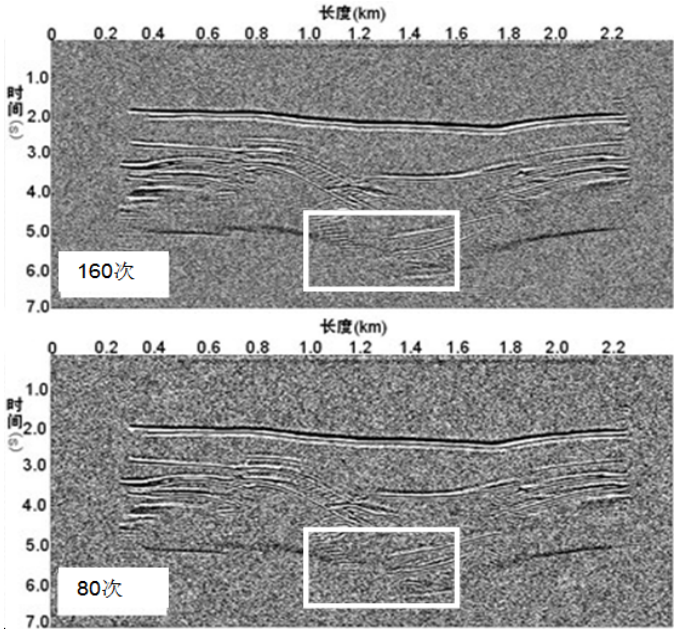


Figure 4. Forward section comparison of different folds. Note: The *x*-axis represents length; the *y*-axis represents time. The number of times in the upper part of the figure is 160 times, and the number of times in the lower part of the figure is 80 times

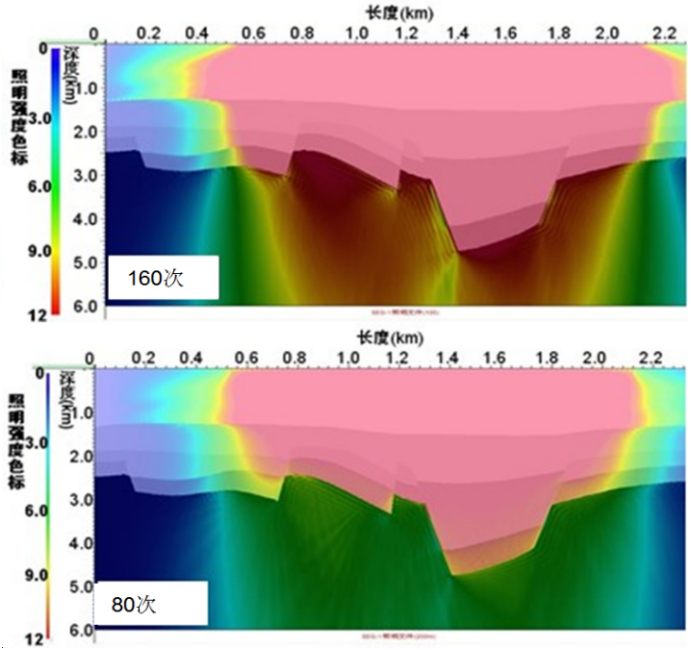


Figure 5. Illumination comparison of different folds. Note: The *x*-axis represents the length; the *y*-axis represents the color code of strength of illumination (left), depth (right)

2.3. Using single-well stimulation instead of combined-well stimulation to achieve cost optimization without compromising the quality of data acquisition

While the shot density increases with the optimization of the number of coverages, the cost of data acquisition also increases. Therefore, it is important to control the cost while ensuring the quality of data acquisition. Therefore, we propose to use single-well excitation instead of combined-well excitation. However, the efficacy

of this method needs to be verified through a few tests. With this method, a single-point test is far from enough, and systematic line tests are needed to compare the profile effects of single-well and combined-well stimulation to determine whether such stimulation optimization is feasible [8].

In terms of single-shot quality, the excitation effect of combined wells is better than that of single wells, but the final geological interpretation is carried out on the final seismic stacked profile. This optimization involves doubling the coverage. The question we need to answer is whether increasing the coverage can compensate for, or even outperform, the difference between single well and combined-well single shots. This emphasizes the importance of enhancing line testing [9].

We carried out single-well and combined-well excitation comparison tests on a two-dimensional line, using a 2-line and 2-shot observation system, with the two excitation lines located within the two receiving lines. One of the excitation lines used an excitation factor of 10 kg for a single well, and the other excitation line used an excitation factor of 6 kg for 4 wells. The other acquisition factors were identical for both lines [10].

Judging from the final processed migration profile (**Figure 6**), the signal-to-noise ratio and imaging effect of the target layer of the two-factor profiles were equivalent, so the cost optimization plan of using single-well stimulation is feasible. In this way, data quality is improved by increasing the number, while the cost is controlled.

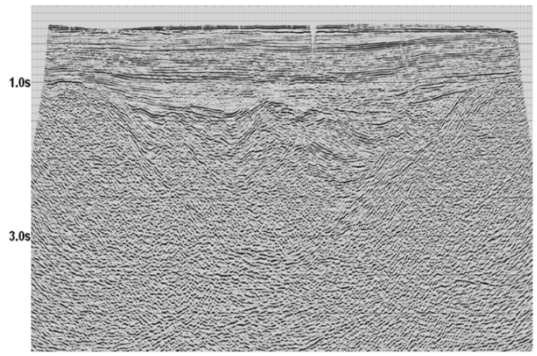


Figure 6a. Migration section of 100-fold (1 × 10 kg).

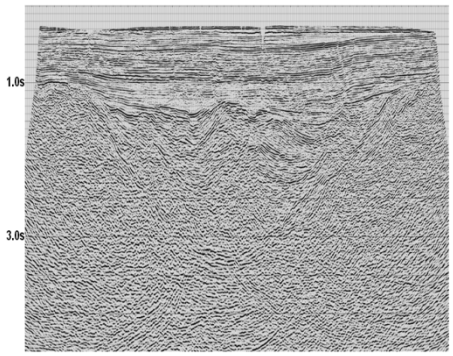


Figure 6b. Migration section of 100-fold (4 × 6 kg).

2.4. Strengthen the observation system to ensure the quality of the collection

There is no doubt that the design of the observation system is an important aspect of seismic data acquisition. In order to ensure the acquisition quality and fulfill the requirements of pre-stack migration processing, the concepts of sufficient sampling, uniform sampling, and symmetric sampling are followed in the parameter design of the seismic acquisition and observation system in the LWT exploration area.

Through acquisition parameter analysis, forward illumination simulation, and observation system evaluation, the 24L3S192R acquisition template was finally adopted. This observation system was greatly enhanced, both in terms of the number of single-line receiving channels and the total number of receiving lines. The size of the panel grids was 12.5 m × 12.5 m. **Figure 7** shows the dip-moveout (DMO) impulse response waveform of the 12.5 m. The uniform distribution of offset and azimuth angles within the grids prevented the collection of footprints [11]. Moreover, from the corresponding F-K spectrum recorded by a single shot (**Figure 8**), it was found that the track distance of 25 m, and the 12.5 m × 12.5 m panel grids prevented the folding frequency of the refracted wave and ground roll wave from aliasing the effective wave frequency. This proved that the panel grid size selected for this seismic acquisition was suitable.

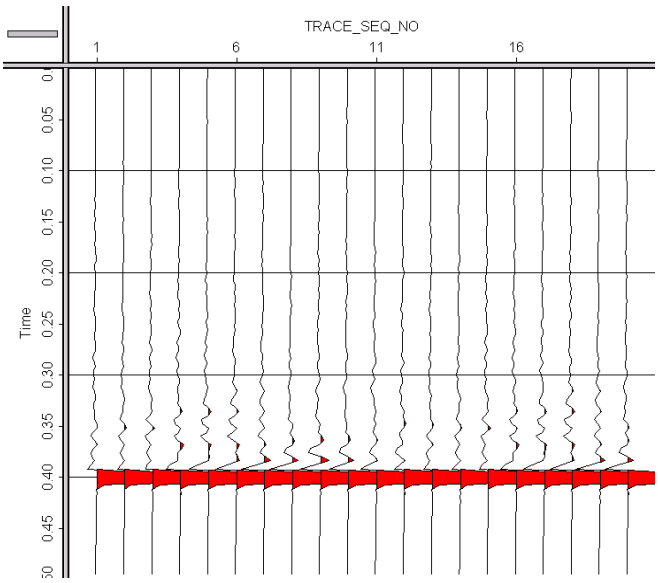


Figure 7. The waveform of impulse response wavelet

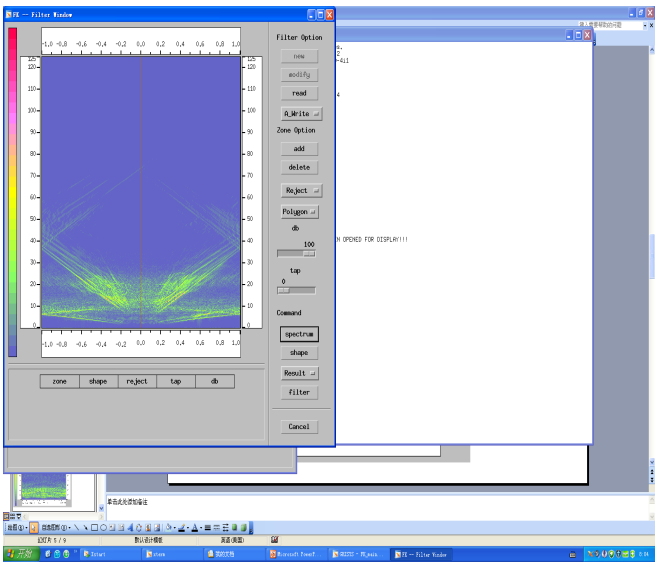


Figure 8. FK spectrum of single shot record

3. Optimization effect analysis: Profile analysis

In short, the excitation optimization plan mentioned above is to use single-well excitation instead of combined-well excitation to reduce cost. The observation system was also optimized by increasing the density of excitation points, the number of single-line receiving channels, and the total number of receiving lines to increase the number of coverages. Besides, small panel grids were used to avoid collecting footprints.

The comparison of the old and new migration profiles of the survey lines at the same position is shown in **Figure 9**. A new seismic profile (top of **Figure 9**) was acquired after executing the excitation optimization plan. Regardless of the signal-to-noise ratio and resolution, or interlayer information and deep imaging, the data quality was greatly improved compared to the old profile collected in 2004 (bottom of **Figure 9**). The quantitative analysis results of the profile spectrum can also be supported. The bandwidth of the deep layers in the new profile (the frame area in Figure 9) is 20 Hz wider than that of the old profile.

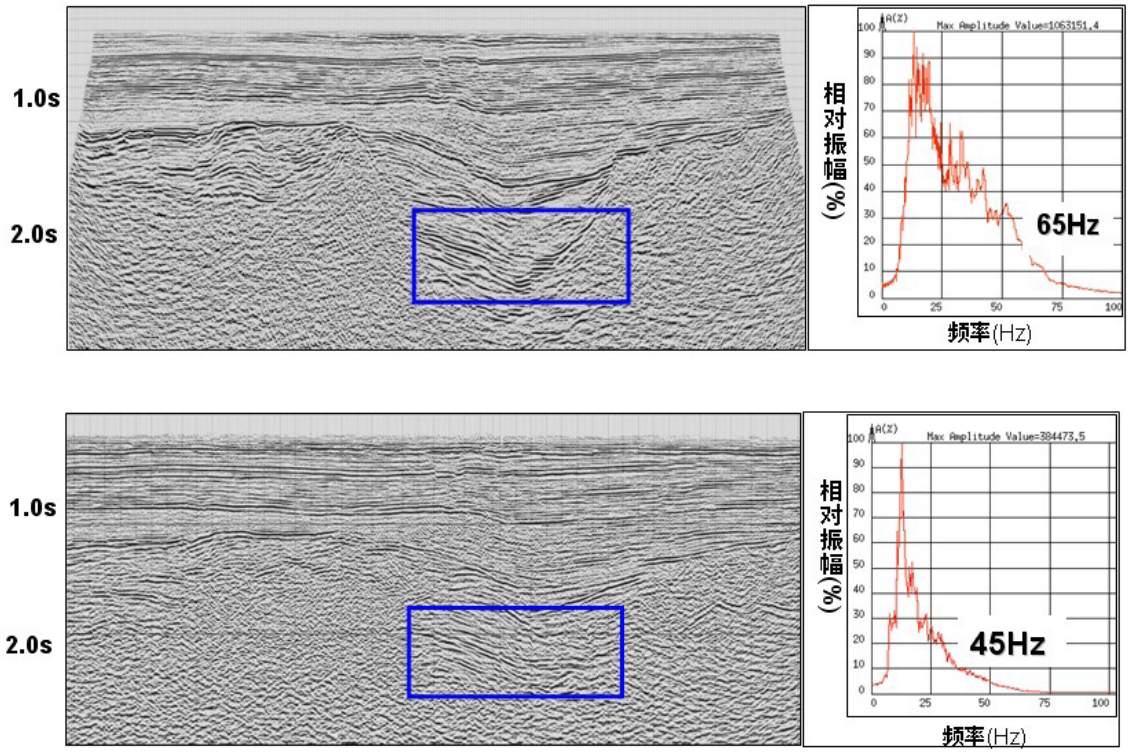


Figure 9 Analysis of optimization effect comparison of new and old sections. Note: The *x*-axis represents the frequency; the *y*-axis represents the relative amplitude

The higher data frequency has greatly improved resolution, enriched information in shallow layers, ensured good continuity for mid-layer events, increased the visibility of microstructural features, strengthened deep reflection energy, clarified structural boundaries, and significantly enhanced imaging quality. This clearly demonstrates the effectiveness of the stimulation optimization scheme described in this article.

4. Conclusion

Through the single-well and combination-well point test, line test, and the application of single-well for the three-dimensional seismic profile in the LWT exploration area in Inner Mongolia, several conclusions can be made.

(1) The signal-to-noise ratio of the target layer stimulated by a single shot fired by a combined well is higher than that of a single shot fired by a single well, and the continuity of the event axis is better. However, the effect of the combined well on noise suppression is greatly weakened after superposition. The stimulation effect of combined wells is basically the same as that of single well stimulation.

(2) By changing the combined well to single-well excitation, the observation system can be optimized, such as increasing the number of single-line receiving channels and the total number of receiving lines, and increasing the number of coverages, all without increasing the cost of data acquisition. These measures improve the data signal-to-noise in areas with low signal-to-noise ratio.

(3) Both combined-well stimulation and single-well stimulation have achieved good results in the LWT exploration area in Inner Mongolia, these methods can be applied in other areas with sufficient testing.

Disclosure statement

The author declares no conflict of interest.

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Indoor Space Modeling and Parametric Component Construction Based on 3D Laser Point Cloud Data

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Abstract: In order to enhance modeling efficiency and accuracy, we utilized 3D laser point cloud data for indoor space modeling. Point cloud data was obtained with a 3D laser scanner and optimized with Autodesk Recap and Revit software to extract geometric information about the indoor environment. Furthermore, we proposed a method for constructing indoor elements based on parametric components. The research outcomes of this paper will offer new methods and tools for indoor space modeling and design. The approach of indoor space modeling based on 3D laser point cloud data and parametric component construction can enhance modeling efficiency and accuracy, providing architects, interior designers, and decorators with a better working platform and design reference.

Keywords: 3D laser scanning technology; Indoor space; point cloud data; Building information modeling (BIM)

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1. Introduction

As technology continues to advance and the scope of applications expands, there is a growing demand for the modeling of indoor spaces and the construction of components. Indoor space modeling refers to the transformation of real-world indoor environments into digital three-dimensional models for the purpose of analysis, visualization, and various applications. Parametric component construction, on the other hand, involves generating component models that meet specific requirements through computer programs, using adjustable parameters or rules.

In the past, indoor space modeling and component construction heavily relied on manual measurements and manual modeling, which were time-consuming, labor-intensive, and prone to errors. However, with the emergence and maturity of 3D laser scanning technology, based on 3D laser point cloud data, indoor space modeling and parametric component construction have become rapid, efficient, and highly accurate [1]. 3D laser scanning technology involves the use of laser scanners or laser scanning cameras to capture a vast amount of point cloud data of the target indoor space. These point cloud data contain rich geometric and topological

information, accurately reflecting the shape, structure, and details of the indoor environment. Parametric component construction leverages point cloud data and modeling algorithms to automatically generate component models that comply with specific rules and parameters.

Therefore, we aimed explore how to acquire point cloud data of indoor spaces using 3D laser scanning technology and achieve precise modeling of indoor spaces and automated generation of components through point cloud processing and parametric modeling methods through this study. This will significantly enhance the efficiency and accuracy of indoor space modeling and component construction, providing robust support and application foundations for fields such as architectural design, interior decoration, cultural heritage preservation, and more.

2. Introduction to 3D laser scanning technology and its advantages

A 3D laser scanner is a device capable of capturing three-dimensional point cloud data of indoor or outdoor environments. The 3D laser scanner described in this paper operates based on time-of-flight measurement and involves the following key steps. (i) Emission of laser beam: The scanner emits a laser beam, typically in the infrared spectrum. (ii) Reception of reflected signals: When the laser beam strikes surfaces on the target object, some of the light is reflected back and is received by the scanner's receiver. (iii) Calculation of time or phase difference: Using either the time of flight or phase measurement, the scanner calculates the time or phase difference required for the laser beam to travel from emission to reception; this information is used to determine the distance to the target object. (iv) Scanning point cloud data: During the scanning process, the scanner continuously changes the direction of the laser beam. By collecting and combining the acquired point cloud data, a comprehensive three-dimensional point cloud of the entire scene is generated. (v) Data processing: The obtained point cloud data can be subjected to various processing steps using algorithms and software; these steps may include filtering, registration, segmentation, and more, ultimately resulting in the generation of high-quality three-dimensional models.

3D laser scanning technology offers advantages such as high precision, non-contact measurement, efficiency, comprehensiveness, completeness, and visualization, among others. These advantages have led to its widespread application in fields such as architecture, design, engineering, cultural heritage preservation, manufacturing, and more. Additionally, it has driven progress and innovation in these areas.

3. Project overview and technical roadmap

To validate the effectiveness of the methods presented in this paper for establishing indoor models and parametric components, a residential indoor space within a residential community was selected as the experimental subject. The floor plan of the indoor space is shown in **Figure 1**. This indoor space is divided into two levels, connected by a three-turn staircase. The second floor space includes sloping beams and an attic. Using manual measurement methods would be extremely time-consuming and labor-intensive, and using drones for surveying would be challenging due to the indoor environment.

Considering the advantages and disadvantages of different surveying methods and based on the on-site conditions and technical feasibility, ground-based 3D laser scanning was chosen as the method for three-dimensional modeling of the indoor space.

The equipment used for this experiment is the FARO Focus3D X330 3D scanner. The detailed specifications of the scanner include the following: scanning element (laser module), scanning range (0–330 m), scanning medium (any), scanning speed (976,000 points/second), scanning light source (infrared laser),

instrument size (240 × 200 × 100 mm), instrument weight (5.2 kg), instrument interface (USB 2.0 or Wi-Fi), instrument pixels (70 million), optical resolution (600 × 1200 dpi), operating temperature (5–40°C), and operating humidity (non-condensing). The software tools used for data processing and integration were Autodesk Recap and Revit. The specific technical roadmap is shown in **Figure 2**.

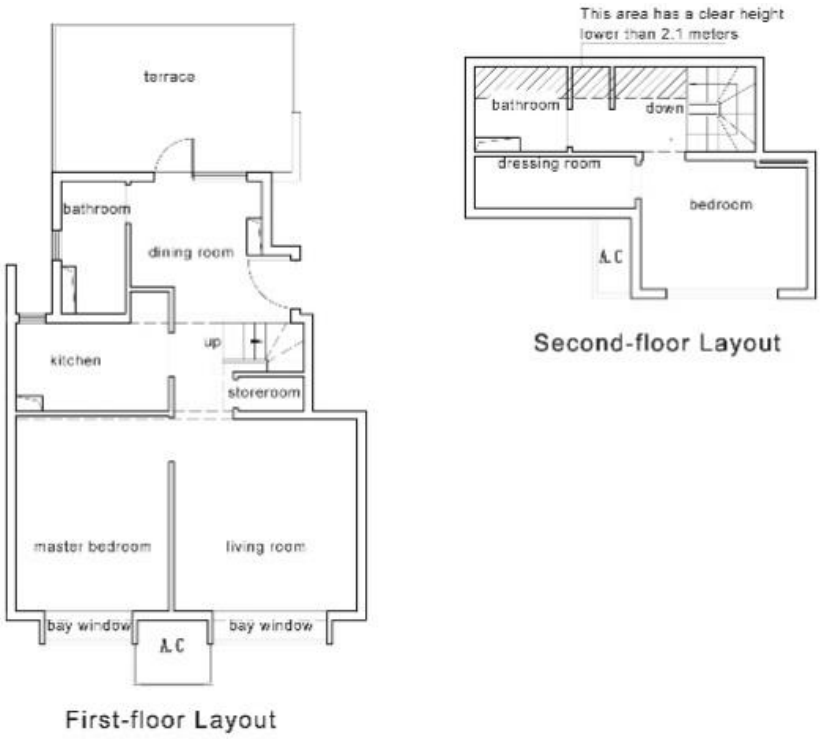


Figure 1. Project floor plan

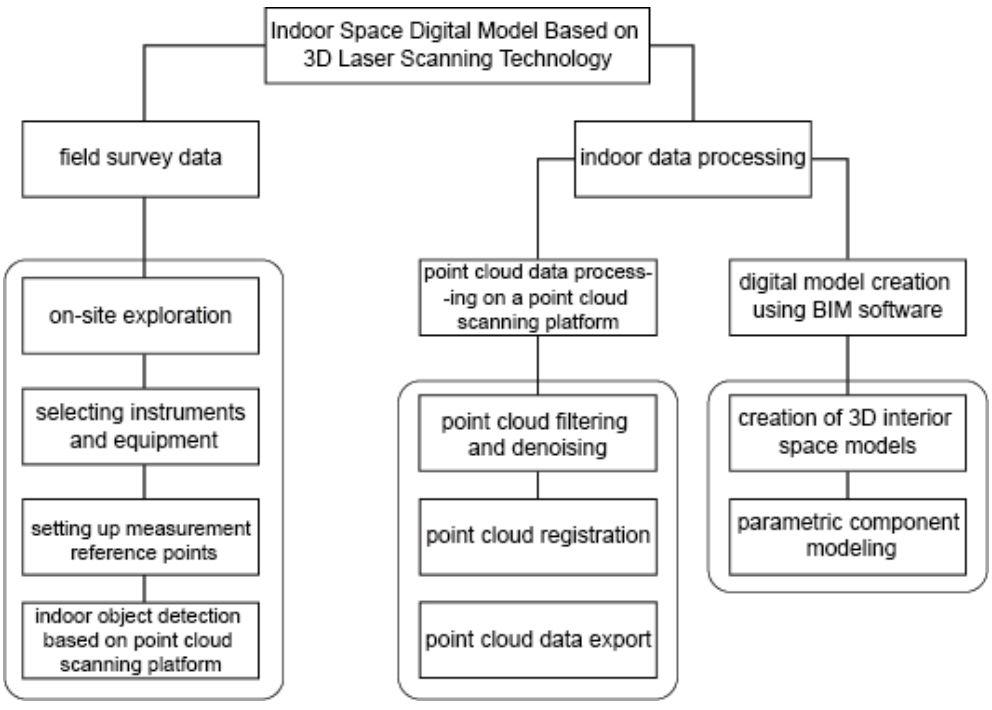


Figure 2. Technical roadmap

4. Field data collection

4.1. Site layout

Site layout is crucial before conducting the scanning process. Firstly, based on the requirements of the scanning task and the characteristics of the indoor space, the indoor area was divided into multiple scanning regions. Each region included the objects to be scanned while avoiding overlap or omissions as much as possible. Then, the scanners were placed at suitable positions. Several factors that were considered include the field of view, scanner height, scanner angles, and accessibility. The scanner covered the target area and achieve the desired scan density and angles.

As shown in **Figure 3**, point cloud data from two adjacent spaces are required, with Station 1 and Station 2 being set up for data collection. The diagonal region represents the overlapping area between the scan ranges of Station 1 and Station 2. Typically, in order to successfully stitch together data from two scanning areas, the overlapping region should be at least 30%. As shown on the left side of the image below, if the overlapping area between the two stations is too small, there won't be enough data for successful stitching. Therefore, it was necessary to set up a Station 3 at the connection point between the two spaces. Station 3 can bridge the data from Station 1 and Station 2, significantly increasing the overlap rate between the two stations, enabling successful connection [2]. The final station layout is shown in **Figure 4**, where solid circle markers represent data collection stations, and hollow circle markers represent station connection points.

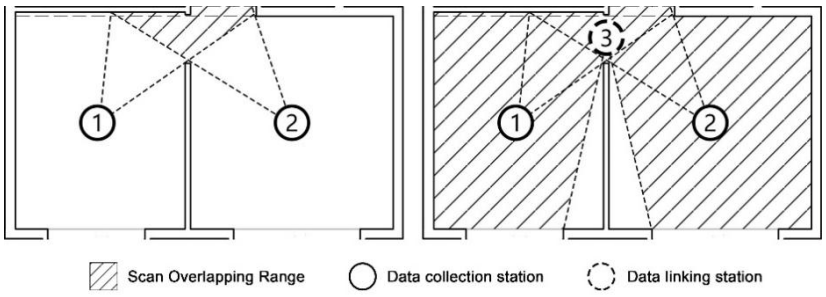


Figure 3. Scan overlap area comparison

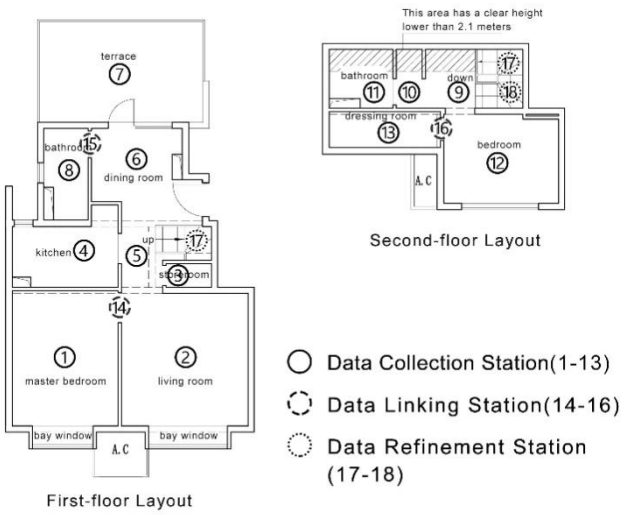


Figure 4. Scanner station layout diagram

4.2. Equipment installation

The legs of the tripod were extended and secured to be parallel with the ground. The tripod's height was adjusted to the preset level, ensuring that the scanning range includes reference points. A safety tether was used to secure the scanner to the tripod, ensuring the consistency and stability of the scan data. An SD card was inserted into the device to store the captured point cloud data. Once the instrument was placed on the station, the instrument's built-in level was used to confirm that the scanner is in a level position to prevent any errors in the scan data.

4.3. Scanning process

Once the instrument was set up, the operator clicked the start button on the main interface, and then moved away from the scanning area. The scanner started scanning automatically. During the scanning process, it was important to avoid any individuals entering the scanning area to reduce noise and prevent occlusion of data. Periodically, the calibration status of the scanner was checked to ensure the accuracy and consistency of data collection. Finally, data collection was completed at all stations, and the field data acquisition work was concluded.

5. Indoor data processing

5.1. Point cloud data processing

For the processed point cloud data, Autodesk Recap was used for stitching and noise reduction. Recap is a professional 3D point cloud processing and modeling software developed by Autodesk. Recap can integrate large amounts of point cloud data and generate high-quality digital models and visualizations.

The generated data files were imported into Revit for indoor space modeling and the creation of parametric components. Revit is a building information modeling (BIM) software also developed by Autodesk, used in fields such as architectural design, structural design, MEP (mechanical, electrical, and plumbing) design, and construction. The workflow for indoor data processing is described below.

(i) Data import and pre-processing

The unprocessed FLS format point cloud data was imported into Recap, The point cloud data were then pre-processed to improve its quality. This preprocessing includes point cloud filtering and noise reduction.

(a) Point cloud filtering

Point cloud filtering involves smoothing the point cloud data and removing excess noise and outliers. Filters can be applied based on attributes such as point position, intensity, and color to enhance the point cloud quality.

(b) Noise reduction

Noise reduction involves cutting the point cloud data within a defined geometric range, retaining only the necessary data within the specified area.

(ii) Point cloud registration and feature extraction

After preprocessing the point cloud data, Recap software performs point cloud registration to align the point clouds. This process is automatically conducted by Recap and employs the iterative closest point (ICP) algorithm to find the best rigid transformation that aligns the point clouds from different positions. Once registered, the point cloud data is in the same coordinate system [3].

After point cloud alignment, there may still be some slight mismatches or drifts. Recap further optimizes the matching precision through registration operations. Recap provides a registration data (**Figure 5**), which

displays three metrics: “Overlap,” “Balance,” and “Points < 6mm.” These metrics evaluate the overlap between point cloud data from multiple scan positions, the uniformity of point distribution, and the precision of the data.

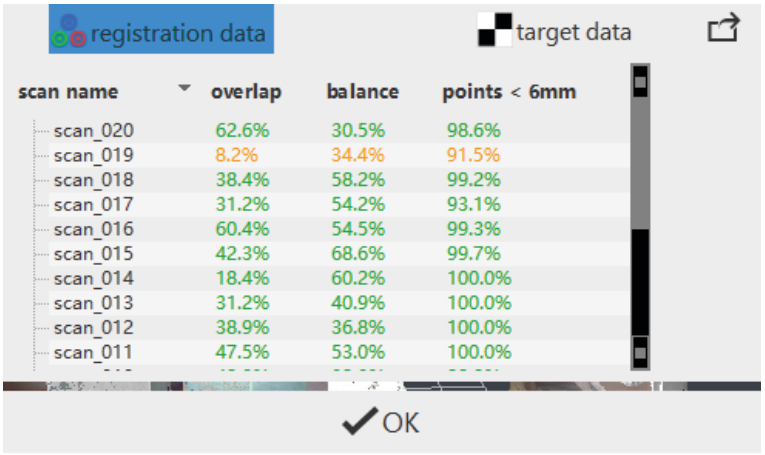


Figure 5. Registration data

Once the registration is complete, all point cloud data will be stitched together and placed within the previously defined coordinate system. At this stage, excess noise or unwanted point cloud data can still be removed by selecting and deleting them. Recap provides several automated feature extraction tools that can identify and extract features with specific geometric shapes or attributes within the point cloud data. These features may include walls, floors, ceilings, columns, and more.

After completing the above steps, a complete point cloud data model of the indoor space is formed. The final indoor point cloud data model is illustrated in the following images (**Figure 6** and **Figure 7**). Recap offers various analysis tools, such as volume calculations, point cloud measurements, and cross-sectional analysis. These tools can be used to extract various information about the indoor space, such as volume, area, height, and more. Once the point cloud data processing is complete, you can export the results in the desired formats, such as CAD files (DWG, DXF), BIM models (RVT, RCP), or other 3D model files (OBJ, FBX, etc.).

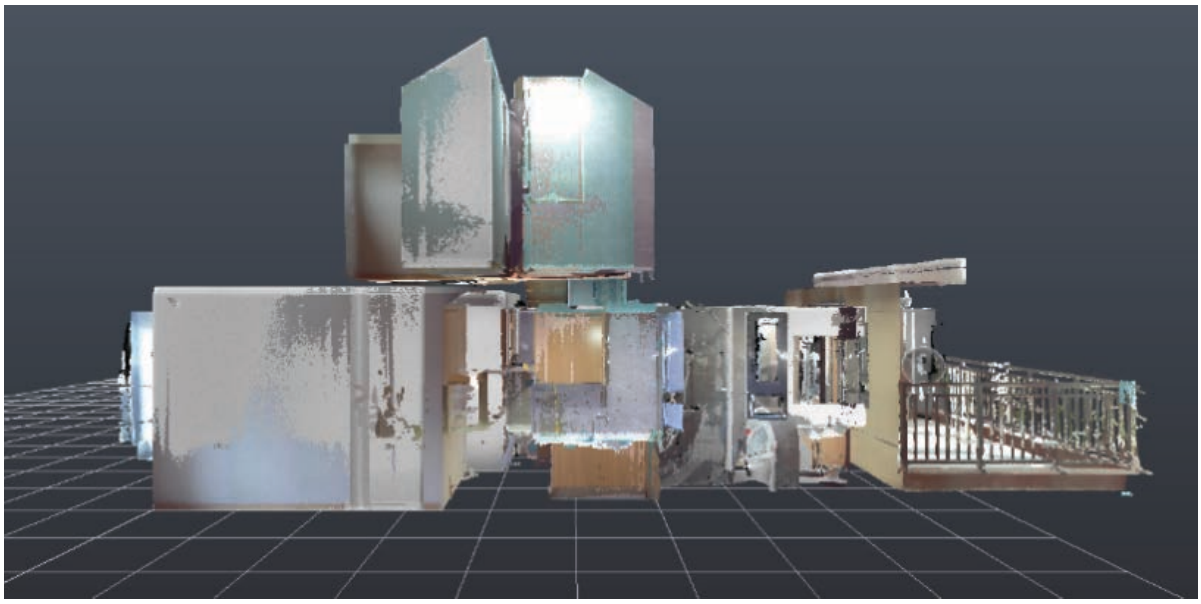


Figure 6. Indoor space 3D laser scanning point cloud data (overall)



Figure 7. Indoor space 3D laser scanning point cloud data (partial)

5.2. Establishment of three-dimensional indoor space model and construction of parametric components

(1) Importing and aligning point cloud data

After processing the point cloud data, the data was imported using a built-in function of Revit. Then, the imported point cloud data was aligned with the model base point by dragging the point cloud data or using Revit's modification tools. Common feature points, edges, or planes could be selected for aligning the point cloud data.

(2) Creating model elements

After importing the point cloud model, the process began with creating the basic geometric shapes of the model in Revit, such as walls, floors, and ceilings. Point cloud data served as a reference to help determine the position and shape of these basic elements. Geometric shapes were drawn in Revit based on the information from the point cloud data and were modeled according to the measured dimensions and positions. Parameters and attributes for these elements were set as required[4].

In Revit, by drawing floor plans and defining parameters such as dimensions, positions, and attributes for elements, the software will automatically create corresponding 3D models. This workflow, based on parametric modeling, links the drawing of floor plans to the creation of 3D models, allowing designers to more intuitively understand and adjust the spatial relationships and geometric shapes of architectural elements.

(3) Creation of parametric components

After creating the model, the next step involved using Revit's parametric modeling feature to transform the created model elements into parametric components. Revit offers a range of predefined component types, including doors, windows, and furniture, among others. Parameters were then defined for the selected component type. Parameters served as the fundamental units for controlling component properties, encompassing dimensions, materials, types, and more. Depending on the characteristics and design requirements of the component, appropriate parameter types, such as length, width, height, and material, were selected.

During the definition of parameters for components, parameters were associated with the geometric features of the model elements. This was done by selecting the geometric elements of the component and linking them to the appropriate parameters, ensuring that changes in parameters automatically affected the geometric shape of the component. (**Figure 8**).

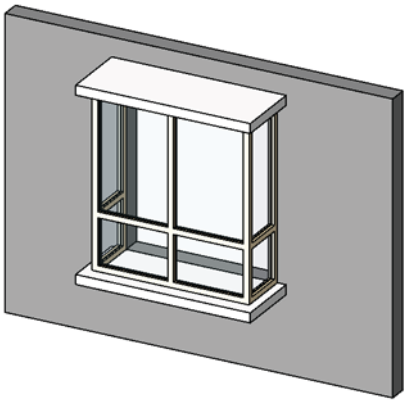


Figure 8. Parametric bay window

Then, a type catalog was created for the component type. A type catalog is a collection of component types with similar features. By defining a type catalog, component types could be better organized and managed, simplifying subsequent parametric modeling and use. Numerical values of parameters were adjusted to automatically modify the component's dimensions, shape, and material properties. The component was further fine-tuned by modifying parameter values based on design requirements and changes.

(4) Editing, optimization, and drawing output

After completing the model construction, further editing and optimization of the model involved using Revit's editing tools to adjust the dimensions, positions, and properties of elements. The model's appearance and visual effects were enhanced by adding materials, textures, and colors. Once the model construction was finished, Revit was used to generate various drawings and outputs (**Figure 9**). Views, sections, and profiles were defined to present the model from different perspectives and scales. This included creating floor plans, elevations, sections, as well as 3D views for design presentations, construction drawings, and visual displays.

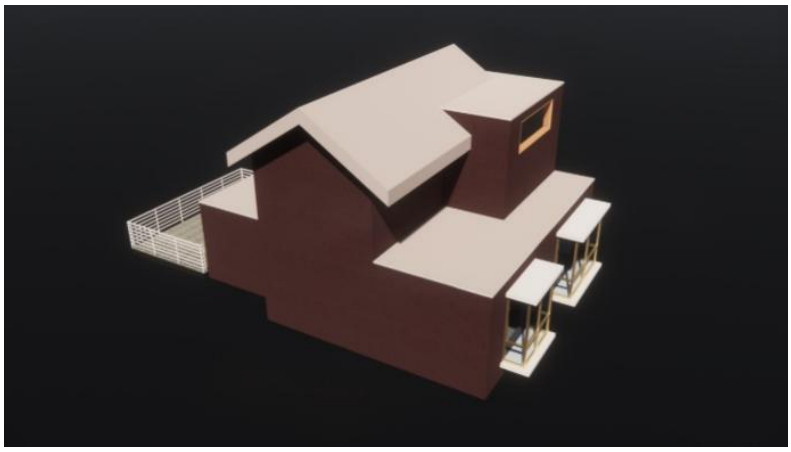


Figure 9. Indoor space 3D model

6. Conclusion

This research aimed to achieve indoor space modeling and parametric component creation based on three-dimensional laser point cloud data. High-precision point cloud data was acquired using a laser scanner, and

Autodesk Recap and Revit software were employed for data processing and modeling. Through the processing and analysis of point cloud data, we successfully reconstructed a three-dimensional model of indoor space and utilized parametric component technology for component creation and optimization. This provides more accurate, efficient, and visual tools and methods for interior design, construction, and maintenance.

However, there are still challenges and areas for improvement that need further exploration. Firstly, the processing and modeling of point cloud data still require significant manual intervention and operations, particularly during the point cloud registration and segmentation stages. Therefore, the development of automated and intelligent algorithms and tools is an important direction to reduce human effort and improve efficiency. Secondly, the current point cloud data processing and modeling mainly focus on static indoor environments, and challenges remain for dynamic and complex scenarios such as human activities and moving objects. Effectively processing and utilizing dynamic information to make modeling results more realistic and reliable is one of the future research directions.

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Disclosure statement

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Analysis of Intelligent Construction Technology of Building Prefabricated Components Based on BIM

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Abstract: In this paper, the intelligent construction of prefabricated components is analyzed based on building information modeling (BIM). It includes an overview of BIM-based prefabricated components and intelligent construction, intelligent production lines in BIM-based intelligent construction systems, and analysis of the application of intelligent manufacturing in BIM-based prefabricated components. It was found that the determination of construction goals, the establishment of intelligent construction systems, and the application of intelligent construction systems are all areas that need to be emphasized in producing prefabricated building components through intelligent construction. It is hoped that this analysis can provide some reference for the application of intelligent construction and the improvement of the quality of prefabricated building components.

Keywords: Construction engineering; Prefabricated components; Intelligent construction technology

Online publication: October 25, 2023

1. Introduction

In the process of manufacturing prefabricated building components through intelligent construction, relevant units and staff first need to be knowledgeable about intelligent construction and fully understand their intelligent production line. Besides, the requirements for manufacturing the prefabricated building components should also be considered. In this way, intelligent construction can be applied appropriately.

2. An overview of BIM-based intelligent construction of prefabricated components

2.1. Introduction of BIM and intelligent construction

BIM technology is a digital management tool that has been widely used in modern engineering design, construction, and management. It enables the creation of digital, information-based models using specialized software and facilitates the intelligent production of diverse prefabricated components. Intelligent construction involved introducing advanced intelligent technology and other related technologies into building construction. Intelligent construction serves to reduce the dependence on labor, thereby improving the cost-effectiveness,

reliability and safety of building constructions [1]. As intelligent technology develops, the application of intelligent construction technology in the field of modern construction has also been increasing. The application of intelligent construction is especially evident in the manufacture of prefabricated building components, intelligent construction technology.

2.2. The advantages of BIM-based intelligent construction in prefabricated component manufacture

As far as the current manufacturing of prefabricated components in construction projects is concerned, the application advantages of BIM-based intelligent construction technology mainly include the following aspects: (i) It can comprehensively transform the extensive production process of traditional building prefabricated components to achieve industrialization, standardization, digitization and Intelligent component manufacturing effect. (ii) Intelligent supervision and management of various process links such as the design, production and application of prefabricated building components can be carried out to ensure the manufacturing and application effects of prefabricated components to the greatest extent and meet the actual application needs of modern construction projects. (iii) It can realize information sharing in each prefabricated component production link, so as to achieve good communication and coordination effects between various organizations and staff. (iv) Through intelligent monitoring and management, significant savings in human resources can be achieved in the production of prefabricated components, and the adverse impact of human factors on production and manufacturing quality can be effectively avoided, thereby saving more manufacturing costs for relevant enterprises. With these advantages, intelligent construction technology has been widely used in the manufacturing and processing of modern building prefabricated components, and its application prospects are also very bright.

3. Intelligent production lines in BIM-based intelligent construction systems

3.1. Basic overview

In the intelligent construction system based on BIM, the intelligent production line is an integrated intelligent system based on information and physics. Intelligent production lines can integrate the physical construction process and the information computing process, allowing real-time interaction between the two. In this way, a closed-loop system composed of status monitoring, real-time analysis, optimization decision-making, and precise control modules can be formed. With this system, many problems in the production and manufacturing of building prefabricated components can be solved effectively. This not only enables a better allocation of manufacturing resources, but also enables dynamic and intelligent management of the entire prefabricated component manufacturing process.

3.2. Main components and functions

The intelligent production line includes several components. (i) Design (BIM): Utilizing BIM technology, the architectural, structural, interior, and mechanical and electrical elements are seamlessly integrated, resulting in the creation of a three-dimensional visual design effect. (ii) Enterprise resource planning system (ERP): ERP involves the management of projects, sales, quality, technology, laboratories, component delivery, procurement inventory, and construction sites. Intelligent decision-making in cost accounting, construction period forecasting, financial management, and other aspects can be made through comprehensive acquisition of all kinds of real manufacturing data. (iii) Manufacturing execution system (MES): MES involves the management production planned orders and production orders. After issuing the production plan, the BIM component

design data will be analyzed and sent to the digital production and manufacturing workshop, thereby realizing the automatic setting of production equipment parameters [2]. At the same time, production line information can also be uploaded to the intelligent decision-making layer to achieve timely feedback and adjustment of production progress. (iv) Digital workshop: Leveraging the computer-aided manufacturing (CAM) system and the supervisory control and data acquisition (SCADA) system for issuing prefabrication instructions, data acquisition, intelligent monitoring, video surveillance, and event notifications, the production process is automated based on the specific design data of prefabricated components. At the same time, all operating data of the automation equipment can be uploaded to the MES in real time. (v) Automated equipment: All equipment on site is controlled through Programmable Logic Controller (PLC) or Computerized Numerical Control (CNC) system to strictly implement various production process instructions or parameters issued by the digital workshop, thereby realizing automated production of prefabricated building components. (vi) Integration of the intelligent production line functions: Cloud platforms and various production factors are horizontally integrated under BIM technology, and various types of intelligent production and manufacturing information are vertically integrated through MES and ERP systems. At the same time, the organic integration between the production line and artificial intelligence can also be achieved, thereby realizing the comprehensive application of intelligent construction.

4. Application analysis of BIM-based intelligent construction of prefabricated components

4.1. Objectives of BIM-based intelligent construction

There are several objectives of producing building prefabricated components through BIM-based intelligent construction. (i) With the help of industrial IoT, all logistics information in the factory can be traced across the board and controlled. Engineering configuration, component production, and product quality should also offer auxiliary decision-making support for specific component production. (ii) Through the rational application of intelligent and highly integrated information management systems, each segment of the production line can be made more transparent, thereby comprehensively improving the manufacturing process of prefabricated components, and realizing a seamless connection between the production site and operations and sales. (iii) Utilizing production management information services can improve internal control, boost production efficiency, and enhance product quality while reducing manufacturing costs for prefabricated components. This helps achieve the goals of lean production and digital and intelligent production management [3]. (iv) Through the reasonable application of intelligent construction technology and its systems, intelligent production, data visualization, and quality traceability can be achieved.

4.2. Establishing a BIM-based intelligent construction system

When manufacturing prefabricated building components through BIM-based intelligent construction, the entire production process of prefabricated components, including the design, simulation, manufacturing, and optimization of BIM-based components all need to be included in the overall framework. In this process, advanced measurement and control technology should also be applied accordingly to build an intelligent data collection and production control system. This integrates the database, data collection, process control, and production management systems in the system. Intelligent algorithms perform real-time analysis and optimization of production data, which is then promptly fed back to the system's operating end.

In the construction of BIM-based intelligent construction systems, an integrated production planning service empowerment model is used for information management. MES and SCADA are used to supervise the

entire manufacturing process of prefabricated building components and all automated production equipment involved, thereby achieving real-time collection of all production data, real-time monitoring of the production process, and intelligent production scheduling, equipment management, and data analysis [4]. With digital twin technology, the production process of components can be visualized, thereby building a high-efficiency, high-quality, and low-cost intelligent manufacturing system for the manufacturing of prefabricated building components.

4.3. Applications of BIM-based intelligent construction system

When manufacturing prefabricated building components through a BIM-based intelligent construction system, the intelligent construction of prefabricated components needs to be carried out based on the BIM digital information model, which includes several aspects.

(1) During the overall production process and the operation of each automated equipment, various types of data are collected in real time mainly through the MES system and SCADA system. The production process is continuously monitored, with real-time management of production equipment and quality. Intelligent production scheduling is conducted through real-time statistics and analysis of production data. In this process, data interaction and data sharing can be achieved between various subsystems on the intelligent production line. At the same time, with the help of digital twin technology, the overall production process can be visualized, and the actual operating status of each automated production equipment can also be monitored remotely.

(2) The SCADA system communicates with the access bus PLC in real time through a fieldbus, allowing it to read the status data of the PLC register in each device. This data is used as the basis for a comprehensive analysis of the status of various automation equipment [5]. Simultaneously, the system can write automated production and manufacturing instructions in the PLC register. These instructions guide the PLC to execute the appropriate production equipment operations automatically, thereby achieving the objectives of automated and intelligent prefabricated component production.

(3) In intelligent manufacturing, the MES system acts as the execution center and the ERP system acts as the resource management platform. Through the combination of these two systems, various types of intelligent manufacturing resources can be vertically integrated to further improve the overall operation efficiency and the quality of prefabricated components. The MES system facilitates lean management of all prefabricated component production processes, optimizes resource allocation, digitizes equipment operation, maintenance, and quality management. It is seamlessly integrated with ERP, establishing excellent interoperability across all levels of the intelligent construction system, ensuring comprehensive digital coverage [6].

(4) The EMS system is used as the basis to establish an intelligent construction architecture, and all the functions of project order, quality management, procurement management, equipment management, warehouse management, and finished product yard management are incorporated into a warehouse management system (WMS) and ERP system. This results in the construction of a visual, flexible, and intelligent information production management system for building prefabricated components [7]. In this process, relevant units and staff should introduce the information architecture of manufacturing enterprises from the International Organization for Standardization to achieve seamless integration between BIM systems, ERP systems, MES systems, and other related systems. This will enable the effective application of intelligent construction technology in the production and manufacturing of prefabricated building components.

(5) The MES system serves as the fundamental architecture for establishing a connection between the system and the BIM design end of building prefabricated components. It comprehensively acquires material and process information in line with the specific BIM design plan for prefabricated component production. The system interfaces with the underlying prefabricated component manufacturing equipment, enabling seamless transmission of various production process data. This transmission is based on the control instructions derived from the analysis of component process information, combined with the bottom-level system control instructions provided in the CNC program. The ultimate aim is to achieve flexible production of prefabricated components [8]. Technical personnel should create a data interface within the intelligent production line to establish a connection with the enterprise ERP system. This connection enables real-time data exchange between the intelligent production line and the entire production enterprise, facilitating seamless information integration across the entire production enterprise. As far as the current prefabricated component intelligent management system is concerned, the main components should include authority control, design and research and development, data import, production planning, production supervision, finished product storage yard, logistics and delivery, and report center. Through the reasonable construction and application of this system, the entire production process of modern building prefabricated components can be optimized [9].

(6) Considering the comprehensive construction status of the intelligent production line and leveraging existing research and development achievements, such as the material foundation and quality control system, a digital, automated, and intelligent production management platform will be established for the entire production process of prefabricated components within the construction project.

(7) By using advanced database technology and allowing multiple data systems to work together through effective communication, a close link between the MES and ERP systems can be created. This connection will enable the automation and smart control of the entire manufacturing process for prefabricated components [10]. This can effectively solve various quality problems in the traditional production methods of prefabricated components, improve the production efficiency and quality of the components, and lay a solid foundation for the healthy development of modern construction projects.

5. Conclusion

In summary, BIM-based intelligent construction plays an indispensable role in the production and manufacturing of prefabricated components in construction projects. Therefore, relevant units, researchers and technicians must strengthen the research of BIM-based intelligent construction. By aligning it with real-world scenarios and practical production requirements, a well-structured BIM-based intelligent construction system can be established. This will ensure the judicious utilization of each subsystem within the system. In this way, it is possible to achieve the intelligent design and manufacturing of prefabricated components in modern construction projects. Moreover, the manufacturing efficiency and quality can also be maximized, and the actual needs of prefabricated components in construction projects can be met.

Disclosure statement

The authors declare no conflict of interest.

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Design and Construction Technology of Prefabricated Reinforced Concrete Slab Culverts

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Abstract: Compared with traditional cast-in-situ concrete slab culverts, prefabricated reinforced concrete slab culverts can be produced more quickly and has strong quality controllability, strong earthquake resistance, and repeatability. They will be the primary production method of slab culverts in the future. This article offers a comprehensive review of the design and construction technology associated with prefabricated reinforced concrete slab culverts. The objective is to provide a valuable reference for related enterprises, enhance the quality of design and construction in precast pile configuration, and, in turn, contribute to the advancement of construction projects within our country.

Keywords: Slab culvert; Prefabricated reinforced concrete; Design points; Construction technology

Online publication: October 25, 2023

1. Introduction

The staff involved in designing and producing the slab culverts should be skillful and experienced to ensure that the design and manufacturing of slab culverts comply with national and local standards and specifications and ensure the quality and safety of the project. To avoid problems in terms of the quality and design of the slab culverts, research on the design and construction technology of prefabricated reinforced concrete slab culverts essential, so as to improve the overall quality of projects in China.

2. Overview of prefabricated reinforced concrete slab culverts

Prefabricated reinforced concrete slab culvert is used to build the upper covering structure of a tunnel. It usually comprises precast concrete panels, steel bars, bolts, and splices. Many factors need to be considered in the design and manufacture of tunnel covers, such as support, load, and stability. In terms of function, in transportation projects such as railways, roads, and subways, slab culverts serve the purpose of spanning over roads or railway tracks when they intersect with mountainous terrain or water systems[1].

3. Key points in the design of prefabricated reinforced concrete slab culverts

3.1. Material selection

Prefabricated reinforced concrete slab culvert is a novel structure in road and railway traffic engineering. It is important to select suitable materials when designing and manufacturing concrete slab culverts to ensure its firmness, durability, and safety. Prefabricated reinforced concrete slab culverts are mainly made of concrete, steel bars, bolts and expansion anchors, steel plates, and pieces.

Factors to consider during material selection include strength grade, impermeability, and performance. Among them, the strength of the materials should be determined based on the load-bearing requirements of the slab culvert. The choice of impermeability level should align with the project's need to resist water seepage. Construction performance primarily revolves around factors like concrete slump and setting time, ensuring a smooth pouring process.

As for the steel bars, the diameter and cross-sectional area of the steel bars should be selected based on the design requirements and structural stress characteristics of the slab culvert to ensure sufficient load-bearing capacity. Characteristics like tensile strength and durability should be considered.

The primary consideration for bolts and expansion anchors is their strength and durability, so as to ensure they can bear the load of structural connections [2].

3.2. Key points of component design

The components of prefabricated reinforced concrete slab culvert mainly include side wall T-shaped components, cover components, and corbel components.

3.2.1. Side wall T-shaped component design

When designing side wall T-shaped component, it is necessary to ensure appropriate strength and stability while also ensuring the convenience of the whole construction process. Besides, it is necessary to consider its relationship with the cover plate, corbels, and other components. The T-shaped components should be easily installed and connected. The criteria for the T-shaped components are listed below.

(i) The specific dimensions of the components should be designed according to the needs of the project. They are generally poured with reinforced concrete, and their appearance should be consistent with the culvert wall material used on the other side of the wall.

(ii) Q235B steel bars are commonly used; the diameter of the steel bars is 28 mm, and the steel bars are reinforced with 6\Φ 28 steel bars.

(iii) C50 grade concrete should be used, and the concrete thickness should be 25cm.

3.2.2. Cover plate design

As one of the load-bearing parts of the culvert, the cover plate needs to be strong and stable while using the least amount of raw materials to reduce costs. Specific relevant design parameters can be found below.

(i) The specific dimensions of the cover plate should be designed according to the needs of the project and are generally poured with reinforced concrete.

(ii) It is generally recommended to use Q235B steel bars with a steel bar diameter of 10 mm and 6\Φ10 steel bars for reinforcement.

(iii) C50 grade concrete should be used; the thickness of the concrete should be 20–25 cm. The length and width of the cover plate depend on the specific situation and are generally 5 m × 2 m.

3.2.3. Corbel design

When determining the size of the corbels for prefabricated reinforced concrete slab culverts, the primary consideration is its load-bearing capacity. As one of the load-bearing parts of the culvert, the corbels need sufficient strength and stability. At the same time, it is also important to ensure the convenience of processing and construction. Q235B steel bars with a steel bar diameter of 14 mm and 6\Φ14 bars for steel bar reinforcement are usually recommended. Besides, it is recommended to use C50 grade concrete. The thickness of the concrete should be designed between 20 and 25 cm. The length and width of the corbels depend on the specific situation, but they are generally 5 m × 1 m [3].

3.3. Foundation design

The type of foundation used for prefabricated reinforced concrete slab culverts is selected based on the following factors: geological conditions and load-bearing requirements. Architects can choose between simple foundations (such as plate and strip foundations) or complex foundations (such as pile and capped foundations). The steps in designing prefabricated reinforced concrete slab culvert foundation are described below.

Step 1: The foundation bearing capacity and internal force calculation are calculated. Bearing capacity refers to the load the foundation can withstand within a certain depth. The main calculation methods include standard static pressure plate load test, drilling coring test, depth standard penetration test, etc. Through these calculations, the suitable type of foundation can then be selected and the dimensions of the foundation can be determined. The calculation of foundation internal forces involves the design unit determining the foundation's internal forces, including bending moment, shear force, axial force, and so on. These calculations are based on the load conditions, foundation type, and design dimensions of the prefabricated reinforced concrete slab culvert.

Step 2: The foundation size is determined by calculating the internal forces of the foundation. The length, width, and depth of the foundation are then determined to satisfy the load-bearing requirements of the prefabricated reinforced concrete slab culvert.

Step 3: Material calculation is performed to determine the quantity of materials needed for the foundation. This process involves estimating the total amount of reinforcement, concrete, and other materials based on the foundation's size [4].

The specifications of designing prefabricated reinforced concrete slab culvert foundation is described below.

Table 1. Design of prefabricated reinforced concrete slab culvert foundation (with steel bars)

No.	Elements	Description
1	Geological conditions	The foundation is yellow soil, and the foundation bearing capacity coefficient is k = 60kPa/m²
2	Load condition	The load on the prefabricated reinforced concrete slab culvert is a static load of 20kN/m² and a dynamic load of 25kN/m²
3	Size of foundation	Taking a 3 m × 3 m foundation as an example, its depth should be 1.2 m, C50 concrete should be used, and the HRB400 threaded steel bars should be used as reinforcement, which are reinforced according to the design load ratio.
4	Area	9 m^2
5	Nett height	1.2 m
6	Concrete	Concrete C35: 2.16 m^3
7	Steel bars	HRB400 spiral steel bar: 8t, steel bar diameter (16 mm)
8	Base depth	1.2 m

3.4. Calculation of soil pressure at culvert top under different embedding methods

3.4.1. Soil pile method

The soil pile method is commonly used to calculate soil pressure at the top of a culvert. This method is based on the following assumption: The bearing effect of the soil on the top of the channel on the channel is mainly transmitted through the soil piles. According to this assumption, the soil pressure on the soil piles at the bottom of the trench is the pressure evenly distributed on the top. The calculation formula of earth pressure at the culvert top is as follows:

$$P = \gamma \times H \times L \times K \qquad (1)$$

In Formula (1), P is the soil pressure at the top of the culvert, γ is the unit weight of the soil, H is the distance from the top of the culvert to the bottom of the soil pile, L is the width of the culvert, and K is the influence coefficient of the soil pile.

3.4.2. Soil pile force concentration coefficient method

The soil pile stress concentration factor method is simplified for calculating soil pressure on the culvert top. This method assumes that the soil-bearing effect at the top of the culvert is concentratedly borne by one or more soil piles located at the bottom of the culvert in a smaller size. In this case, the soil pressure on the culvert top is seen as a concentrated effect on the soil piles rather than evenly distributed on the entire culvert top. The formula for calculating earth pressure at the culvert top is as follows:

$$P = \gamma \times H \times K \qquad (2)$$

In Formula (2), P is the soil pressure at the top of the culvert, γ is the unit weight of the soil, H is the distance from the top of the culvert to the bottom of the soil pile, and K is the force concentration coefficient of the soil pile.

3.4.3. Limit equilibrium method

The limit equilibrium method relies on an internal mechanical analysis of the soil to compute the soil pressure on the culvert top. This method makes an assumption regarding a specific friction angle within the soil, implying that the shear strength within the soil can counteract the shear force exerted on the ground. The soil pressure at the top of the culvert can be calculated by applying the equilibrium principle in soil mechanics. In this method, the friction angle of the soil at the bottom of the culvert and the friction angle of the external earth are the key parameters that need to be considered [5].

4. Research on construction technology of prefabricated reinforced concrete slab culverts

4.1. Production of prefabricated components

Prefabricated component production is the first link in the construction stage of prefabricated reinforced concrete slab culverts. The key points of this link include formwork production, steel bar processing, concrete pouring, and quality inspection. **Figure 1** are photos of the production site of prefabricated reinforced concrete cover components.



Figure 1. Photos of the production site of prefabricated reinforced concrete cover components

The manufacturing of molds requires high precision, exquisite shape, and accurate parameters. During the manufacturing process, it is essential to prioritize factors such as stability, resistance to rust, and ease of maintenance for the mold. This ensures that the mold can be utilized effectively over an extended period, maintaining its accuracy and quality. Secondly, in the process of working with steel bars for prefabricated components, crucial technical aspects include the control of steel bar dimensions and spacing, bending, cutting, and more. Employing suitable steel bar processing techniques can enhance production efficiency, guarantee construction quality, and minimize wastage. Thirdly, while pouring concrete, attention should be paid to the uniformity and quality of the concrete to avoid problems such as gaps, waves, cracks, etc. When pouring concrete, the water-cement ratio must be controlled to ensure the strength and durability of the concrete. Finally, after prefabricated components are produced, they must undergo inspection and quality control. Strict inspection and quality control can ensure product reliability and reduce construction risks, thereby meeting the usage requirements of highways and bridges [6].

4.2. On-site foundation construction

Key points of on-site foundation construction include foundation treatment and construction.

On one hand, on-site foundation treatment is the first step in on-site foundation construction. Before carrying out the culvert foundation treatment, it is necessary to clean up the debris and sediment on surface of the foundation to ensure that it is completely flat. In instances with more complex geological conditions, surveys and preparatory work are necessary to establish the foundation's bearing capacity and stability. On the other hand, foundation construction encompasses activities such as measuring foundation elevation, cleaning the foundation base, creating foundation formwork, processing foundation steel bars, and more. In cases involving deeply buried culverts, additional measures like wellhead piping or pipe gallery connections are

required. Throughout the construction process, strict control over the entry and exit of personnel and machinery is crucial to prevent any impact or damage to the foundation surface. Besides, ensuring the personal safety of on-site workers is also paramount [7].

4.3. Transportation and assembly of prefabricated components

During the transportation stage of prefabricated components, the construction unit must reasonably arrange the loading and unloading sequence, use appropriate lifting equipment and tools to ensure the safe transfer of prefabricated components, and take appropriate protective measures, such as reinforcing packaging or using anti-shock linings, etc, so that the components would not be damaged during transportation. Second, the components should be delivered using proper vehicles to ensure that the prefabricated components can be transported safely and provide necessary support and fixation as required [8].

It is necessary to ensure that the flatness and levelness of the foundation during the preparatory phase to facilitate the assembly of components. Secondly, the prefabricated components should be transported to the installation location based on a predetermined sequence. It is also important to ensure correct alignment and connection of the components to ensure the stability of the overall structure, as shown in **Figure 2**.



Figure 2. Photos of transportation and assembly of prefabricated components

During joint treatment, it is crucial to use suitable treatment materials and methods to ensure that the prefabricated components are tightly connected and have sufficient strength and waterproof performance. Lastly, during the assembly process, the construction unit must maintain continuous monitoring and make necessary adjustments to the components' position and orientation, ensuring that the assembly quality aligns with the design specifications [9].

4.4. Finishing of the prefabricated slab culvert

After the prefabricated slab culvert is completed, the surface of the cover plate should be cleaned. This includes removing stains, grout, and particles that may be present. A high-pressure water gun can be used to clean the surface and grinding and plastering can be performed to smoothen out the surface. Secondly, the gaps between the prefabricated cover plate and other components or openings should be filled to ensure the tightness of the overall structure. To achieve sealing and waterproofing, durable materials like sealants can be used for filling, or substances such as mortar can be used to establish a strong bond between the filling material and the cover plate. The overall aesthetic of the culvert is also important. The concrete sections should undergo treatments such as polishing or spraying, and exposed steel bars should be protected with galvanization or anti-rust paint for corrosion prevention. Thirdly, it is crucial to timely enhance the drainage system to prevent water accumulation within the structure. This involves setting up drainage holes or pipes, which should be made from materials like ceramics, winding, or PVC with good corrosion resistance and proper sealing. Finally, after constructing the prefabricated slab culvert, adjustments should be made to suit the specific circumstances. For instance, during winter or in cold areas, immediate insulation of the concrete components is necessary to improve their strength and anti-freeze performance [10].

5. Conclusion

This article presents a review on the design and construction technology of prefabricated reinforced concrete slab culverts. It delves into the critical design aspects of prefabricated reinforced concrete slab culverts, considering four dimensions: material selection, component design, foundation form design, and culvert top soil pressure calculation. Simultaneously, the article examines key construction techniques for prefabricated reinforced concrete slab culverts across four stages: production, foundation construction, component transportation and assembly, and refinement. This comprehensive exploration provides us with a thorough understanding of prefabricated reinforced concrete slab culverts, offering a strong foundation for enhancing the design and construction standards of future engineering projects.

Disclosure statement

The author declares no conflict of interest.

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Research on Developing BIM Intelligent Construction Programs Based on Application-Oriented Talent Cultivation

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Abstract: Cultivating application-oriented talents have become essential in vocational and higher education. This concept also applies to BIM intelligent construction programs. Based on literature review and general observations, we analyzed the connotation, key points, and value of developing a BIM intelligent construction program based on application-oriented talent cultivation. We also identified problems in the development of the program such as lack of comprehensive planning and the school being the sole authority in program development. Therefore, we proposed several strategies to address these problems, including systematic program development planning and fostering a multi-faceted partnership between schools and the industry. The goal is to provide valuable insights for the development of relevant programs in the new era.

Keywords: Application-oriented talent training; BIM intelligent construction; Professional construction

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1. Introduction

The increasing maturity of BIM technology has given rise to the BIM intelligent construction profession. As an emerging profession, it needs to be constructed more effectively, and the development of this profession also needs to be highly consistent with new educational and talent training concepts. The cultivation of application-oriented talents is crucial to drive the development of this profession. However, this process can be affected by many factors, and some problems are prone to occur. This shows that the system construction of the corresponding major is complex, and many factors need to be considered. Therefore, measures need to be taken to address the problem in developing BIM intelligent construction program based on application-oriented talent cultivation.

2. Overview of BIM intelligent construction program based on application-oriented talent cultivation

(1) Connotation

BIM intelligent construction program based on application-oriented talent cultivation is the general

term for a series of professional construction activities carried out with the goal of professional development under application-oriented training. BIM intelligent construction is a dynamic project involving relatively diverse elements, which requires many perspectives. The training of application-oriented talents should be done with the goal of developing construction professionals.

(2) Key points

There are some critical points in developing BIM intelligent construction program based on application-oriented talent cultivation. The quality of the students depends on how well the essential tasks are done. These essential tasks include construction planning, number of staff, the curriculum, and the evaluation methods for the students.

(3) The value of this training concept

The development of BIM intelligent construction program based on application-oriented talent cultivation has significant value, which is reflected in multiple levels. By integrating application-oriented training into the curriculum effectively, BIM intelligent construction students will learn how to apply their knowledge and develop practical skills. The better development and application of some new courses can further improve the quality of professional courses. Moreover with a good balance of theoretical and practical lessons in each course, the students professional qualities and practical skills can be better can be better developed. This enhances the students' chances of employment and their career development opportunities.

3. Analysis of BIM intelligent construction program based on application-oriented talent cultivation

(1) Lack of planning

Some schools have tried to build BIM intelligent construction programs based on application-oriented talent training. However, the final results could be better, which indicates the need for a more effective program planning. The work involved in the establishment of majors is extensive, and more elements of application-oriented training should be incorporated to make the courses more systematic and complex. Some schools do not fully understand the concept of application-oriented talent training. Therefore, they usually do not conduct a detailed analysis before constructing the BIM intelligent construction course. Besides, they do not have a systematic plan while establishing the major, and the courses do not have a specific direction or purpose [1]. Over time, it has been difficult to form a good BIM intelligent construction environment in schools. Even if certain efforts have been made on other levels, the quality of the course will still be less ideal if the planning is not in place.

(2) Limited course content

After comparing the BIM intelligent construction programs in some schools, it was found that the reason some struggle to make progress in the construction of majors is because the system in which the course in constructed is relatively rigid. The school usually has full authority over curriculum design and the organization of academic activities. This model provided schools with better control over program development and allowed them more autonomy in program management. However, in the training of application-oriented talents, the disadvantages of this model becomes more apparent. Teachers and students should both play a role in program development, and when collaborating with external companies for applied talent development, these companies can also become primary participants in program development. When a school remains the sole entity responsible for program development, the approach to applied talent training becomes quite narrow. It restricts the diversity of

program development strategies, hindering the effectiveness of program development.

(3) Lack of unique courses in BIM intelligent construction programs

When it comes to program development, curriculum design is an essential aspect. Looking at it from the perspective of application-oriented training, many educational institutions tend to overlook curriculum design in the context of their BIM intelligent construction program development. Even among schools that have taken steps in curriculum development, some may lack distinctive courses, which presents a challenge in the development of BIM intelligent construction programs [2]. Currently, many schools have not fully embraced the idea of application-oriented talent development to actively create distinct courses. When it comes to the collaboration between academia and industry in professional education and talent development, the limited number of distinct courses fails to adequately support new educational and talent development methods. The shortage of such courses often means that the curriculum lacks distinctiveness, which, in turn, hampers the development of specialized talent in the field of BIM Intelligent Construction, subjecting it to various constraints.

(4) Lack of systematic evaluation of BIM intelligent construction major

Various issues can arise in the development of BIM intelligent construction program based on application-oriented talent cultivation, especially when there is a need to balance the development of the program and the teaching of the courses. In theory, there should be a more effective evaluation of the relevant professional development. However, in practice, many schools have not adequately established an evaluation mechanism for professional development in the field of BIM intelligent construction. The absence of a specific evaluation mechanism makes it challenging to conduct effective evaluations directly related to professional development [3]. When there is no systematic evaluation of BIM intelligent construction programs, it becomes challenging for schools to grasp the situation of the program and its effect on talent cultivation. As a results, many problems in the program may go unnoticed. Besides, without proper evaluation methods, it is difficult to make adjustments in the program because there is lack of effective reference.

4. Measures to improve BIM intelligent construction program based on application-oriented talent cultivation

(1) Systematic program planning

Given the complexity and diverse aspects involved in the development of BIM intelligent construction program based on application-oriented talent cultivation, it is imperative for schools to establish a comprehensive development plan for this specific program. This plan will offer clear guidance for carrying out various activities related to program development at different levels and stages [4]. For instance, a university introduced a BIM intelligent construction program in 2021. In 2022, the university conducted an in-depth analysis of the current state of the program's development. Emphasizing application-oriented talent cultivation, they carried out a thorough needs analysis for program development. Based on this, the university formulated a detailed program development plan. This plan clarified the roles of different entities involved in program development and the specific responsibilities of each. Moreover, it provided a refined framework for multi-entity program development. Setting clear, phased objectives enhanced the purpose and direction of program development activities. Hence, this proves that a systematic and well-thought-out plan serves as a crucial foundation of the development of BIM intelligent construction program. Developing the program based on a systematic

plan also enhances the program's purpose, direction, and organization [5].

(2) Fundamentals in industry-education collaboration-based comprehensive program development.

It is crucial to continually diversify the entities involved in the development of BIM intelligent construction program. Especially when cultivating application-oriented talents based on the industry-education integration concept, the number of entities involved in professional education increases [6]. For instance, in the development of the BIM intelligent construction program at a certain school, the school, companies, teachers, and students are all considered specific entities involved in the development. With multiple entities actively participating, each contributes differently to the professional development. The school is primarily responsible for the comprehensive planning of the BIM intelligent construction program development and holds a significant advantage in curriculum development. Companies contribute by offering input on curriculum design, enriching teaching content, and providing feedback on BIM practical aspects through industry-education integration. Additionally, teachers and students provide feedback based on their teaching and learning experiences, which serve as valuable reference information for the school's leadership in the major development. The involvement of multiple entities in the BIM intelligent construction program development results in more diverse approaches and outcomes that align better with expectations [7].

(3) Actively creating distinctive courses

In the context of BIM intelligent construction program based on application-oriented talent cultivation, the development and creation of distinctive courses are of paramount importance. Building on the development of these specialized courses not only supports industry-education integrated professional teaching but also aids in application-oriented talent development. For example, in recent years, a certain school has made significant efforts in BIM intelligent construction program development based on application-oriented talent training and has successfully created several distinctive school-based courses. Among these, the course "Comprehensive Application of BIM Technology" has significantly benefited students by enhancing their understanding and proficiency in BIM technology applications. To meet the requirements of application-oriented talent development, the school has introduced specialized courses such as "Fundamentals of BIM Technology," "Practical Internship for BIM Technology Fundamentals," "Application of BIM in Engineering," and a hands-on course on "BIM Drawing Practice." The development of these specialized courses not only aids in enhancing the effectiveness of application-oriented talent development but also results in a noticeable improvement in course teaching quality.

(4) Dynamically conduct evaluation and adjustment of professional construction

In the process of developing the application-oriented talent training for BIM intelligent construction major, various challenges can arise. To address these challenges, a twofold approach can be taken. On one hand, schools can engage in specific planning and experimentation from different perspectives for major development. On the other hand, a system can be established for evaluating the progress of major development, so that necessary adjustments can be made based on the evaluation results. For instance, a certain school has not only been proactive in experimenting with major development but has also taken steps to create an evaluation mechanism related to this initiative [9]. In this context, fundamental evaluation criteria include the development and implementation of school-based courses, students' proficiency in practical skills related to their major, and the effectiveness of industry-education collaboration in talent development. Furthermore, the schools are to assess the outcomes of specific decisions made in the course of major development. By successfully obtaining these evaluation

results and gaining a comprehensive understanding of the state of the program development, the school's capabilities in program development will continue to improve [10]. Hence, when undertaking major development based on application-oriented talent cultivation, it is essential to perform ongoing evaluations and utilize these dynamic assessments as a foundation for further adjustments and enhancements. This approach ensures a higher degree of control over program development.

5. Conclusion

In the development of the BIM intelligent construction program based on application-oriented talent cultivation, effective planning is the foundation. Approaches such as diversifying the stakeholders and creating distinctive courses offer significant support for program development. However, it is essential not to overlook the development of the teaching staff. The quality and active involvement of teachers directly impact various aspects of program development, including course instruction, dynamic program growth, and overall program quality. Therefore, to align with the specific needs of BIM intelligent construction program development, it's crucial to focus on teacher training and actively enhance the quality of the teaching staff. This effort also contributes to the success of the program based on application-oriented talent cultivation.

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Analysis of Soundproof Technology of Assembled Steel Structure Houses

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Abstract: The problem of noise has always been highlighted in assembled steel structure houses. Therefore, it is necessary to use effective soundproof measures where steel beams intersect with the reserved line pipe openings, doors, windows, elevator shafts, and other locations. In this paper, we will investigate the areas with subpar soundproof performance in an assembled steel structure residential project and propose suitable noise control measures to address this issue.

Keywords: Assembled steel structure; Residential engineering; Sound insulation; Construction technology

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1. Introduction

The acoustic environment is one of the necessary factors for healthy housing. In the process of continuous development and promotion of assembled steel structure housing, its physical properties have been optimized in many aspects. However, soundproof performance has not received adequate attention, and the high assembly rate and lightweight properties of steel structures pose challenges to improving soundproofing. This limitation somewhat hinders the broader application of assembled steel structure housing. Human activities produce noise, and air conditioning, ventilation, heating, and other equipment can also produce continuous low-frequency noise. This affects the daily lives of people, and even causes chronic damage to the body. In fact, steel structures can further amplify low-frequency noise and increase the propagation distance and penetration of vibrations [1]. Therefore, in order to improve the living standard of the people in the assembled steel structure housing, it is necessary to carry out an in-depth discussion on the soundproofing of these types of houses.

2. Overview of the project

In an assembled steel structure residential district covering a construction area of 142,666 square meters, consisting of 10 high-rise buildings and 4 associated podiums, the entire system is based on steel structures. The interior infill wall material is a lightweight autoclaved aerated slat wall, and the elevator shaft occupies the core cylinder position, featuring anti-flexing steel plate walls. This residential district holds a green three-star

building certification and is recognized as a healthy building. In terms of construction, the acoustic control for this assembled steel structure residential district primarily revolves around managing the sound at reserved line pipe openings on steel beams, doors, windows, elevators, shafts, subdivided walls, and pipelines, among other locations.

3. Causes of poor soundproofing of assembled steel structure houses

(i) Partition walls

The walls of traditional houses are mainly made of heavy materials, resulting in adequate soundproofing. However, in assembled steel structure houses, almost all the walls are lightweight, including the partition walls between two households, resulting in the soundproofing between different households being less than 40dB, which is less than the required standards.

(ii) Intercomponent porosity

There may be pores between assembly components, because air is the main medium for sound propagation, so there is a close correlation between room airtightness and acoustic performance. If there are errors in the design due to improper selection of materials or unskilled workers, it may lead to excessive pores between assembly components, which affects the soundproofing of the building.

(iii) Steel beams and columns

Compared to traditional concrete houses, steel frame structures require additional cladding due to their unique materials and processing methods. Soundproof treatment often gets overlooked or may not even be considered. Steel structures inherently have limited soundproofing and strong sound transmission characteristics. Combined with the growing use of modern equipment like air conditioning and heating systems that generate low-frequency noise, the utilization of steel beams and columns can lead to suboptimal soundproofing in assembled steel structure houses [2].

4. Noise control measures

(i) Sound insulation measures for holes reserved for wires and pipes on steel beams

In assembled steel structure buildings, there are more integrated functional systems, resulting in complex equipment pipelines. Additionally, the building demands a considerable net height, resulting in limited space at the top. Consequently, most pipelines need to cross over beams. After the pipeline installation, there tends to be a gap between the pipelines and the steel structure. This gap allows the noise generated by equipment operation to quickly propagate through it, potentially leading to noise pollution. Therefore, it is necessary to use appropriate blocking measures to improve the soundproof effect. Current blocking measures mainly include using fire-resistant mastic or rock wool. Before applying fire-resistant mastic, it is imperative to verify the completion of all pipeline projects. Then, the fire-resistant mastic is used to fill the gaps. It is essential to consider that fire-resistant mastic may undergo changes in hardness due to variations in ambient temperature. To prevent any detachment of the fire-resistant cement from the gap, it is imperative to weld steel plates on both sides of the gap. The recommended thickness for the fire-resistant mastic filling is generally more than 50 mm, and the steel plate should have a thickness exceeding 1.2 mm. For the application of the rock wool insulation method, it is also necessary to await the completion of pipeline installation. Typically, the gap between the pipeline and the steel structure falls within the range of 30 to 50mm. It is essential to cut the rock wool into appropriately sized pieces and proceed with the filling process. Subsequently, a plate is

installed as a second layer of insulation. This precaution is taken to prevent rock wool from falling through the gap and causing environmental contamination. In summary, fire-resistant mastic tends to offer superior results compared to rock wool insulation. It is easier to apply, effective, and does not cause secondary pollution [3].

(ii) Sound control measures for windows and doors

Doors and windows are usually thinner and have more gaps, so they are less soundproof than the walls. Therefore, they have become a typical weak link in the soundproofing of houses. In order to improve the soundproof effect of windows and doors, their quality should be improved. The soundproof performance should be regarded as one of the main assessment indexes when choosing the doors and windows from a manufacturer, so that the quality of the doors and windows are in line with the relevant standards. In addition, the installation precision should also be improved to reduce the installation gap to enhance the soundproof effect.

In contemporary assembly steel structure housing projects, sectional doors are often designed as comprehensive doors that combine functions like burglary and fire protection. For doors with heightened soundproofing requirements beyond typical standards, two specialized approaches are commonly employed. The first approach is rooted in the principle of mass law, which posits that the greater the weight per unit area of the door, the better the soundproofing effect. This involves enhancing the door's thickness and weight. The second approach involves the use of a multi-layer composite structure. Multiple materials with distinct properties, such as steel plates, wooden panels, sound-absorbing materials, and damping materials, are layered to create the door. Since there is a significant impedance contrast between these diverse materials, they effectively enhance the soundproofing effect.

As for the windows, because they play a role in the ventilation and lighting of the house, they have to be made of glass. In order to improve the soundproof effect of windows, double glass, multi-layered glass, or thicker glass should be used. The separation between adjacent layers of glass should be maintained at a distance of 10–15 cm. When using double or multi-layer glass, it is advisable to avoid placing the glass layers in a completely parallel configuration to prevent resonance or the coincidence effect caused by identical thicknesses between layers, which can result in sound leakage. Furthermore, installing sound-absorbing materials within the window seals between the different glass layers can further enhance the soundproofing effect [4].

(iii) Measures to improve the soundproof effect of elevator shafts

The primary source of noise within the elevator shaft during operation is the mechanical sound resulting from the friction between the elevator car, counterweight guide shoe, and the guide rail. This noise becomes particularly significant when there are issues with the guide rail's installation. Common problems include a substantial deviation from perpendicularity between the guide rail's side and the working surface, excessive steps on the guide rail connecting surface, improper adjustment of the guide shoe gap, damage to the guide boot, twisted wire ropes, and uneven tension in the wire rope. Furthermore, the elevator operates within an enclosed shaft, and its high-speed, vertical movement can generate wind noise within the shaft. Additionally, it is worth noting that the elevator's traction motor relies on air cooling, which can contribute to the overall noise in the system. When the rotor's circumferential speed exceeds 60 m/s or the rotational speed surpasses 2,000 revolutions per minute, it becomes the primary source of ventilation noise within the shaft [5]. The wall around the elevator shaft is also the partition wall between the public area and the household, so it is necessary to apply

appropriate soundproof measures. Typically, in a standard elevator shaft, glass wool is used with mineral powder particles sprayed on it for soundproofing. However, when the rock wool boards are in place, the wind pressure generated during elevator operation can blow the sound-absorbing panels within the glass wool out, causing secondary pollution and a decrease in sound insulation effectiveness. To address this, an alternative method is to combine rock wool with the application of sprayed silica sand. When doing so, it's advisable to select fire-rated (A grade) silica sand material with NRC $\geq$ 0.5, VOC $\leq$ 120 g/L, and formaldehyde content $\leq$ 100 mg/kg. This approach helps to maintain soundproofing while minimizing potential pollution issues. The situation of the slatwall in the shaft is first observed, and cement mortar is then used to smoothen out the gaps or any leakage. Next, a binding agent should be applied, the glass wool is secured in place, and rock wool nails are then used along with thermal insulation nails. It is important to ensure that at least 6 rock wool nails are used to secure each rock wool board. Afterward, the seams between each rock wool board should undergo a secondary grouting treatment. Finally, spray silica pore sand should be applied, ensuring complete coverage of the insulation nails, with the thickness of the silica pore sand being controlled at 3 mm. This approach helps ensure effective soundproofing in the elevator shaft [6].

(iv) Control measures for soundproofing in house walls

Partition walls are traditionally made of clay brick, with a thickness of 24 cm, and their weighted soundproofing is about 53 dB, which is satisfactory. However the walls in assembly steel structure houses are lightweight, so their soundproof performance is far worse than the ordinary clay brick walls. Therefore, it is important to look into the materials used to make the walls [7]. There are currently three types of new wall materials: block-type, light steel keel type, and hollow plate strip type. In high-rise residential buildings, achieving both "lightweight walls" and "excellent acoustic performance" can be realized using two approaches. The first method involves employing a double-wall system, using lightweight blocks and lightweight slats as wall materials, with a cavity of 50 to 100 mm established between the two layers of materials. This cavity is then filled with rock wool or other sound-absorbing materials. Care should be taken during construction to avoid creating acoustic bridges between the two layers of the wall. In the second approach, two layers of wall panels are installed at each end of the light steel keel, with the thickness of wall panels being 8–12 mm. The cavities of the two layers of wall panels are filled with rockwool or other sound-absorbing materials, so as to achieve satisfactory soundproof effect, i.e., 49–52 dB. Several other measures can be taken to improve the soundproof effect of the lightweight walls: (a) Adding elastic strips between the keel and the plate, such as elastic pads or elastic metal strips, etc., which can improve the soundproof effect by about 3 dB compared to directly fixing the plate onto the keel [8]. (b) The keel width determines the width of the cavity between the two sides of the wall panel; a keel with a width of 75 mm provides the best soundproofing effect, and a double-row keel configuration can be employed to enhance the soundproofing performance compared to a single-row keel. (c)

The more layers of boards on both sides of a lightweight partition wall, the greater the soundproofing of the wall. Typically, each additional layer of board increases the weighted soundproofing of the partition wall by about 3 dB. To avoid the occurrence of sound frequency valleys in the main frequency range of 100–2500 Hz, it is advisable to minimize the board thickness. The wall panel thickness should be controlled at 12 mm, and the ceiling can be 9.5 mm. Using boards with different thicknesses on different sides or staggering the thicknesses on the same side can further enhance the soundproofing effect. (d) It is necessary to fill up cavities or gaps on the wall, a gap on

the wall that is one ten-thousandth of the wall area, can reduce the soundproof effect of the wall by about 10 dB [9].

(v) Control measures for soundproofing of piping and equipment

Indoor sources of noise, such as bathroom downpipes and the vibrations from operating indoor equipment, stem primarily from pipes and equipment. The main sources of sound include downpipes, air filters, and air conditioning systems. To meet building standards and improve the indoor living environment, it is essential to apply soundproofing and vibration-damping measures to the installation of pipes and equipment [10]. In general, equipment can be equipped with spring hangers for support. For sewage pipes, elastic hanging rods or hangers can be installed on the horizontal pipe segments, and rubber mats can be wrapped around the exterior of the pipes. In the vertical riser sections, it's advisable to use thick sound insulation felts along with 1.2 mm-thick melamine sponges for soundproofing. When pipes pass through walls, it's important to use fire-resistant mastic or rock wool for sealing, with preference given to fire-resistant mastic where feasible due to its superior soundproofing properties [11].

5. Conclusion

At present, assembled steel structure has become the trend of the construction industry, and measures should be taken to improve the soundproof effect of these buildings while also achieving energy efficiency and environmental sustainability. Therefore, the dynamic and static areas inside the building should be reasonably laid out during the design stage. Moreover, it is crucial to choose suitable materials for important areas and opt for modern construction materials. This method helps control noise during construction, ensures smooth coordination among all stages, and improves the soundproofing of assembled steel structure residential buildings. This enhances the quality of life for the building's occupants and promotes the use of assembled steel structures, benefiting the local community.

Disclosure statement

The author declares no conflict of interest.

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A Proposal for the Restitution of the World's First Baptistry and University, Mor Yakup Church, Turkey

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Abstract: The structure known today as St. Jacob's Church represents one of the oldest Christian medieval monuments in the region. With the emergence of findings suggesting that the structure was the world's first university during recent excavation efforts, it has gained even more significance. Since 2006, the excavation works conducted by the Mardin Museum Directorate in the vicinity of Mor Yakup Church have yielded information about various phases of the structure. However, assessments regarding the nature of the structure are still debated within the academic environment. This study aimed to thoroughly investigate the functional changes and periods that St. Jacob's Church underwent throughout history and to provide a detailed description and restitution for each period. In this study, we utilized excavation reports, data from written sources related to the settlement and structure, information obtained from the structure itself, traces existing on the structure, and data derived from architectural necessities (logic/scenario). The results indicate that this structure served three different functions (baptistry, church, university) and went through two main periods (pre-Christianity and post-Christianity).

Keywords: Medieval monuments; Christian architecture; Conservation; Restitution; Mardin

Online publication: October 25, 2023

1. Introduction

Throughout history, the town known as Nisibis or Nesbin, presently referred to as Nusaybin, is a district located in the province of Mardin, Turkey. The city of Nisibis stands as one of the oldest settlements in Mesopotamia. The structure known today as the Mor Yakup Church in Nusaybin was investigated in this study. Situated in the district of Nusaybin, which is a part of Mardin province, the church was originally built in the year 311 AD by Bishop Mar Jacob of Nusaybin. The building features a three-aisled basilical layout and is characterized by its architecture and intricate high-relief stone ornamentations, reflecting the traits of the late Roman to early Byzantine period [1].

There is a limited number of studies available in the literature regarding the structure. Upon reviewing these studies, it was found that there had been no clear understanding of the building's physical stratification and functional coherence. The limited research can be categorized into three main groups: investigations aimed at understanding the historical development of the settlement (Nusaybin) where the structure is located [2-11], studies focusing on the identity of Mor Yakup, after whom the building is named [12,13], and research centered around the excavations carried out around the structure and the remains discovered [14,15].

Upon a detailed examination of these research groups, it becomes apparent that there is an insufficient number of published sources that define the architecture, function, and periods of St. Jacob's Church, which results in a lack of clear historical information about the church's past. While excavation studies showcasing the horizontal coherence of different historical periods reveal the cultural stratification, they fall short of providing adequate information about the vanished parts of the structure, and the scarcity of sources contributes to the limited academic awareness of the building.

In this context, the original nature of Mor Yakup Church remains a topic of debate among researchers. Data obtained from excavation works conducted by the Mardin Museum Directorate around the structure since 2006 has provided information about different periods of the building. However, this information falls short of providing clarity about the building's physical stratification and functional coherence. Assessments regarding the nature of the structure are still under discussion in academic circles, and there exists a significant gap in the literature on this topic. Addressing these needs, the purpose of this study is to thoroughly investigate the functional changes and periods that Mor Yakup Church underwent throughout history and to provide a detailed description and restitution for each period. Within the scope of the study, excavation results are evaluated along with information from written sources to develop an assessment of the structure's past. This assessment leads to periodization and, consequently, the development of a detailed description/restitution. This study demonstrates that the structure served three different functions (baptistry, church, university) and went through two main periods (pre-Christianity and post-Christianity).

2. Materials and methods

Historical research aimed at understanding the past of the structure was compiled from two types of sources. The first group of sources was centered on the remains uncovered through excavation works carried out around the structure. These sources included periodical written and visual references as well as excavation reports.

The second source was derived from written sources related to the settlement and structure, considering the structure's transformations over time, information obtained directly from the structure, traces existing on the structure, and data derived from architectural necessities (logic/scenario). Through these means, a periodization and description (restitution) for each period of the structure was developed.

3. Results

Within the scope of the study, excavation reports were evaluated, along with the characteristics of the structure and information found in written sources. This evaluation led to an assessment of the structure's history, periodization, and subsequently, the development of a completion/restitution. In this section, the changes in the functions of the structure over time, the periods it went through, and the reasons behind them are presented.

3.1. Evaluation of excavation reports, written sources, and similar examples

Ongoing excavations at the Monastery of Mor Yakup Church continue to shed light on its historical significance.

During the 2013 excavations, significant findings were unearthed that illuminate Syriac history. The discovery of the oldest Syriac inscriptions at this site has strengthened the argument that the Nisibis School was one of the earliest universities. In this regard, the structure is considered the world's first educational university, where subjects like philosophy, logic, literature, geometry, astronomy, medicine, and law were taught.

In the excavations conducted in 2013, different areas on the northern, southern, and eastern facades of the building emerged with distinct material qualities, construction techniques, and architectural elements. To the northwest of Mor Yakup Church, remains of a structure were uncovered, where part of the central apse was identified, and some parts were found to be beneath the existing road. The remains of the structure, known as the Nusaybin Cathedral, are attributed in sources to being commissioned by Mor Yakup between 313 and 320 [16] (**Figure 1a**).

(a) (b)

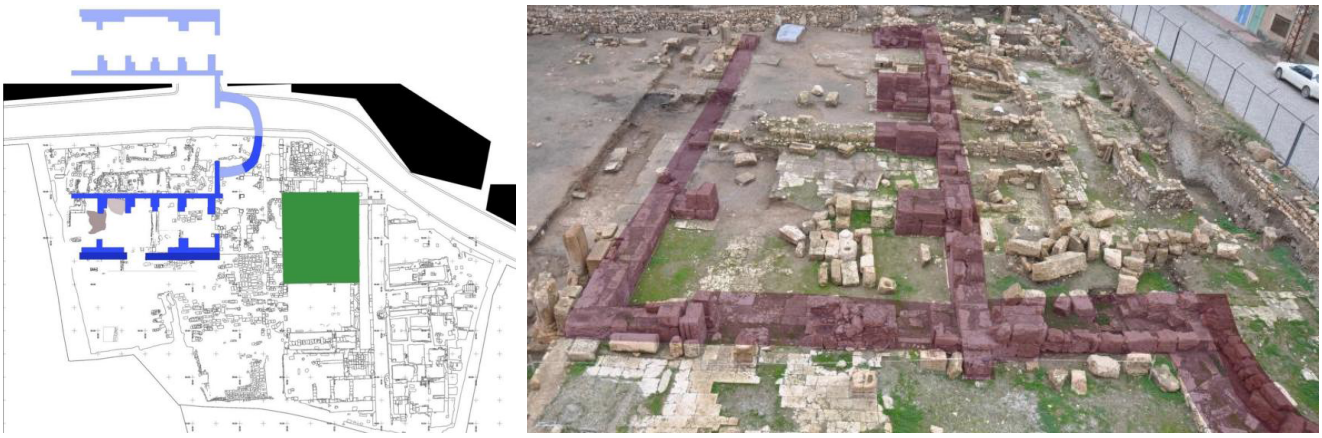


Figure 1. (a) Cathedral ruins uncovered through excavation (dark blue) and reconstruction (light blue)** and preserved section of the church (green), (b) completion of the ruins believed to be associated with Mor Yakup Cathedral.

Today, while no remains of the church are left above the ground of the cathedral, the baptistry section has been preserved up to the present day. The remaining part of the complex, recognized today as a church, is described as the first baptistry with clear depictions, evident in various written documents that have reached us [17] (**Figure 1b**). As indicated by the Greek inscription on the south facade of the structure, the baptistry was constructed in 359. The inscription was actually placed upon an existing structure. However, significant new additions were made to the existing building. Two additional spaces were added to the north and south of the structure, a longitudinal extension was constructed along the eastern wall, and an apse arrangement was added to the east of all three spaces. The descent from the lower space is from the adorned central space, while the exit is from the northern space. This structural feature suggests the idea that those who were baptized would descend and emerge into the northern chamber. The decorations in the central space were also created during this period, around the mid-4th century.

It should be noted that the three-aisled arrangement was a common plan in Early Christian Eastern baptisteries. In this context, comparable examples include Kenīset Bath-Zabbai (Zenobia-Syria), Kenīsat Mār Simʿān al-Amūdī (Kalat Simean-Syria), Kenīset Mar-Mīna (Egypt), Side and Ephesus (Anatolia), Gerasa (Jordan), and some baptisteries in Cyprus [18]. Despite all these similar examples, as highlighted by the inscription, St. Jacob's Church emerges as the oldest baptistry structure (**Figure 2**). Regarding the standing baptistry structure within the building, it can be suggested that the presence of different periods in the structure is due to interventions arising from changes in the city's historical development and the transformation in the educational system, parallel to changes in system and function over time.

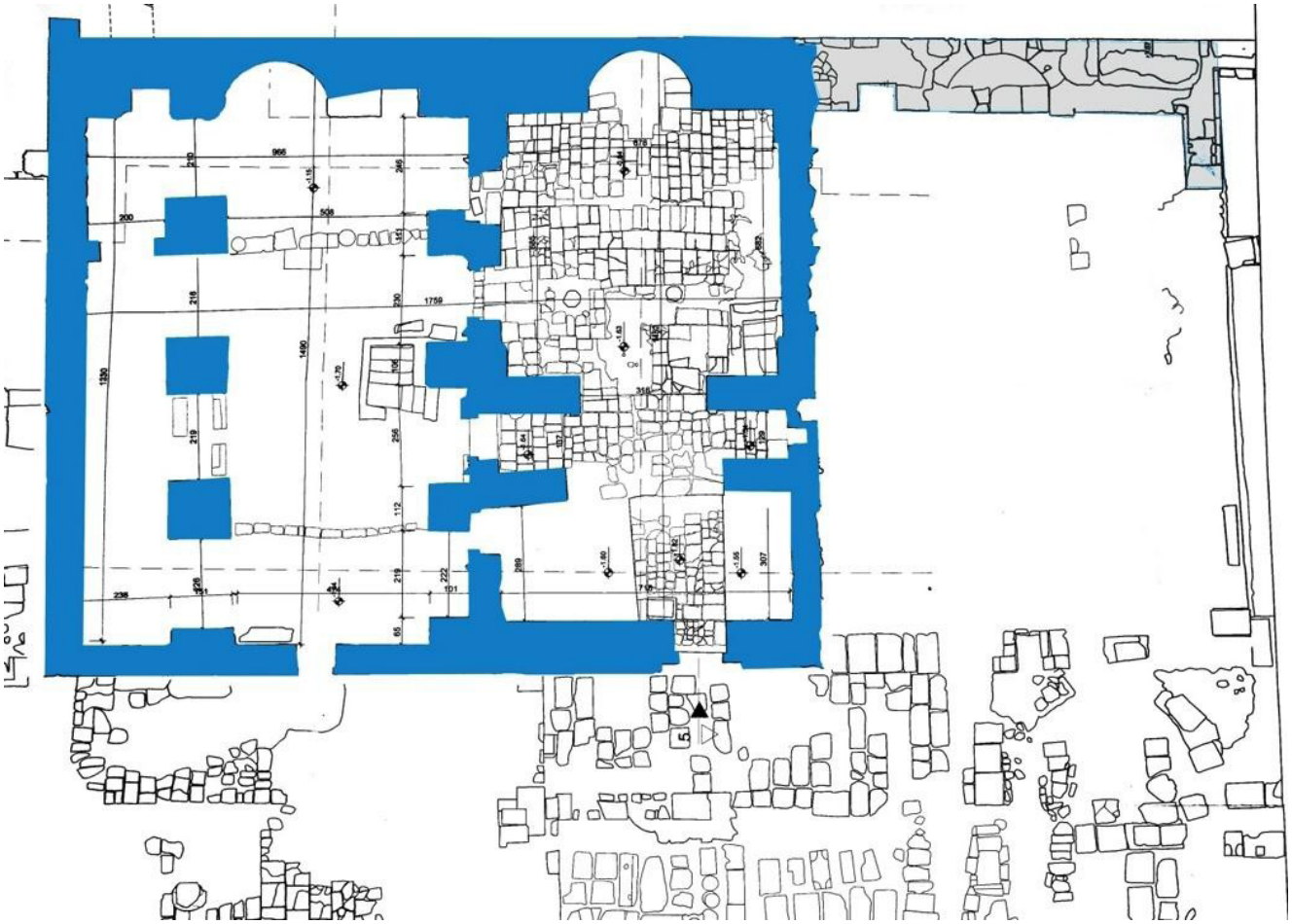


Figure 2. The third aisle on the south side of the revealed structure uncovered through excavation

3.2. The chronological phases and historical periods of the structure

Regarding the standing baptistry structure within the building, the presence of different periods can be attributed to interventions driven by changes in the historical development of the city and transformations in the education system. In parallel with these changes, shifts in system and function over time have contributed to the existence of various periods within the structure. When comparing the existing structure and remains with similar examples, three significant periods aligned with the advent of Christianity can be identified:

(i) First period (359–717): This phase encompasses the earliest period of the structure, aligning with the historical shift towards Christianity.

(ii) Second period (741–1871): This period reflects changes and adaptations made to the structure after the Arab-Byzantine wars.

(iii) Third period (1872–1884) and 1885–2012: This final phase spans the period up until the excavation works from 1885 to 2012.

3.2.1. First period (359–717)

This period covers the Early Christian era and characterizes the structure as a three-unit complex consisting of a baptistry and two churches. The structure, which measures 8.80 × 16.08 meters, features a dual-space baptistry at its center, with units to the north and south defined as churches. Part of the cathedral complex affiliated with the bishopric, the structure might also be part of a larger configuration along with other adjacent remnants. Data defining the unity of the three spaces include wall thicknesses, material characteristics, construction techniques,

the presence of apses on the eastern facade, organic wall connections between the northeastern and southeastern corners of the central space, and the walls of the northern and southern spaces, as well as the presence of similarly decorated friezes on the walls of the central and northern spaces.

On the structure's wall, a label indicating "baptistry" is found, and in historical sources, the structure is referred to as the "first baptistry with an inscription." During this period, the baptistry and churches of the Nusaybin cathedral were united into a single mass with a colonnaded narthex on the west side. The section identified as the central baptistry consists of two spaces accessed through a door in the narthex area on the west. The upper structure of the space with apses on the north and south sides, which are accessed through two adorned doors, is domed. The entrance area to the west of this space is divided into three sections and features a vaulted ceiling. Small square spaces are situated in the northeast and southeast corners of this area. Due to the special use for the baptism ritual, these spaces have windows opening to the churches. The churches to the north and south of the baptistry unit are accessed through two doors each from the narthex on the west. In the northern church, these doors are present but closed, while in the southern church, openings can be observed in the remaining wall. The churches have a three-aisled plan with a semi-circular apse in the center. The vaulted structure of the colonnaded aisles and the central aisle is shaped according to existing traces and vaults in the walls (**Figure 3**).

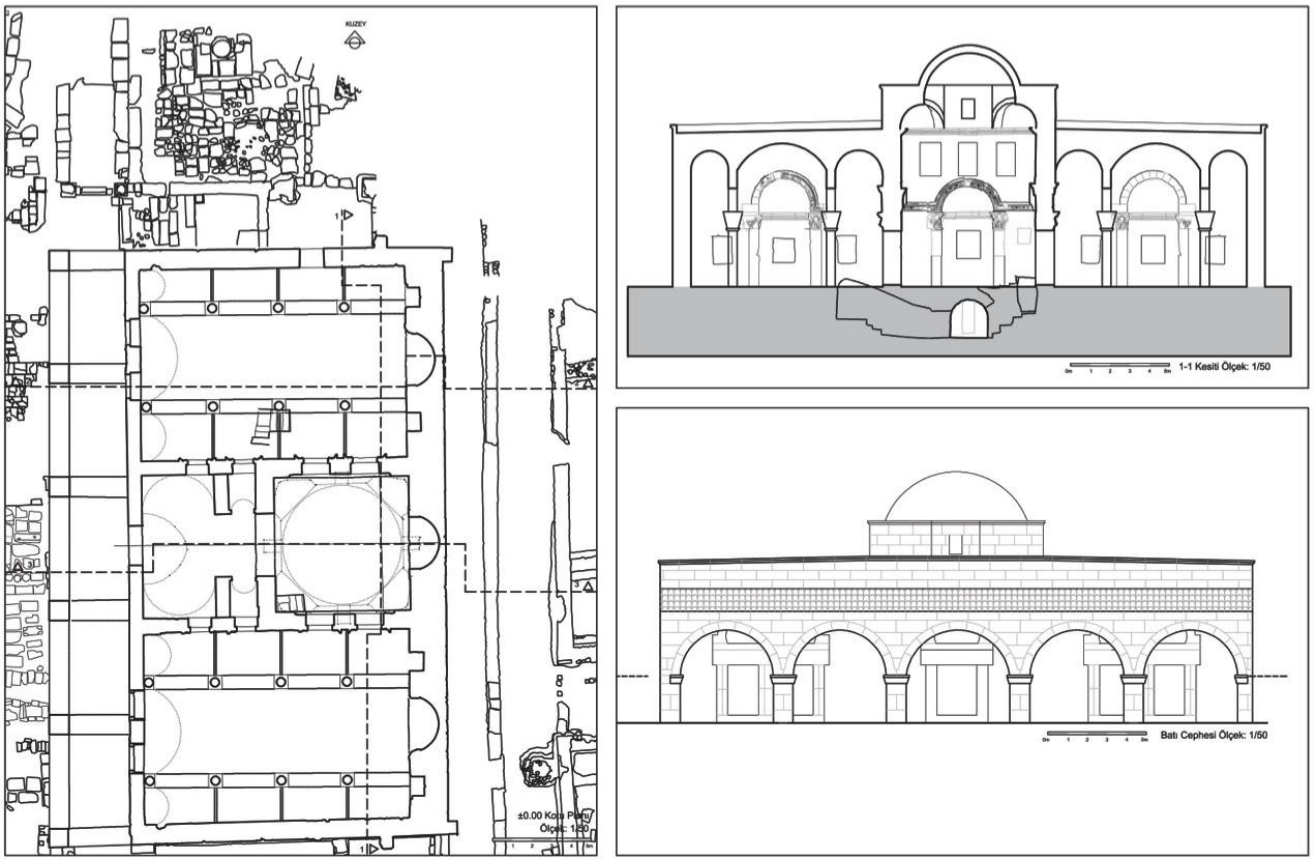


Figure 3. First period (359–717) completion/reconstruction

3.2.2. Second period (741–1871)

Established around 3000 BC, the settlement that was ruled by the Akkadians, Sumerians, Babylonians, Mitannians, Assyrians, Medes-Persians, Seleucids (Seleucids), and later the Abgar Kingdom, came under the dominion of the Romans. Until the year 637 AD, it changed hands between the Romans and the Sassanids. In the year 637, Islamic forces took control. Subsequently, the traces of all periods can be observed in various parts of the

region to varying extents. Throughout this lengthy era, many civilizations and communities settled in and inhabited the geography, only to be destroyed and rebuilt due to various disasters. During the second period, a portion of the structure collapsed in the 7th century due to an earthquake. The baptistery and the northern section of the structure were also reduced in size. It is believed that the collapsed sections were repaired using rubble stones and lime mortar. In this period, the southern part of the ruined structure was transformed into a two-aisled church. Written sources refer to the structure as a church from the 8th century onwards [3].

Based on the differences in construction materials and techniques, it can be observed that the ground floor took on its present appearance. Utilizing the characteristics of the regional architecture, it has been determined that the superstructure of the building, except for the domed space on the northeast, consists of vaulted sections and flat roofs. With reference to Gertrude Bell's photographs, it has been identified that the eastern and southern parts of the building are situated in a position partially buried in the ground (**Figure 4**).

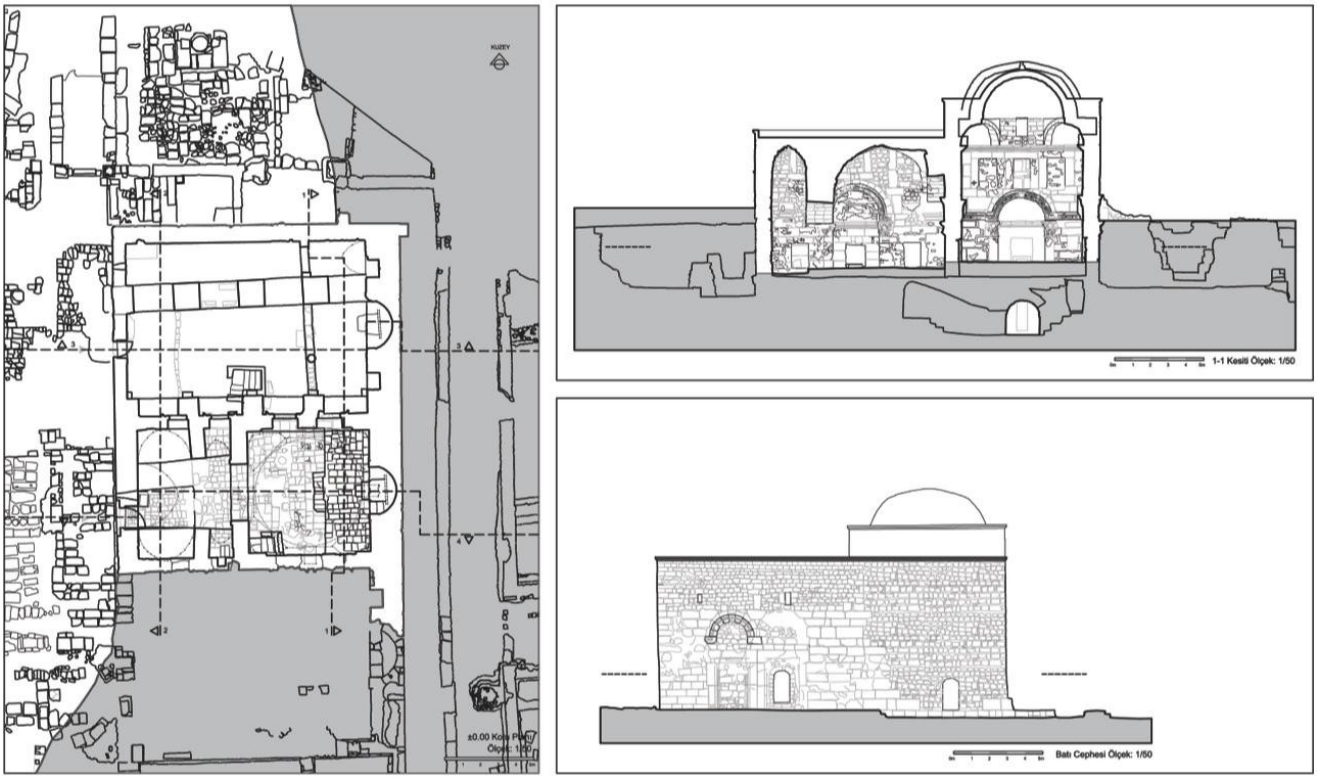


Figure 4. Second period (741–1871) description/restitution.

3.2.3. Third period

The third period is divided into three distinct phases: Phase A (1872–1884), Phase B (1885–2012), and the post-excavation period following the 2013 archaeological dig (Phase C).

(i) Phase A (1872–1884)

During this period, an additional floor was added to the western facade of the structure, and a stone staircase was constructed in the northwestern corner to access this upper floor. The central open eyvān and the two rooms opening into this eyvān were utilized as episcopal spaces. The architectural coherence and integrity of the baptistry dome were achieved in this phase by connecting the added floor with the baptistry dome through a narrow, vaulted area. Due to the introduction of the additional floor, a small toilet unit was appended to the staircase landing on the terrace. Consequently, the building adopted a two-story appearance with a flat roof during this period (**Figure 5**).

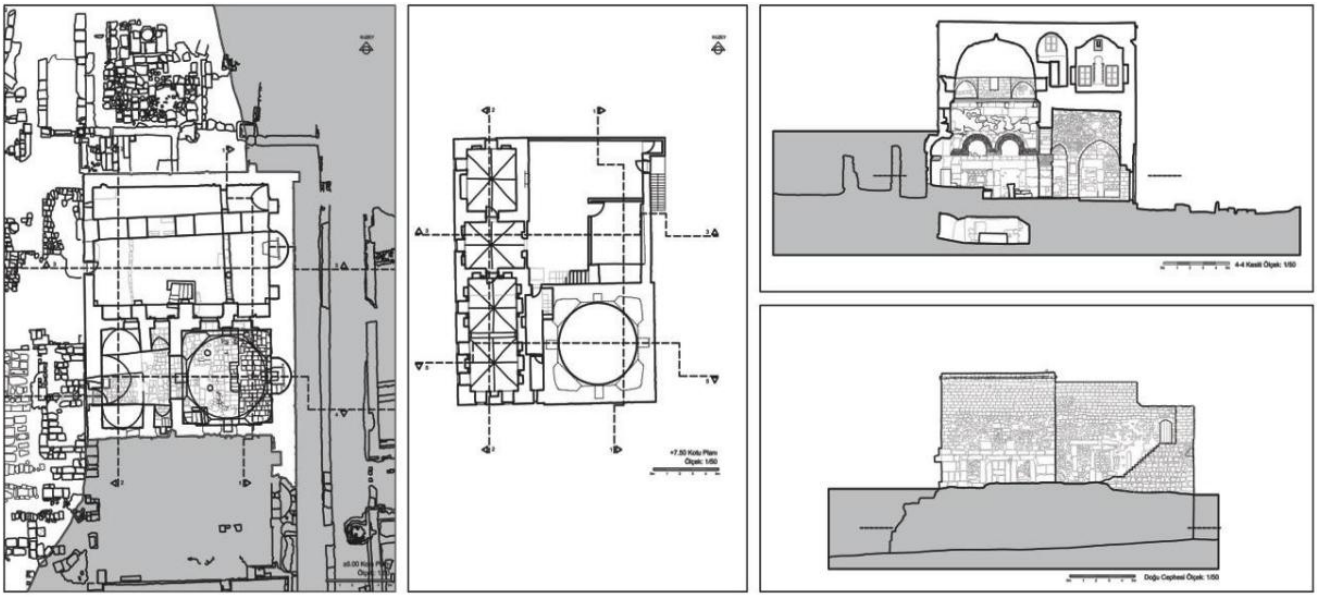


Figure 5. Third period/Phase A (1872–1884) description/reconstruction

(ii) Phase B (1885–2012)

Description/Reconstruction: The information regarding Phase B (1885–2012) is primarily sourced from Gertrude Bell's photographs. These documents reveal significant transformations in the building's architecture during this period.

Based on these records, it becomes evident that during this phase:

(a) The vaulted space between the dome and living areas was enclosed to create a room.

(b) The eyvān was closed off with a wall.

(c) An additional section, now serving as the kitchen, was annexed to the building.

(d) A staircase leading to the dome was introduced within the vaulted space.

As a result of these changes, the lower floor continued to host spaces for dual-unit religious rituals, while the upper floor was adapted into residential units through the added structures. This upper floor accommodated the individual responsible for the maintenance of the church. Notably, certain sections of the building remained underground, and openings on the lower floor were sealed with rubble, maintaining this state (**Figure 6**).

(iii) Phase C (2013 excavations)

The excavations at the Monastery of Mor Yakup are still ongoing. This monastery was once recognized as the world's first educational university where subjects like philosophy, logic, literature, geometry, astronomy, medicine, and law were taught. The results of the excavations conducted in 2013 have yielded the discovery of the oldest Syriac inscriptions here, further strengthening the argument for Nisibis School being the earliest university. Significant inscriptions found during the archaeological excavations at Mor Yakup Monastery in Mardin Nusaybin also support the notion that the Nisibis Academy was the world's first university. Noteworthy findings related to Syriac history have also been obtained [17,19].

4. Discussion

As a result of the excavation findings, the evaluation of the structure's features, the analysis of historical sources, an assessment of the building's past, a chronological classification, and consequently a description/reconstruction have been developed. Through the excavation works and the examination of comparable examples, it can be conc-

(a)



(b)

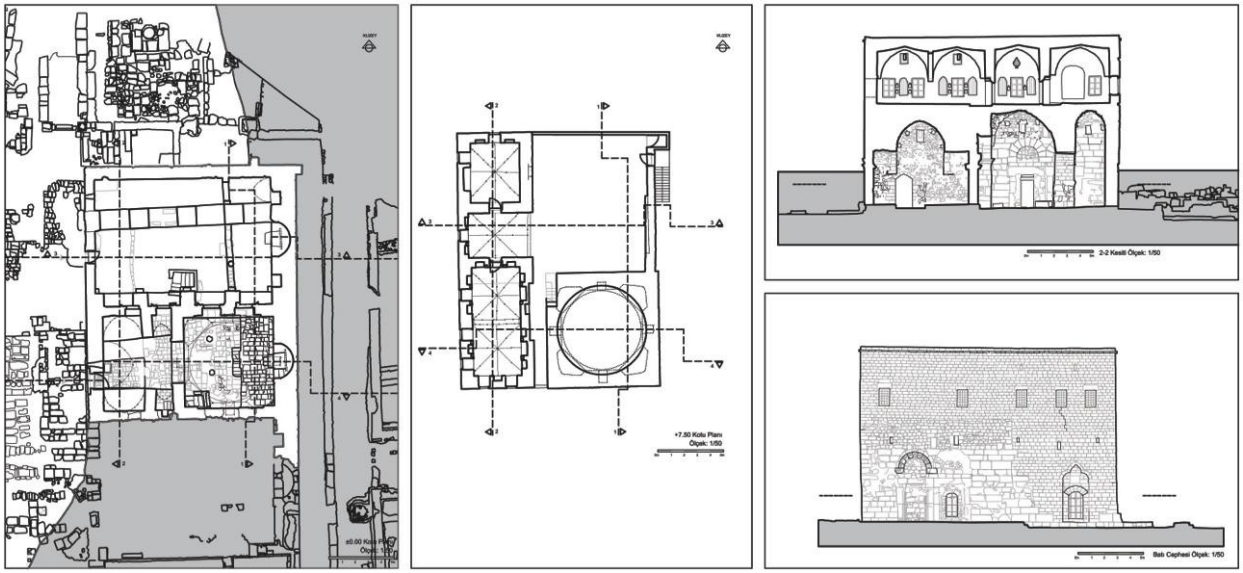


Figure 6. (a) Third period, Phase A: the staircase and toilet on the north facade, along with the sealed openings on the west facade, belong to this phase. (b) Third period, Phase B (1885–2012) description/reconstruction

luded that the standing structure today is the baptistery of the complex, and the adjacent excavation site reveals the remains of a connected cathedral. The evaluation of the excavation results and comparative analysis of similar instances have led to the determination that the existing structure is the baptistery, while the ruins uncovered in the vicinity belong to the associated cathedral. This conclusion has been derived from thorough assessments of the excavation scope, the building's characteristics, and references found in written sources.

In the course of this research, it was observed that the exact timing and circumstances of the cathedral, located at the heart of the city, being completely demolished could not be definitively determined. Within the scope of the study, a discussion can be framed as follows:

One of the possibilities regarding the date of this destruction is linked to the city of Nusaybin's conquest by the Persians in the year 573. During this period, it is known that the Christian population of the city was temporarily displaced. Another possibility arose during the intensification of conflicts between the Byzantine Empire and the Sassanid Persians in the 7th century. In this era, Nusaybin held significant military importance for the Sassanids. The third likelihood is that the massive earthquake in 717 could have been responsible for the city's destruction. According to ancient sources, an earthquake in 717 devastated Nusaybin. In 758, a metropolitan named Cyprian oversaw the reconstruction of the city's cathedral. This structure is likely the one

found through excavations, dated to the 8th century, and located in the northern part of the baptistery.

Presumably, during this period, the cathedral that was previously built by Mar Yaʿqôḇ Nṣîḇnāyâ in the 4th century and recently uncovered through ongoing excavations was no longer in its original place. Consequently, the remaining part of the baptistery was likely altered to convert it into a church. Some researchers suggest that during this time, Mor Yakup's tomb was moved from the old cathedral and placed in the space beneath the former baptistery, which was transformed into a crypt. From then on, the structure came to be known as the Church of Mor Yakup [3].

Regardless of which possibility is accurate, one certain aspect is that the church was demolished in the year 758/759. After the existing church adjacent to the northern wall of the baptistery collapsed during that time, Bishop Cyprian (741–767) consecrated the baptistery as a church. In his own words, he presented it as "the holy place of the great church of Nusaybin was constructed." The fact that the present-day church is described as the "great church" indicates the absence of the previous cathedral [3]. In relation to the structure, Falla Castelfranchi (1980) proposes the following interpretation: He considers the wall that protrudes from the southeastern corner as evidence of adjacent structures and suggests the presence of two wide side chambers extending from the central cubic area. These three chambers feature small apses on their eastern walls. The architectural decorations in the apse of the northern section were found to be identical to those in the southern apse, implying that these two elements should be regarded as contemporary. The discovery of a stone-paved floor in the southern part, the equal length and width of the northern and southern sections, the exposed foundation of apses on the eastern edge of this platform, and the apse's dimensions aligning with those of the cubic and northern apses all support Falla Castelfranchi's (1980) view that the baptistery is a three-aisled structure [18].

5. Conclusion

In conclusion, based on the research conducted in this study, the structure has undergone three distinct functions (baptistery, church, university) and can be divided into two primary periods (pre-Christianity and post-Christianity). When examining the functions that the structure has served, it becomes evident that the building known as Mor Yakup Church has a long history even before its role as a church.

The initial phase of a structure with an uncertain function in a significant Roman border town could be attributed to the pre-Christian era. In cities with continuous habitation, repurposing existing structures is often a preferred practice. In the case of Nusaybin, it is highly likely that during the Byzantine period, when the city was built upon the existing Roman settlement, past structures were repurposed. A crypt-like space, evaluated differently from the architectural conventions of the early Byzantine period, could potentially be a remnant from a pre-Christian era. However, concrete evidence for this is lacking.

In summary, considering the existing structure and comparative examples, three major periods coincide with the presence of Christianity within the structure:

(i) The first period (359–717)
(ii) The second period (741–1871)
(iii) The third period (1872–1884) and the period from 1885 to 2012, extending until the 2013 excavation phase

The structure, with the spread of Christianity in the region, was repurposed as a "baptistery" connected to a cathedral and monastery complex. Initially, during the early Christian period, the structure functioned as a baptistery and was later transformed into a church in the 8th century. Today, it is known as the Mor Yakup Church and is associated with the Syriac Orthodox Church. The surviving section of the complex, which is

recognized as a church today, is described in sources as the first baptistery with a clear depiction of its purpose. The 2013 excavations revealed the oldest Syriac inscriptions on this site, further supporting the argument that the Nisibis School was one of the earliest universities. The significant inscriptions discovered during the archaeological excavations at Mor Yakup Monastery in Mardin Nusaybin also bolster the notion that the Nisibis Academy could be considered the world's first university.

Disclosure statement

The authors declare no conflict of interest.

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Innoscience Research covers biology, chemistry, physics and many other disciplines. It mainly focuses on the improvement of human health. It aims to promote the cooperation, exploration and exchange among researchers from different countries. By establishing platforms, Innoscience integrates the demands from different fields to realize the combination of clinical research and basic research and to accelerate and deepen the international scientific cooperation.

Cooperation Mode



Clinical Workers



In-service Doctors





Foreign Researchers





Hospital



University



Scientific institutions

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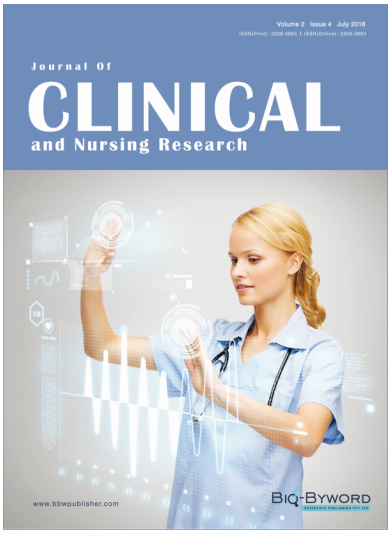
OUR JOURNALS



The *Journal of Architectural Research and Development* is an international peer-reviewed and open access journal which is devoted to establish a bridge between theory and practice in the fields of architectural and design research, urban planning and built environment research.

Topics covered but not limited to:

- Architectural design
- Architectural technology, including new technologies and energy saving technologies
- Architectural practice
- Urban planning
- Impacts of architecture on environment



Journal of Clinical and Nursing Research (JCNR) is an international, peer reviewed and open access journal that seeks to promote the development and exchange of knowledge which is directly relevant to all clinical and nursing research and practice. Articles which explore the meaning, prevention, treatment, outcome and impact of a high standard clinical and nursing practice and discipline are encouraged to be submitted as original article, review, case report, short communication and letters.

Topics covered by not limited to:

- Development of clinical and nursing research, evaluation, evidence-based practice and scientific enquiry
- Patients and family experiences of health care
- Clinical and nursing research to enhance patient safety and reduce harm to patients
- Ethics
- Clinical and Nursing history
- Medicine



Journal of Electronic Research and Application is an international, peer-reviewed and open access journal which publishes original articles, reviews, short communications, case studies and letters in the field of electronic research and application.

Topics covered but not limited to:

- Automation
- Circuit Analysis and Application
- Electric and Electronic Measurement Systems
- Electrical Engineering
- Electronic Materials
- Electronics and Communications Engineering
- Power Systems and Power Electronics
- Signal Processing
- Telecommunications Engineering
- Wireless and Mobile Communication