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Nag Mohashoy Temple Complex, Narayanganj: A Case Study of Adaptive Reuse for Hindu Religious Site

Sayed Ahmed*

Department of Architecture, Leading University, Sylhet, Bangladesh

Corresponding author: Sayed Ahmed, ar.sayedahmed@gmail.com

Abstract: With an emphasis on the religious component of reuse potentiality, this study investigates the crucial nexus between spatial development and the conservation model for religious practice with socio-communal dimensions. Adaptive reuse is a critical tactic for global preservation and revitalization to elevate heritage sites in culturally significant locations but provides contemporary functions to them simultaneously. This study examines the various facets of adaptive reuse concerning the religious cultural heritage of suppressed minorities, stressing its insight and importance including the inherent cultural worth of ancient structures and difficulties through creative solutions to modify the temple with modern purposes. The research methodology approaches through an extensive analysis of the literature and case studies and ends with design interventions. It looks into the socioeconomic advantages of adaptive reuse in religious practice, such as the promotion of pilgrimage tourism, community revitalization, and sustainable development. The possible findings will emphasize the conversation on sustainable heritage management by combining theoretical frameworks with practical discoveries as an architectural project with certain concepts.

Keywords: Cultural heritage; Architectural conservation; Sustainability; Adaptive reuse; Community participation

Online publication: November 1, 2024

1. Research aim

Historic pilgrimage and tourist sites should go with the adaptive reuse trend of contemporary conservation architecture. For that, the conservation of religious heritages should be integrated into urban development, tourism, local economy revitalization, and governance. To continue the legacy, protecting traditional resources and promoting cultural aspects of religious heritages are essential for the future sustainable development of human society.

1.1. Objectives

(1) To preserve the importance and role of the cultural and religious heritages of Narayanganj city with

authenticity and integrity.

(2) To derive and enhance a city image for any particular religious community, which is crucial for their existence.

(3) To include adaptive reuse policy in social, political, and urban planning factors for the protection of both intangible and tangible dimensions of any heritage

(4) To develop value systems in that society, the implementation of the adaptive reuse concept in ancient religious sites needs to be integrated into city inhabitants' daily lives.

(5) To involve economic factors for achieving sustainability through adaptive reuse in community participation and religious pilgrimage.

1.2. Methodology

(1) Analysis of the site context with existing regulatory and planning instruments of the Temple site was done in simple free-hand sketches to identify positive aspects of the site.

(2) The direct, indirect, and induced indicators from Hindu religious and cultural heritage on the entire city system were identified to assess both the impacts of the project on the buildings themselves and the surrounding urban context.

(3) Deduction and critical analysis of architectural design processes to derive innovative design solutions. The design itself was segregated into three major stages to assess the final design outcomes: religious, economic, and social impacts of adaptive reuse (**Figure 1**).

(4) The participative phase was based on the involvement of different inhabitants through interviews aiming at understanding the reasons why these urban religious spaces have different impacts and are successful as a distinct and identifiable public culture.

(5) A field survey was conducted with a focused user group and experts in the local context, including representatives of the Hindu community, religious institutions, and academic scholars, and employees from Narayanganj City Corporation.

(6) Some limitations were acknowledged and excluded during the design implementation. For example, potential land reacquisition from illegal encroachment was not utilized in this study.

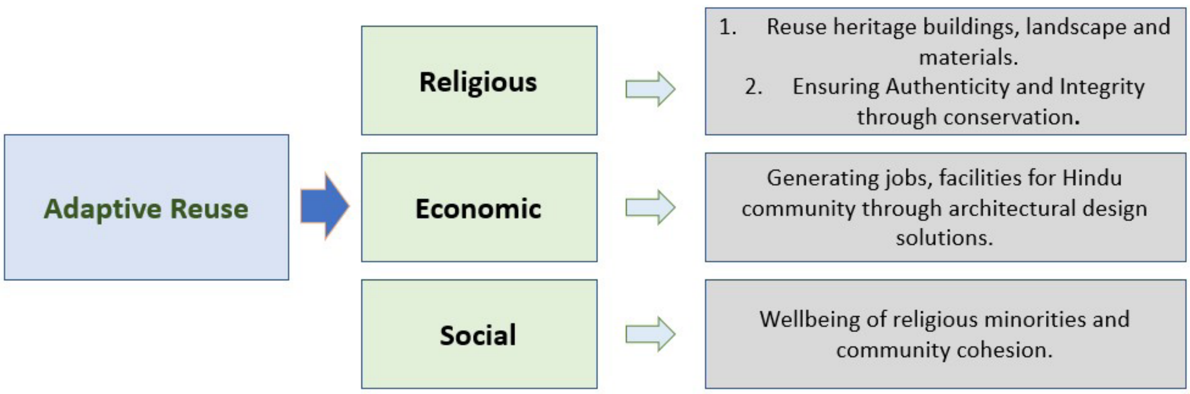

Figure 1. The methodology of adaptive reuse is achieved through three stages of community assessment: religious, economic, and social dimensions of heritage conservation

2. Literature review

Religious monuments in disrepair are not evaluated for their moral worth. Instead, they are burdens and are even targets for demolition worldwide. Heritage sites of today must have a thoughtful and dynamic engagement with our "ancient and recent past" [1]. Political, social, economic, technical, cultural, regulatory, commercial, management and other variables are among the many stakeholders that must be considered to address a variety of issues by bringing in a variety of disciplines [2]. Rather than attempting to capture a specific moment in time, adaptive reuse breathes new life into any place by examining alternatives that fall in between demolition and museum conversion. When an adaptable project adds a new layer without removing previous ones, it becomes an essential component of the site's lengthy history. It is not the end result, rather, it is a step forward [3, 4].

The adaptive reuse of cultural heritage (religion is also an integral part of it) can foster innovation, create productive networks, and contribute to sustainable development by facilitating cross-fertilization, knowledge sharing, and resource sharing in open hubs [5]. Adaptive reuse of cultural/religious heritage, highlighting its importance in sustainable development, cost-effective architecture, and preservation. It discusses its potential in urban regeneration, vacancy analysis, and industrial heritage repurposing. It discusses methodologies, models, and case studies, highlighting their impact on regional growth, sustainable development, and retail design [6]. Adaptive reuse involves modifying a building's function and structure, often through commercial development and retail reuse in historical centers, while preserving facades rather than demolishing authenticities [7]. Cultural heritage adaptive reuse promotes innovation, creativity, and social capital, fostering productive networks and cost reductions. Local communities and creative enterprises drive reuse through function innovation [8].

Adaptive reuse is a practice of modifying old structures for new needs, which is crucial in modern architectural practice for sustainable development, economic necessity, and recognition of architectural legacy benefits [9]. However, stating this; the United Nations Educational, Scientific and Cultural Organization (UNESCO) shifts itself from protection to pro-action, aligning interventions with demand and growth strategies, recognizing heritage potential in regional development priorities, and unlocking funding for adaptive reuse and urban transformation projects [10]. In its Burra Charter, the Australian International Council on Monuments and Sites (ICOMOS) listed seven guidelines that should be followed to carry out adaptive reuse projects successfully through assembling a multidisciplinary design team, including stakeholders, preserving the character and quality of the legacy, and, lastly, creating a financial model to guarantee life-cycle investment over time [11]. Adaptive reuse is a tactic used to boost a site's potential value in structural, artistic, and distinctive ways when a previously inhabited building or piece of land has become obsolete [12]. Five principles should be combined with adaptive reuse: it should serve the purpose of the redesigned function, last a long time and adapt to new uses, react well and enhance the quality of its context, and be aesthetically pleasing and coherent for both users and bystanders and possess sustainable qualities [13].

The compatibility of creative values with intrinsic values, or the "admissible limits for changing" is a crucial concern in adaptive reuse initiatives. Intrinsic values are those associated with historical importance and collective memory. Adaptive values, on the other hand, are those associated with new use values, which are problems about appropriate "choices" that require careful decision-making [14]. As part of the reuse project, the building is first assessed to determine the standards for the best design options. These are derived from the set of values attached to the structure and its intended function [15]. Numerous scientific studies on the topic of reuse emphasize the possible advantages at the urban and territorial levels, including increased building and soil market value, social promotion, and local economic development [16]. These concepts of remodeling and transformation—intervention, insertion, and installation—are all realistic and commonly used in practice [17]. The skills and desire of the designer, along with their talent and inventiveness, are the most important factors in the success of creative reuse. It is a comprehensive strategy that considers the psychological requirements of city dwellers, economic value, practical issues, and artistic appeal [18]. According to academics such as Rappaport, who distinguishes meanings into three levels, basic values of a community's religious identity, philosophical systems, and cultural patterns can be found in the higher meaning [19].

3. Case studies

3.1. Concert House, Anneliese Brost Music forum, Bochum, Germany

Bez+Kock Architekten of Germany implemented this innovative design over a church in 2016 (**Figure 2**). The concert hall is an ensemble, adjusted by two new concert halls that surround an existing church building and transform it into a foyer. Both the existing and the new facades consist of the same facing brick. The facade concept calls for the new brick to be refined with white plaster, enriching the dialogue between the two elements. The materials of this project convey true expressions of its design decisions and contrasting character. Among three material choices, bricks were the most celebrated element. The facade of the new building is provided with a front shell of white slate brickwork (**Figure 3**), the shards of which correspond to that of the church building.

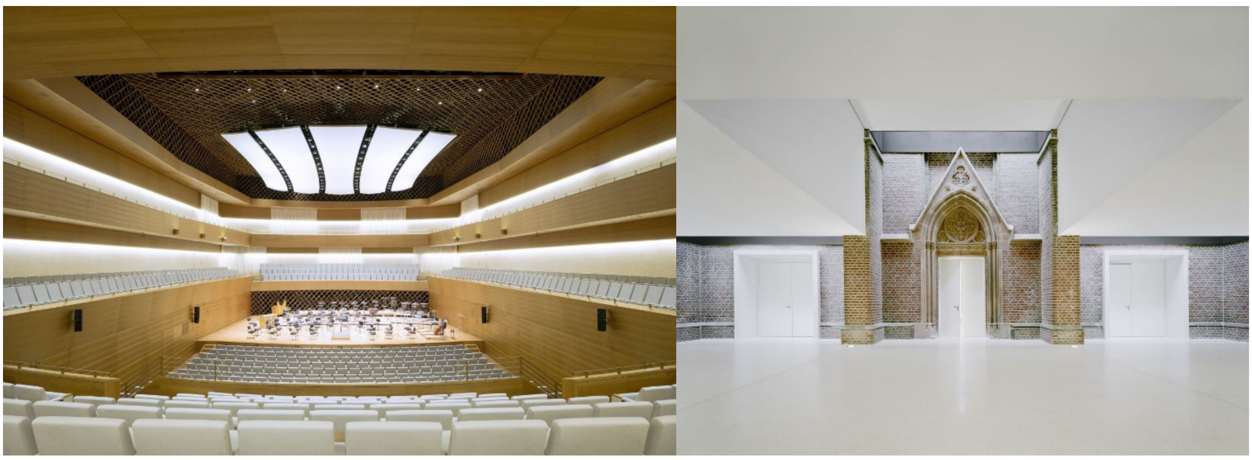

Figure 2. The Concert House, Anneliese Brost Music forum in Bochum, Germany

Figure 3. Concert House, adapted reuse of a medieval church at Bochum, Germany, where a religious site was converted into an amusement function

In the same way, the outer wall of the large hall is also treated as an interior forecourt. In contrast to the new church, the brick was covered with a thin white lime plaster layer. Additionally, its high-quality fabric in interior design consists of three differently colored yarns. The resultant effect creates a different visual effect from near and far in the three-dimensional surfaces. These are distinguished by their high abrasion resistance and are therefore particularly suitable as a material for the concert seats. Lastly, Stucco Lustro material was applied to the exterior walls of the hall with an incline of 0.5°. Such craftsmanship and feel give the surface a particular quality. Due to its properties as a hard-mineral material, it also fulfills the acoustic requirements [20].

3.2. Manah Mosque, Manah, Oman

About 160 km from Muscat, the capital of Oman, the Manah Historic Mosque is situated on the outskirts of the sizable city of Manah. It is a historical gem. Inscriptions inside the mihrab attest to the inventiveness of its ornamental engravings, which date back to 1534 AD. However, the mosque is older than this date. It appears that this date only relates to the mihrab's engraving. There is currently no recorded information regarding the mosque's initial construction as a building. There is a small pulpit next to the mihrab that is quite distinctive. It looks like a pulpit from the early Islamic era and has five little steps that rise above the mosque floor during the Friday speech.

This mosque's strategic location has been chosen by the Omani government to become a heritage area, highlighting the natural beauty and rich cultural legacy of Oman. Its preservation is under the direction of the Ministry of Heritage and Tourism, keeping its historical authenticity unaltered to protect Oman's religious and cultural legacy. When visitors enter the mosque's main building, they are astounded by how large the area is and how magnificent the building's historic architecture is. The mosque features eight wooden doorways with ornate arches that lead to its five arcade-filled interiors. The five cylindrical pillars and arches that connect the parts in a geometric pattern that is unique from Oman's historic Islamic architecture define these arcades (**Figure 4**).

Figure 4. Manah Mosque at Manah, Oman where the worshiping character of this Islamic religious site was kept strictly original

The mosque also features several historically significant architectural features, with its mihrab (prayer niche) standing out as one of the most notable in Omani mosques with special archaeological value. In addition to its traditional wooden covering, which showcases traditional workmanship, the mosque has ceiling holes for lighting and ventilation, which make up for the lack of traditional windows and provide a distinct interior atmosphere while distributing natural light and fresh air evenly. The mosque was built in the traditional architectural style that was popular in the area at the time, utilizing basic materials such as clay, gypsum, and the traditional mortar technique of Oman [21].

4. Conservation project of Nagbari Temple Complex

4.1. Life of Saint Nag Mohashoy

This saint was born in 1846. His full name was Durga Charan Nag (**Figure 5**). He was very intelligent from his early childhood. He used to travel 10 miles every day to go to Normal School in Dacca, through a jungle to the west of his home. He continued this for 15 months. He started medical study at Campbell Medical College in Calcutta. But later, he became a disciple of Ram Krishna Paramhangsha and shunned the material wealth for eternal Sannyasi life. He is still remembered for his renunciation and love for God. He wrote a book, “Suggestions for the Boys,” which was a textbook for primary school students in Bangladesh for a long time. He is called the “Jewel of Deovog.” He died in his home courtyard in 1899 [22].

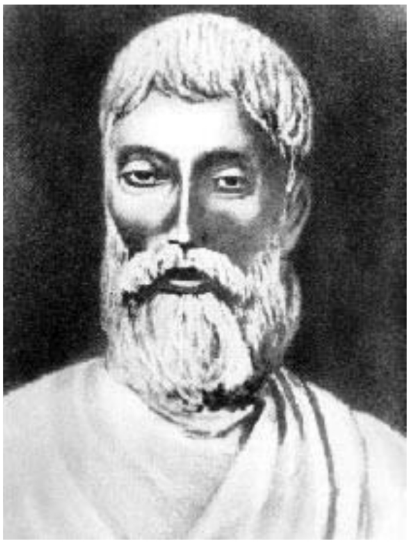

Figure 5. Durga Charan Nag (1846-1899)

4.2. Significance of the project

The Hindu community is one of the notable minorities in Bangladesh, and historically, they influenced Narayanganj city. Particularly, saint Nag Mohashoy’s memory that is associated with this place could be felt all over the diaspora and Bengali Hindus’ minds for his life and teachings. That’s why the Narayanganj city corporation took this initiative to protect the “spirit” of his homestead and enhance communal harmony.

4.3. Location of site

The given site was located on the western side of Narayanganj city, on the banks of the Shitalakshya River. It stretches between areas like Nagbari and Deovog (**Figure 6**). The site is itself a landmark, housing a controversially constructed diabetes hospital. It is accessible by all modes of transportation services, motorized or non-motorized vehicles, that are available in the city.

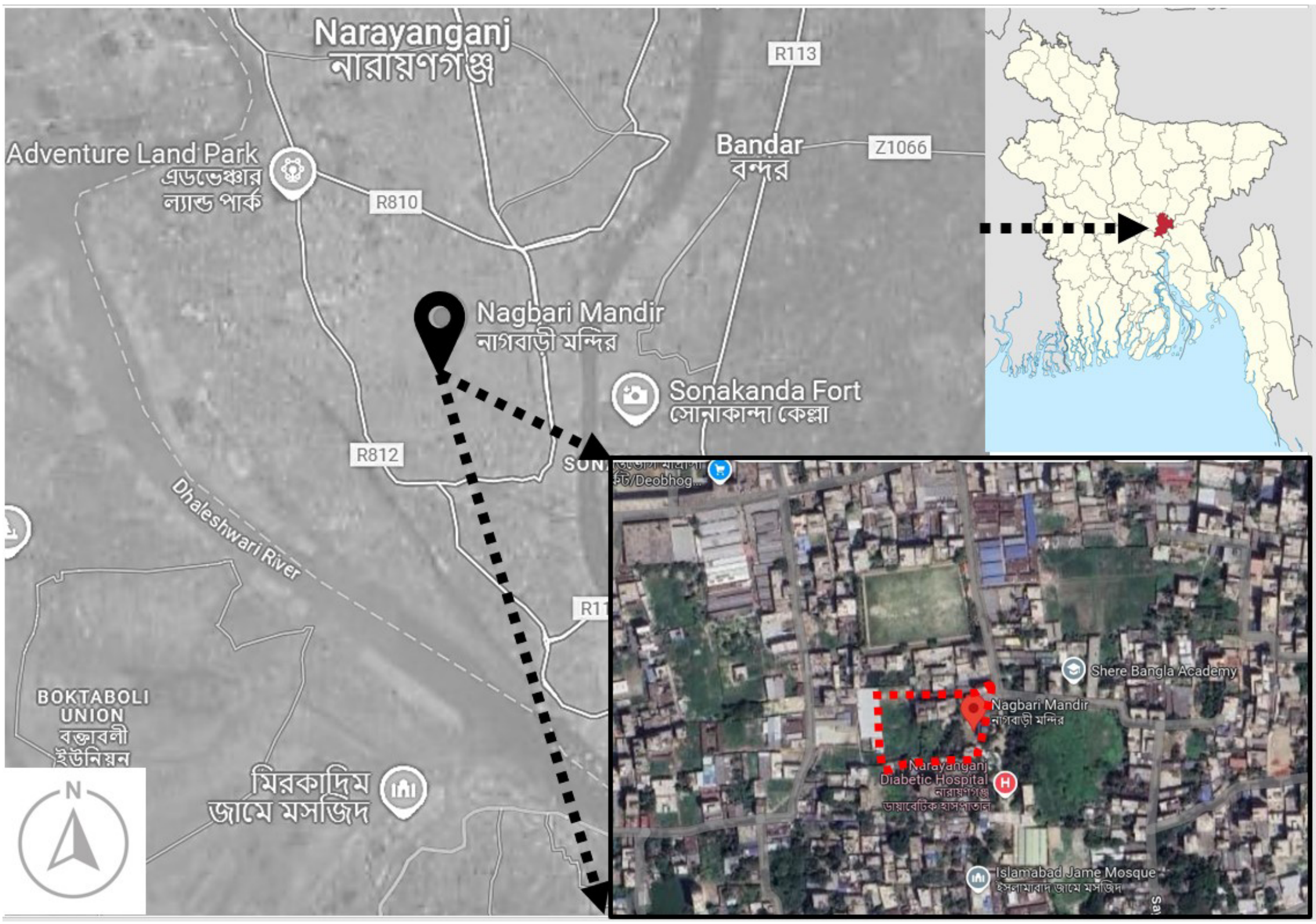

Figure 6. Location of the Nagbari temple site, Poschim Deovog road, Narayanganj City Corporation area at coordinates: 23.61332308181181, 90.49165437929906

4.4. Original state of the project

The original homestead of this saint was struck by poverty. The site was like an island, surrounded by water bodies. The boats used to sail at his homestead at a deck on its north side. Local trees like Bilombo, Koroi, and Chalta were around the homestead. There were four houses in this complex, all scattered to each cardinal according to the vernacular practice of that time, and should have been arranged to center a courtyard (**Figure 9**). The doors of his original houses were perforated. He always wanted to stay in Sannyasi life, and he dreamt about a mythical hut of his own like the Munis and Rishis of the Mahabharata. Even during his last breath, he saw the hut of a Muni in Vordwaj Tirtha, situated in a Himalayan valley. His last resting place was a Toktaposh (bed mat) in his courtyard. He took simplicity in his lifestyle for his preparation for death.

He was always busy with his religious rituals when he stayed in Deovog. Every Saturday, there was a religious event. Every evening, there used to be puja (worship). Some festivals this saint used to perform in his homestead with great enthusiasm were worship dedicated to deities like Rotonti puja, Vograg puja, Durga puja, Kali puja, Swarashati puja, Jagatdhatri puja, and daily enchanting ritual like Songkirton. He used to welcome the local dramatists to stage plays related to religious teachings. A drama dedicated to the life of Nag Mohashoy was staged here when he was still alive. Guests from Calcutta and other parts of Bengal used to reside here for 10 to 15 days. After the saint's death, a Quadruple Square wooden Shikhara-style temple was erected (**Figure**

7) in 1910. It resembles the four qualities of his religious teaching: Dhormo (righteousness), Ortho (grandeur), Kam (illusion and disturbance), and Moksha (highest attainment) [22].

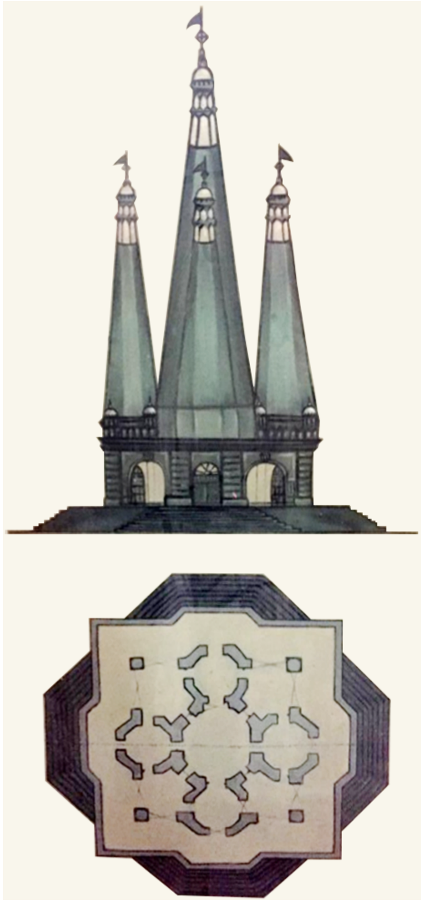

Figure 7. The drawing of the wooden octagonal Shikhara-style temple which is extinct today.

4.5. Existing situation of the project

The old heritage temple standing over the previous wooden temple has been converted into a museum. Its ground floor is used as the community office. This building became vulnerable. Thus, the devotees built an adjacent small temple with corrugated sheets that could not provide enough worship space and large-scale festival arrangements (**Figure 8a**). Land encroachment from surrounding Muslim communities, hospitals, political pressure, etc. has shirked its total land size. Additionally, security problems are acute for this religious site due to local thieves and the potential for violence from extremist groups for their greed on the temple's unprotected lands.

A two-story yellow building with an additional informal floor made with corrugated sheets over its roof was erected at the entrance of the complex. This was built to collect the expenses of the temple. Money collected from its tenants' monthly rentals is the vital income source of this temple to meet all the expenditures (**Figure 8b**). Moreover, a public kitchen built on the opposite side also generates some income and supports its religious functions during religious festivals. A residential quarter for the guests and priests was started but nipped in the bud due to a lack of patronization (**Figure 8c**).

Figure 8. (a) The old temple in the middle, (b) the entrance of the building hidden by unplanned commercial residence development, (c) the incomplete residence of priests due to lack of funding

5. Site analysis

Data particular to the site, such as master plans, maps, historic development, and vintage photos, were gathered. Literature reviews connected to the site's genesis, past planning concepts, expansion, change, and continuity, land usage addressing public and private ownerships, socio-cultural physiognomies, etc. were prepared.

To better grasp the spirit of existing spaces, numerous hand sketches and AutoCAD designs were created. Through the use of analysis tools, natural elements were uncovered through the creation of freehand sketches that showed the terrain, climatic conditions, visual and auditory aspects, and position of the place. To discern the scopes and strategies in design decisions, the built environment study of Narayanganj city was conducted following its religious image. This involved identifying elements such as physical or man-made characteristics, patterns of urban fabric, figure-ground and reverse figure-ground, street network, spatial organization, hierarchy of open spaces, and existing architectural typologies in the drawings **(Figure 10)**. It is now clear that the overall location has a lot going for it, and the residents have high hopes for these areas that are designed to evoke memories.

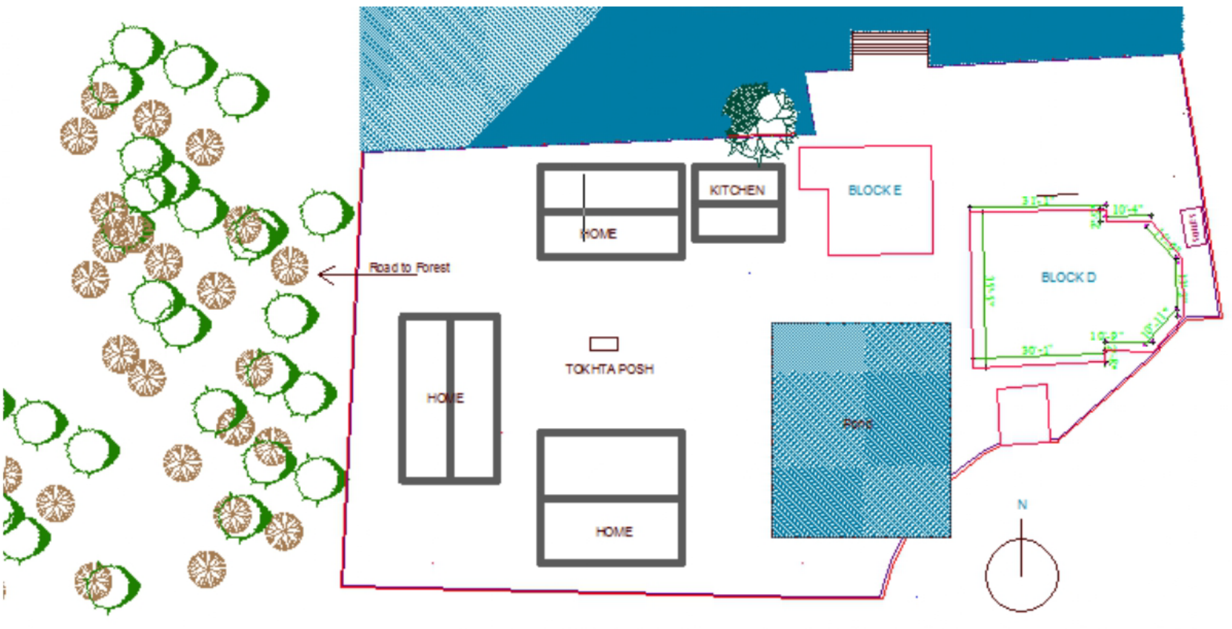

Figure 9. Trace of the original vernacular settlement of the saint: lake in the north with decks to tie boats, pond in the east for drinking water, forest in the west, and three huts around a courtyard while a Koroi tree with the kitchen in the northern corner

6. Findings and discussions

6.1. Design interventions and proposals

Collective consent of the local inhabitants found the adaptive reuse principles and associated proposals positively during the field survey which were later followed in design decisions for the overall temple site. Despite having historic segregation after the partition of Bengal in 1947, the site remained a "socialist tissue" that gives the actual essence of religious tolerance. The design solution wanted to integrate religious aspirations with the past. This might be linked by a "Bridge" to germinate a reflection of the past and prosperity with the future.

The prior challenge was to make the abrupt and dilapidated heritage building of a Hindu octagonal temple so that the whole renewal project would start creating dialogues between old buildings and new buildings. Leftover spaces were treated with mild landscape interventions, which were proposed as the "Mandala" principal of Hindu temple design and ending in an axis, resembling the birth of the universe from the natural light penetration echoing the symbol of the Hindu "Om" sign of creation and end. Such "mixing" of colonial temple architecture with contemporary brickwork practice will provide a potential psychological diversity to pilgrims, users, and all the devotees.

The sequence of spaces also offers a series of experiences to explore hierarchy from various directions: above, around, and surroundings. For that, the proposed new building's ground floor was kept vacant deliberately to resemble the courtyard's (called *Uthan* in Bangla) concept of multipurpose functions. The elongated courtyard was proposed from the inspiration of existing court configurations and modeled after the prevailing human walk flow, regardless of the indoor and outdoor relationship of spaces. The complex's main entrance invites visitors with waterfall sounds to resemble the "birth of Ganges" and gradually takes them to the series of "mandala-shaped" three landscape areas where people will explore a square aquarium reflecting the scattered lights on the bottom surface of the overhead bridge.

The floors contained by the bridge are proposed to host regular religious congregations, exhibitions, conferences, symposiums, and seminars, and a sale fair for art pieces and antiques. Such a reciprocatively designed environment of this Nagbari temple complex will offer a "lost link" between the natural and built environment, which is something new and unique, which the city of Narayanganj is currently "not posed with" but later can be proud of.

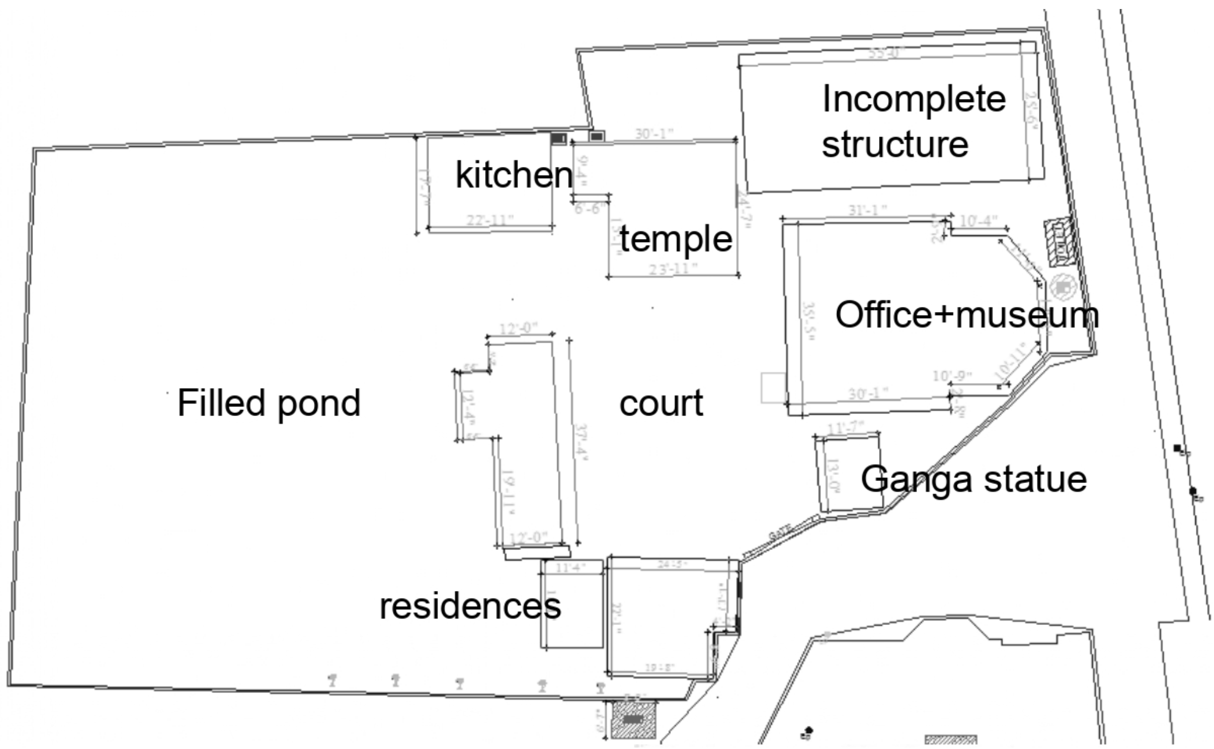

Figure 10. Existing site condition of the temple complex

Figure 11. The four qualities of the design were represented in the landscape by creating the axis connecting four mandalas, Dhormo (righteousness) in rituals and performance, Ortho (grandeur) in stepped Tulsi (sacred tree) alter, Kam (illusion and disturbance) in water body and Moksha (highest attainment) in "Om" sign at the end. The ground floors of all the buildings are kept free-flowing to achieve the openness of vernacular architecture.

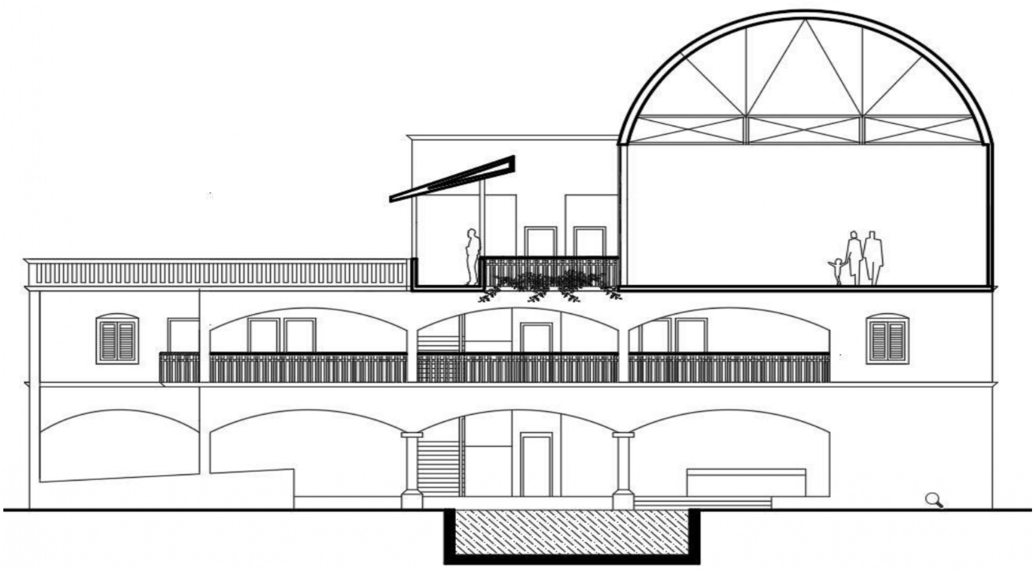

Figure 12. Section showing the permeability and dialogue creation with built spaces with designed landscape

6.2. Analysis and discussion

Religious intervention in architecture could be achieved through collaboration between multidisciplinary and pioneering architectural decisions and concepts that are embedded with spiritual, environmental, as well as economic benefits for the future sustainability of any community. In addition to these, the design outcomes revealed by this Nagbari temple complex project demonstrate how assets of existing heritages, public policy, social strategy, and multidisciplinary teams can come closer with common ideas of religious rituals and practices, which could be adopted and appreciated by all in the society. Achieving such a goal of resilient heritage conservation practice is not an easy exercise, but it is also achievable if researched properly. Determination and willingness to identify new ways of thinking and cross-cultural collaboration between community members are the key steps for such innovation in Narayanganj's cityscape. The power of landscape design additionally revealed the value of land, memories of Saint Nag Mohashoy, and sense of belongingness, all of which have been identified as significant factors in changing perceptions and creating visions for this project. The implementation of natural elements like water and light in the design concept was the perfect exuberance of Hindu spiritual thoughts to convert built forms according to religious inspiration. If used effectively, the major role of religious architecture in this design outcome will encourage future adaptive reuse policies to make urban communities well aware of their cultural heritage. The built environment represented in SketchUp 3D modeling reflected the design idea and derived spaces properly (**Figure 13** to **Figure 15**).

The design of the Nagbari Temple project tried to analyze and understand how the religious building and its surroundings could be embedded in an adaptive reuse model. However, this article is limited to the development of a conceptual design framework and has limitations in terms of applicability in different cultures and regions. It will raise further fundamental questions regarding the usefulness of such religious complex projects, especially in the Western world, where religion has faded from the everyday lives of the people. Site selection, renovating religious buildings with authenticity and integrity, reactivating different functions, and even guiding future urban regeneration and redevelopment strategies. By admitting comparisons, this conceptual project allows meticulous speculations, and this will help other religious sites calculate the success rate of every initiative of adaptive reuse in a religious context. The importance and application of such remodeling can convert these religious sites into major cultural content and significant physical forms of any city. According to the above discussions, two main points could be explained as research outcomes.

Firstly, one main ritual axis that was formed over the landscape in addition to the basic historic elements like the temple tied up east and west cardinals of the site, which was missing. The tie gives a pleasing experience adorned with different kinds of activities where spirituality captures both winter and summer seasons through a change of light (**Figure 11**). Secondly, religious architecture along with residential quarters and commercial land use is brought under cohesion by the dint of adaptive reuse. Holding art exhibitions, rehabilitation, accommodation for Indian tourists, the Hermitage of Saints, museums, and worship places. But still, public and private spaces are separated exactly from each other and thus ensure maintenance, protection, and repair of designed landscapes and built forms in the design solution. The temple complex is turned into something where inhabitants can feel that they "own" it, interact each other easily through created spaces; which will act as the most important step in this area's communal harmony recovery and motivate the Hindu citizens of Narayanganj against any kind of religious violence (**Figure 12**).

Also, the two case studies, one from Europe and another from Asia give us a clear idea about how the conservation thoughts may vary in terms of religious purpose. The German context accepted a very contrasting function of music hall, but the restricted Middle Eastern context of Oman not only managed to preserve the initial appearance but also ensured its religious functions or even enhanced it to some extent. The case study of

Nagbari Temple followed the Asian context.

As a result, architectural decisions for adaptive reuse in this temple complex had satisfied and ensured three basic aspects: open-minded religious administration, a sense of provocative conservation of historic spaces, and community supervision.

Figure 13. The journey ends in Light, to achieve ultimate freedom (Mokhsha) from earthly miseries.

Figure 14. The past is watching the new, so the new is watching the past. The design incorporates the reflexivity between heritage (conservation) and contemporary buildings (echo in extension)

Figure 15. The sequence of mandalas in the Landscape and its three-dimensional representation in built environment

7. Conclusion

The study highlights the importance of adaptive reuse in fostering religious sites to successful cultural and social innovation, creating productive networks, and contributing to sustainable urban economies through religious sentiment of cooperation. It reveals significant factors influencing commercial aspects, religious conflict, and challenging the market's preference for large-scale buildings. Instead, choosing traditional and vernacular practices for "ground to earth" design solutions. Recognizing religious heritage as a strategic resource for sustainable development, adaptive reuse is crucial for cultural continuity, economic efficiency, and heritage preservation. The study also emphasizes the importance of conserving historical, cultural, and architectural sites, particularly those that can be restored to their original uses. It reveals that if authorities' competence is obtained and well supported, then any architect can explore alternative architectural solutions according to occupants' concerns through adaptive reuse.

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Disclosure statement

The author declares no conflict of interest.

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Discussion on Structural Health Monitoring of Urban Underground Road Tunnel

Yike Wei*

China Merchants Chongqing Highway Engineering Testing Center Co., Ltd., Chongqing 400067, China

***Corresponding author:** Yike Wei, 258522747@qq.com

Abstract: The number of urban underground road tunnels in China is increasing year by year, and health monitoring of tunnels is an effective management method to ensure their structural integrity. However, for shorter underground road tunnel projects, insufficient investment often leads to less frequent application of health monitoring systems. The application of intelligent structural health monitoring means can not only reduce the project cost but also help workers fully understand the actual situation of the tunnel structure. Therefore, this paper analyzes the characteristics, problems, and design of the urban underground road tunnel structural health monitoring system, and discusses the implementation of the urban underground road tunnel structural health monitoring system.

Keywords: Urban underground road; Tunnel structure; Health monitoring

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1. Introduction

With China's accelerated urbanization process, there is a significant increase in population and motor vehicles, bringing greater pressure on urban road transport. Among them, the more common problems include environmental pollution, traffic jams, etc., especially in the core urban areas. In order to effectively solve these problems, it is necessary to continuously strengthen the development of underground space and increase underground roads and underground buildings, so as to alleviate urban traffic congestion. The ages of various types of tunnels vary, and in the process of long-term underground operation, problems such as insufficient maintenance and construction defects have gradually become prominent. These problems can lead to structural deformation of underground road tunnels under the combined effect of external factors, which brings potential safety risks and seriously hampers the normal operation of the tunnels. For this reason, it is necessary to strengthen the safety monitoring of tunnels during construction and operation, and constantly pay attention to their operating status.

2. Technical characteristics of structural health monitoring of urban underground road tunnels

2.1. Continuity of monitoring process

Operation and construction are two important phases in the structural health monitoring of urban underground road tunnels, and the monitoring of the construction phase can ensure the safety of engineering construction and provide feedback on the construction situation. The health monitoring of the operation phase can effectively ensure that the tunnel can safely carry out the relevant operation work. The construction of underground road tunnels destroys the equilibrium of the original stratum, and a new equilibrium can be formed through the operation phase, with a certain continuity between these two phases in the actual application process. Therefore, only by strengthening the understanding of the construction and operation phases of the tunnel structure, can the health monitoring system be continuously optimized and improved [1].

2.2. Complexity of tunnel structure

Segment structure is the main force in tunnels. The mechanical response of tunnel structure can be produced by the joint action of stratum structure and segment structure. There are many external factors of force, and the effect and influence of each factor differ. Compared with structures with strong loading capacity such as ground bridges and other large buildings, tunnel structures need to pass through the ground to map the external loads to the tube sheet structure. Therefore, the influence of external loads on tunnel structures is relatively small, and the specific degree of influence and influencing factors need to be studied and explored in depth.

2.3. Durability of monitoring elements

As the outer side of the tunnel structure is a stratum, most of the monitoring elements need to be pre-buried, which requires continuous strengthening of the quality and durability of the monitoring elements. Due to the special environment of tunnel construction, it is necessary to fully consider its durability in wet environments while meeting the basic principles. Therefore, fiber grating sensors can be used to obtain relevant information; this sensor has strong corrosion resistance, small signal attenuation, and strong anti-electromagnetic interference performance, so it is widely used in tunnel monitoring systems [2].

3. Issues in the structural health monitoring system of urban underground road tunnels

3.1. Selection of sensor

In the underground road tunnel structure, multiple sensors will be buried in each section; when selecting the sensors, the sensors with automatic identification numbers should be used to improve the safety and reliability of the wiring work. For example, MEMS sensor has the advantages of low power consumption, small size, convenient deployment, etc., and has been rapidly developed through comparisons and tests before application. In addition, it is necessary to understand the specific conditions and factors in the construction process, so as to clarify the range of the sensor. For instance, the grouting link in the construction process will have an impact on the stress of the segment reinforcement, and the influence of different positions is also different, thus is affected by factors such as assembly stress and jacking force. Some underground road tunnels with large internal diameters should be strengthened in the actual construction and application process to pay more attention to their internal structure, so as to minimize the impact on tunnel safety and quality.

3.2. Selection of monitoring location and content

When choosing the monitoring content, the external water and land pressure can directly affect the deformation and force situation of the building. Settlement data and structural deformation are important factors in determining the safety and practicality of the structure, while the grouting pressure and assembling stress during the construction process will have a direct impact on the structural internal force of the tunnel, thus it is necessary to monitor the structural deformation, structural internal force, etc., as the main monitoring content [3].

When choosing the monitoring location, it is necessary to take into account the surrounding situation and actual conditions of the tunnel, and further screen the deepest and shallowest part of the tunnel, the place where the quality of construction is insufficient, and the place where the condition of the stratum has changed. Since quality problems occurring in tunnel construction are unavoidable and unpredictable, it is necessary to pay sufficient attention and concern to them. In addition, in order to facilitate the analysis and verification of monitoring data, the monitoring objects should be placed in the same or similar sections as far as possible.

3.3. Data synthesis and integration

A large amount of monitoring data is obtained through manual monitoring, automatic monitoring, and geological monitoring of the tunnel structure, which is used to determine the actual health status of the tunnel structure. For example, during the construction of underground road tunnels, quality issues or leakage of tube sheets are highly likely to occur during construction. Therefore, the tunnel structural health monitoring system is not a stand-alone system, but rather, information and data should be accumulated at the beginning of the construction work. In the construction of a tunnel project, data such as construction monitoring and quality are uniformly managed through digital technology, and data such as design and construction are effectively integrated, so as to provide a good platform for data integration of the health monitoring system [4].

3.4. Visualization of health monitoring

Typically, operation managers carry out management after the completion of the tunnel, but due to a lack of strong professional skills, they are not familiar with and do not fully understand the design and construction of the project. Therefore, the application of the health monitoring visualization platform needs to be as intuitive as possible in the management process, simple in presenting the required content, and monitor the data through the three-dimensional view and two-dimensional plan, etc., for better observation and analysis.

3.5. Structural health assessment

Health assessment of the tunnel structure can provide an important reference for maintenance work and programs. In the comprehensive evaluation of a particular structure, applying clearer mechanical concepts enhances the precision of the assessment. The results are highly targeted, fully reflecting issues such as water leakage and structural deformation. Through the comprehensive analysis and evaluation of the geological conditions of the tunnel, the overall state of the entire structure can be derived, and according to the specific conditions of underground tunnels, the pre-buried depth is divided and evaluated to better carry out maintenance and repair work [5].

4. Design of urban underground road tunnel structural health monitoring system

4.1. Architecture of the system

The data layer, interface layer, business layer, and presentation layer together constitute the system design architecture. Among them, the main function and role of the presentation layer is to strengthen the interaction between users and the system through the visualization pane, which can also improve the system's risk resistance and reduce communication costs [6]. While there are more functional services in the business layer, its most critical role is to communicate and connect instructions. The interface layer provides effective access to the relevant data in the read/write persistence container in order to achieve the separation of method and business. The data layer is mainly used to store computer-aided design drawings, data files, etc., so as to achieve the separation of program and data [7].

4.2. General framework of the system

The system mainly consists of several modules: the first module is collecting data. After the typical monitoring items and locations are clarified, the dynamic response of the tunnel structure is tested and collected by sensing devices. The second module is remote monitoring. The information monitored by the sensors on each section is transmitted to the remote monitoring unit through the content, and the data are organized and transmitted [8]. The third module is data transmission. Due to the complex environment of underground road tunnels, a wired connection is the main contact between various devices during the construction process. As the communication distance between the sensor network and the remote monitoring unit is close, and the external interference is small, it can be directly connected through the cable. Since the central control room and remote monitoring unit are mainly connected through the alignment channel, which often contains high-voltage lines, fiber optic transmission can be applied to minimize signal interference effectively [9].

5. Implementation of structural health monitoring system for urban underground road tunnels

5.1. Monitoring section

Based on the actual design and survey data of the line, the left and right sections traverse a deep ravine approximately 60 meters in depth and 300 meters in width. The surrounding rock mainly consists of siltstone and heavily weathered sandstone, with the section located at the boundary between these two materials, classified as Class V surrounding rock. Given the high degree of fracturing in the rock mass, an overrun small conduit support system has been applied, which is suitable for such conditions. Considering the tunnel's geomorphology, geology, and support method, the section with the poorest overall condition on both the left and right lines of Chang'an has been identified as particularly prone to safety risks. To address this, it is crucial to establish a structural health monitoring system in this section to ensure effective monitoring and safety management.

Therefore, this paper focuses on a tunnel structure as the main research object, with particular emphasis on the stress state and deformation level, which are key factors in tunnel deformation and collapse. To address these issues, structural health monitoring is applied during the tunnel's operational phase, with special attention given to deformation values and concrete strain measurements. Critical monitoring parameters include the stress of the second-lining concrete and the stress of the second-lining reinforcement. In the monitoring process, 10 concrete strain gauges and 10 rebar stress gauges are installed in the designated monitoring section, while a convergence monitor is placed on the surface of the lining structure to ensure comprehensive structural monitoring. Vibrating wire strain sensors are selected based on monitoring requirements and actual working conditions, and welded to the specified points. Additionally, laser sensors are organized into a network.

Remote monitoring equipment is deployed at each observation point to collect and manage data, ensuring both authenticity and reliability [10].

5.2. Health status evaluation

The health status evaluation system for urban underground road tunnel structures is complex, primarily utilizing fuzzy theory and hierarchical analysis. This approach allows the evaluation system to effectively combine both manual and automatic monitoring methods. By doing so, the system facilitates a detailed analysis of the tunnel structure's health while enabling the transmission of relevant data and reports for continuous monitoring and assessment.

Currently, certain underground road tunnel structures have gradually unified structural thresholds and monitoring indicators. For example, the monitoring and warning indicator system used in the "yellow tunnel" can be effectively applied [11]. Additionally, health diagnostic index systems for some underground road tunnel structures have been established, allowing for the quantification of health status diagnostic indicators. This process helps clarify relevant diagnostic indicators and characteristics, while also improving the overall evaluation standards for tunnel health monitoring.

According to the five-level classification method, tunnel structures are categorized into five grades: A, B, C, D, and E. Level A indicates an "intact" structure, Level B signifies "slight" damage, Level C represents "more serious" damage, Level D denotes "serious" damage, and Level E reflects "extremely serious" conditions. The health condition and classification of the tunnel structure are determined based on load capacity, allowable deformation range, and artificial monitoring indicators such as engineering reinforcement stress and lining deformation. Additionally, the strain safety level is classified based on the strength of the second lining concrete and reinforcement stress, which is also divided into five levels. The strength of Level A is lower than 70%, the strength of Level B is between 70% and 80%, the strength of Level C is between 80% and 90%, the strength of Level D is between 90% and 100%, and the strength of Level E is more than 100%. Based on relevant standards and regulations, the deformation health level of the tunnel structure section can be determined. The system provides real-time warnings and monitoring for all structural elements, with warnings initiated from Level C. These include both auditory and visual (color) warnings, particularly for critical tunnel structures. This process ensures a comprehensive evaluation of the tunnel's health and generates corresponding health evaluation reports.

6. Conclusion

In summary, when analyzing and discussing the structural health monitoring of urban underground road tunnels, it is essential to establish health evaluation standards that align with the actual load-bearing conditions of the tunnel structure. This paper provided a detailed analysis of key elements within the structural health monitoring system, including the selection of sensors, monitoring positions, and content, as well as the comprehensive integration and visualization of data for health detection and structural evaluation. Additionally, the paper designed the structural health monitoring system's architecture and general framework, focusing on the application of the system in monitoring sections and evaluating the structural health of urban underground road tunnels. This approach ensures that the safety of the tunnel structure is maintained, and effective health monitoring can be conducted to prevent structural failures and ensure operational security.

Disclosure statement

The author declares no conflict of interest.

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Digital Application Objectives and Benefit Analysis of BIM Technology in Large-Scale Comprehensive Development Projects

Chunhui Yang*

School of Civil Engineering, Guangxi Polytechnic of Construction, Nanning 530007, Guangxi Zhuang Autonomous Region, China

Corresponding author: Chunhui Yang, 457706006@qq.com

Abstract: This paper discusses the digital application and benefit analysis of building information model (BIM) technology in the large-scale comprehensive development project of the Guangxi headquarters base. The project covers a total area of 92,100 square meters, with a total construction area of 379,700 square meters, including a variety of architectural forms. Through three-dimensional modeling and simulation analysis, BIM technology significantly enhances the design quality and efficiency, shortens the design cycle by about 20%, and promotes the collaboration and integration of project management, improving the management efficiency by about 25%. During the construction phase, the collision detection and four-dimensional visual management functions of BIM technology have improved construction efficiency by about 15% and saved the cost by about 10%. In addition, BIM technology has promoted green building and sustainable development, achieved the dual improvement of technical and economic indicators and social and economic benefits, set an example for enterprises in digital transformation, and opened up new market businesses.

Keywords: Building information model technology; Large-scale comprehensive development; Digital application; Benefit analysis

Online publication: November 1, 2024

1. Introduction

The rapid development of the construction industry and the increasing number of large-scale comprehensive development projects put forward higher requirements for a refined and intelligent level of design, construction, and management [1]. In this context, building information model (BIM) technology, with its powerful three-dimensional modeling, simulation analysis, and information integration capabilities, has gradually become a key technical means in large-scale comprehensive development projects. This paper aims to explore the digital application of BIM technology in large-scale integrated development projects and the significant benefits it brings.

As a typical case of this study, the large-scale comprehensive development project of the Guangxi headquarters base integrates residential, office, education, and other multiple functions, and is characterized by diverse architectural forms, numerous single buildings, and complex functional layouts. Faced with such a huge engineering project, the traditional design and management methods have made it difficult to meet the needs of efficient, accurate, and collaborative [2]. Therefore, the project team decided to introduce BIM technology to realize the comprehensive optimization of design, construction, and management through its three-dimensional visualization, collision detection, construction simulation, and other functions.

This paper first introduces the specific application objectives of BIM technology in the project, including enhancing the design quality and efficiency, promoting the coordination and integration of project management, promoting green building and sustainable development, and realizing the fine management of the construction process [3,4]. Subsequently, combined with the implementation effect of the project, the specific benefits brought by BIM technology were deeply analyzed from the two dimensions of technical and economic indicators and social and economic benefits [5]. The digital application of BIM technology in large-scale comprehensive development projects can not only effectively improve the design, construction, and management level of the project, but also bring significant economic and social benefits. The research results of this paper are of great significance for promoting the wide application of BIM technology in the construction industry.

2. Project introduction

This project is located in the Guangxi headquarters base, which is a large and multi-functional comprehensive development and construction project, aiming to build a modern community integrating residential, office, and educational functions. The project covers a total area of 92,100 square meters, with a total construction scale of 379,700 square meters, including 23 independent buildings. The renderings of the project (**Figure 1**), the design, and the planning depth reflect the accurate grasp and unique insight of the concept of the modern urban complex. As the digital cornerstone of project design, BIM technology not only transforms this grand idea into a concrete scheme that can be implemented but also accurately captures and reproduces every detail of the design renderings through its three-dimensional modeling and in-depth simulation analysis technology. On this basis, the BIM model also integrates rich data elements and interactive functions to further enhance the depth and breadth of the design. In addition, the advanced collision detection and optimization design capabilities of the BIM model can effectively identify and solve potential design conflicts and construction problems at the initial stage of the project, laying a solid foundation for the smooth progress of the project. The remarkable feature of the project is the diversity of its architectural forms, covering high-rise residential buildings, office buildings with advanced frame-core tube structures, as well as service centers and commercial facilities carefully built using frame structures. These diverse buildings not only add vitality to the regional skyline but also jointly weave a fully functional and modern comprehensive development area.

Figure 1. Office building renderings

3. Application objectives of BIM digital technology

3.1. Enhancing the design quality and efficiency

In the design stage of building engineering, the three-dimensional visualization characteristics of BIM technology are fully utilized to realize the deep optimization of the building scheme. By building accurate BIM models, the design team is able to visually present design ideas, improve design accuracy, and identify and solve potential design problems at early stages, thus significantly reducing the frequency of later design changes. This process not only shortens the design cycle, but also improves the quality and practicability of the design results, and realizes the double improvement of the design efficiency and quality.

3.2. Promoting the collaboration and integration of project management

As a key tool for project management, BIM technology has effectively promoted information sharing and efficient communication between different stages and participating units. Through the BIM platform, the project team can access and integrate the project data in real time to ensure the accuracy and consistency of the information. This management mode of coordination and integration enhances the timeliness and scientificity of project decision-making, improves the overall execution efficiency, and provides a strong guarantee for the smooth progress of the project.

3.3. Promoting green building and sustainable development

In the background of green building and ecological construction, BIM technology plays an irreplaceable role. The BIM model can accurately simulate the performance of buildings under different environmental conditions, such as energy consumption, lighting, ventilation, etc., providing a scientific basis for green building design. In addition, BIM technology also promotes the rational selection and recycling of building materials and reduces the impact of buildings on the environment. Therefore, the application of BIM technology is helpful in promoting the construction industry in the direction of more energy saving, environmental protection, and sustainable development.

3.4. Realizing the fine management of the construction process

During the construction stage, BIM technology provides strong technical support for fine management. Through the collision detection function, BIM can identify and solve the potential conflicts between design and construction in advance, and reduce the site changes and rework phenomenon. At the same time, the construction scheme simulation and the four-dimensional visual management of the construction progress enable the project team to intuitively understand the construction process and progress, and optimize the resource allocation and construction plan. The implementation of these measures not only improves construction efficiency and safety but also effectively reduces construction costs and improves the overall economic benefits of the project.

4. Implementation effect

4.1. Technical and economic target

4.1.1. Design efficiency and quality improvement

Through the application of BIM technology, the efficiency of the project design stage is significantly improved. The three-dimensional visualization feature of the BIM model enables the design team to intuitively show the design idea, discover and solve potential design problems in time, reduce the number of design changes, and shorten the design cycle by about 20%. The design quality has also been significantly improved. The precise modeling and simulation analysis function of the BIM model ensures the feasibility and practicability of the design scheme, reduces the rework and material waste caused by design errors, and improves the overall economic benefit of the project.

4.1.2. Construction efficiency and cost saving

During the construction stage, the collision detection function of BIM technology identifies and solves the potential conflicts in the construction in advance, reduces the on-site changes and rework phenomenon, and improves construction efficiency by about 15%. Through the construction simulation and four-dimensional visual management of the BIM model, the resource allocation and construction plan are optimized, the construction cost is effectively controlled, and the total construction cost is saved by about 10%.

4.1.3. Improved management efficiency

The BIM platform promotes information sharing and efficient communication between different participating units at different stages of the project and improves the coordination and integration of project management. Project decisions were more timely and scientific, and the overall execution efficiency was improved by about 25%.

4.2. Socioeconomic performance

4.2.1. Promoting the digital design level of enterprises

The application of BIM technology has significantly improved the level of digital design of enterprises, making the design process more refined and efficient. Through the BIM model, the seamless connection from conceptual design to construction management, and the practicability and feasibility of the design results are greatly improved.

4.2.2. Enhancing the core competitiveness of enterprises

Mastering BIM technology significantly enhances the core competitiveness of enterprises in the construction industry. Enterprises can undertake more complex and more difficult engineering projects, and show higher professionalism and innovation in the design and construction management.

4.2.3. Improving the social influence of enterprises

Through the successful application of BIM technology in this project, the enterprise has set up a model of digital transformation in the industry and attracted the attention and learning of many peers. The brand image and social influence of the enterprise have been significantly improved.

4.2.4. Developing new market business

The application of BIM technology opens up new markets for enterprises. With the advantages and experience in BIM technology, the company has successfully undertaken a number of engineering projects of similar scale, which has further consolidated the market position and expanded its business scope.

5. Conclusion

This study deeply analyzed the digital application and benefits of BIM technology in the large-scale comprehensive development projects of the Guangxi headquarters base. Through the three-dimensional modeling, simulation analysis, collision detection, and four-dimensional visualization functions of BIM technology, the design efficiency and quality of the project are significantly improved, the design cycle is shortened, and the design changes are reduced. In the construction stage, BIM technology effectively reduces site change and rework, improves construction efficiency, and saves costs. At the same time, the BIM platform promotes the collaboration and integration of project management and enhances the scientific and timeliness of decision-making. In addition, the application of BIM technology also promotes green building and sustainable development and improves the digital design level and core competitiveness of enterprises. The digital application of BIM technology in large-scale comprehensive development projects has brought significant technical, economic, and social benefits, and is an important trend in the future development of the construction industry.

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Research on Intelligent Cost Estimation of Engineering Foundation Projects Based on CSIs Theory

Jie Di[1,2], Wenhao Xing[2,3], Meng Wu[4], Dan Zhang[2,5]*, Jiashuo Zhao[6]

[1]Shijiazhuang Highway Construction and Development Center, Shijiazhuang 050019, Hebei Province, China
[2]Shijiazhuang Tiedao University, Shijiazhuang 050043, Hebei Province, China
[3]Information Department of Hebei Airlines Co., Ltd., Shijiazhuang 050802, Hebei Province, China
[4]Sifang College, Shijiazhuang Tiedao University, Shijiazhuang 051133, Hebei Province, China
[5]Huaxin College, Hebei University of Geosciences, Shijiazhuang 050702, Hebei Province, China
[6]School of Civil Engineering and Transportation, Northeast Forestry University, Harbin 150006, Heilongjiang Province, China
***Corresponding author:** Dan Zhang, 415751351@qq.com

Abstract: Against the backdrop of rapid development in China's construction and infrastructure sectors, discrepancies between project budgets and actual costs have become pronounced, manifesting in project overruns and suspensions, posing significant challenges. To address inaccuracies in investment targets and operational complexities, this study focuses on a beam-bridge construction project in a district of Shijiazhuang city as a case study. Drawing upon historical analogs, the project employs a Work Breakdown Structure (WBS) to decompose the engineering works. Building on theories of Cost Significant (CS) and Whole Life Costing (WLC), the study constructs Cost Significant Items (CSIs) and develops a CNN-BiLSTM-Attention neural network for nonlinear prediction. By identifying significant cost drivers in engineering projects, this paper presents a streamlined cost estimation method that significantly reduces computational burdens, simplifies data collection processes, and optimizes data analysis and forecasting, thereby enhancing prediction accuracy. Finally, validation with real-world cost fluctuation data demonstrates minor errors, meeting predictive requirements across project execution phases.

Keywords: Project management; Cost Significant Items (CSIs); Engineering costing; Intelligent estimation

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1. Research background

The entire lifecycle of engineering projects typically includes conceptual (preparation), development (construction), maintenance (updates), and termination (dismantling) phases. During this period, the Net Present Value (NPV) method aptly captures the cost scenarios across these phases, facilitating the derivation of sub-project life costs and Cost Significant Items (CSIs). CSIs, derived from the "80-20 rule," extract projects that constitute the top 20% of unit costs and contribute to 80% of the total cost, thereby reducing computational complexity and eliminating irrelevant factors. Subsequently, using a specific project cycle as an example, project components are extracted for cost analysis, focusing on core research elements and employing neural networks for cost prediction, which is crucial for analyzing the overall lifecycle costs of projects.

In related research, Duan *et al.* explored a comprehensive cost prediction method integrating CSIs, Fuzzy Inference System (FIS), and WLC, providing a model that combines multiple cost factors for forecasting [1]. Liu *et al.* studied environmental cost estimation methods for green high-speed rail construction, enhancing cost prediction accuracy through CS and Backpropagation Neural Network (BPNN) methods [2]. Duan and Xu further investigated a road engineering valuation model based on Self Organizing Map-Radial Basis Function (SOM-RBF) neural networks, demonstrating the advantages of neural networks in handling nonlinear cost data [3]. Wang *et al.* focused on a dynamic optimization control system for highway construction progress, proposing an integrated approach to project management and cost control [4]. Zhou *et al.* showcased the application of the Complete Ensemble Empirical Mode Decomposition with Adaptive Noise-Squeeze-and-Excitation-Convolutional Neural Network-Bidirectional Long Short-Term Memory (CEEMDAN-SE-CNN-BiLSTM) model in soybean futures price forecasting, offering insights into forecasting complex datasets, albeit with limited direct relevance to construction projects [5]. Zhou validated the effectiveness of quantum bee colony algorithms in Building Information Modeling (BIM) cost management [6]. Liu and Huang and Peng *et al.* demonstrated the benefits of hybrid predictive models, such as Particle Swarm Optimization-Backpropagation Neural Network (PSO-BP) and Salp Swarm Algorithm-Least Squares Support Vector Machine (SSA-LSSVM), which excel in handling complex datasets and improving prediction accuracy [7,8]. Similarly, Li and Ma successfully merged AutoRegressive Integrated Moving Average (ARIMA) with exponential smoothing techniques to speed up and refine cost prediction in construction projects [9]. Yong *et al.* explored the synergy of biogeography-based optimization with backpropagation neural networks, optimizing investment estimation for university construction projects [10]. Fan *et al.* and Liu *et al.* further pushed the boundaries by employing ensemble models that combine various algorithms, significantly improving the predictive performance in non-linear cost data scenarios [11,12]. Lastly, earlier works by Chen *et al.* and Zhang leveraged machine learning and genetic algorithms respectively, to enhance the precision and applicability of cost prediction models across different engineering projects [13, 14]. Guo *et al.* investigated the impact of foundational material projects in construction engineering on the overall project cost through urban renewal big data platforms [15].

2. Model building

2.1. Case study: extraction of CSIs

This case study focuses on the construction of a city viaduct (beam-bridge) on the northern Second Ring Road of Shijiazhuang. The total investment of this project is 264.1 million yuan, with a span of 229.7 m and 8 lanes in both directions. It includes 17 sets of bridge piers (abutments) and is a typical prestressed concrete-supported box girder structure. Based on the list of major engineering material requirements throughout its lifecycle (see **Table 2.1**) and the distribution of engineering cost CSIs (see Table **2.2**), this study extracts prefabricated component reinforcement bars as the research subject, specifically Φ25HRB400 grade steel (formerly known as grade III screw steel).

Table 2.1. List of main engineering material requirements for the whole life cycle of a bridge

ID	Lifecycle stage	Primary material(s)	Secondary material(s)	Additional equipment/tools	Remarks
I1	Design stage	Prestressed concrete beams	Test blocks, reinforcement	Model test materials	
I2	Construction stage (base, pier, superstructure)	Concrete, gravel, sand	Reinforcement, anticorrosive coating	Pile foundation machinery, molds	Waterproofing in base materials
I3	Construction stage (road surface, safety facilities)	Asphalt, safety barriers	Gravel, traffic signs	Roller, installation tools	Line marking for road surface
I4	Maintenance stage (routine and major repairs)	Inspection equipment, replacement parts	Concrete patches, bearings	Repair materials, joints	Includes anticorrosive coating
I5	Demolition/remodeling stage	Demolition machinery	Concrete, reinforcement	Cutting, recycling processing equipment	

Table 2.2. Total cost and distribution of CSIs for the beam-bridge project

Method	Total sub-projects	CSIs content	CSIs cost percentage (%)	CSIs project percentage (%)	Total cost (billion RMB/KM)
Initial cost sub-projects	13	(1) Bridge Pier Foundation Construction (2) Bridge Abutment Construction (3) Production and Installation of Prestressed Concrete Beams	82.38	19.85	1.16
WLC sub-projects	19	(1) Bridge Pier Foundation Construction (2) Bridge Abutment Construction (3) Production and Installation of Prestressed Concrete Beams (4) Reinforced Concrete Bridge Deck Construction (5) Bridge Routine Maintenance and Upkeep	86.31	17.92	1.28
Sub-Projects' WLC	26	(1) Bridge Pier Foundation Construction (2) Bridge Abutment Construction (3) Production and Installation of Prestressed Concrete Beams (4) Bridge Routine Maintenance and Upkeep	84.57	18.64	1.28

2.2. Constructing a WLCS-based database

(1) Determining discount rate: This study focuses on the quantity lists of completed highway construction projects and maintenance costs during operational phases as its research objects. Parameters necessary for cost calculation, such as discount rates, were sourced from industry websites like China Highway Network and Road Construction Cost Network. The method for determining discount rates varies widely. This study adopts a widely accepted academic approach, combining a risk-free rate of return and risk premium. The risk-free rate of return excludes risk factors from capital costs. The selection of the risk-free rate can refer to information on fixed-rate national bond yields published by "China Bond Information Network." Based on the collected research project periods, an average national bond rate of 2.47% over the entire period is selected as the risk-free rate. The risk premium is estimated using the Capital Asset Pricing Model, based on selected publicly listed highway companies in China and Hong Kong, resulting in a rate of 3.67%. The discount rate is thus the sum of these two values, 6.96%, which for convenience can be approximated as 7% for calculations.

(2) Sample selection: The urban highway viaducts primarily include foundations, piers, concrete beams,

and other components. Following international and domestic case studies, this research selects 17 similar projects to build a database, using four newly completed projects as validation samples to assess model prediction accuracy.

(3) Determining CSIs: For the sample projects, Cost Significant Items (CSIs) are calculated to determine the average per kilometer unit cost for each segment of the viaduct. Subsequently, the WLCS unit prices for each segment of the highway are compiled and compared against the average unit cost of 69 for segmental items. Segments with costs exceeding the average are identified as significant projects.

2.3. CNN-BiLSTM-Attention neural network

In handling time-series data, Convolutional Neural Networks (CNNs) demonstrate significant capabilities in feature extraction. However, CNNs have limitations in capturing long-term dependencies within time-series data. In contrast, Bidirectional Long Short-Term Memory networks (BiLSTMs) effectively address the issue of long-term dependency in time-series data. By employing forward and backward memory units, BiLSTMs capture dynamic dependencies of past and future information. By combining these networks, the CNN-BiLSTM model integrates CNN's advantages in spatial feature extraction with BiLSTM's strengths in time-series prediction, thereby significantly enhancing prediction accuracy.

However, when facing scenarios with numerous features and large datasets, the CNN-BiLSTM model may overlook critical feature information at certain key moments, thereby affecting overall learning and prediction capabilities. Introducing an Attention mechanism significantly improves upon this limitation. By assigning different weights to data from various time points, the Attention layer highlights features in the time-series that have the most significant impact on prediction results, further optimizing the model's performance and prediction accuracy. The structure of the CNN-BiLSTM-Attention neural network model is illustrated in **Figure 2.1**.

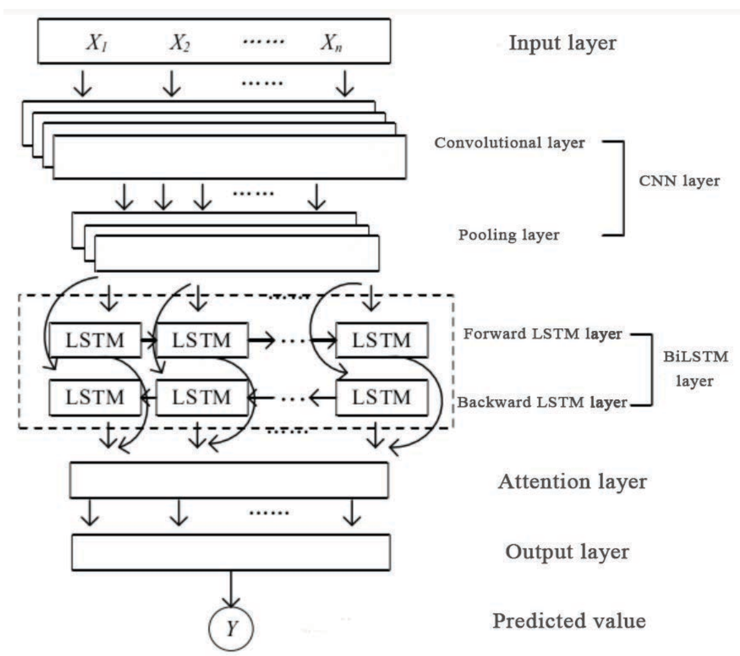


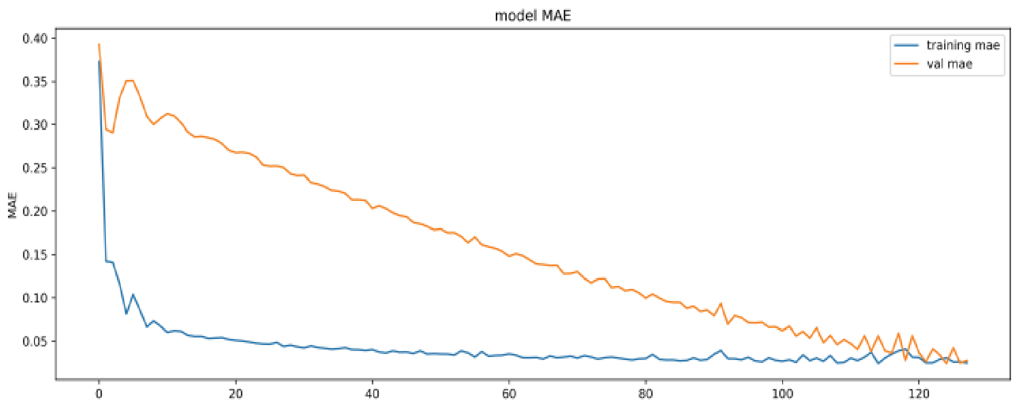
Figure 2.1. Structure of the CNN-BiLSTM-Attention neural network model

3. Model application

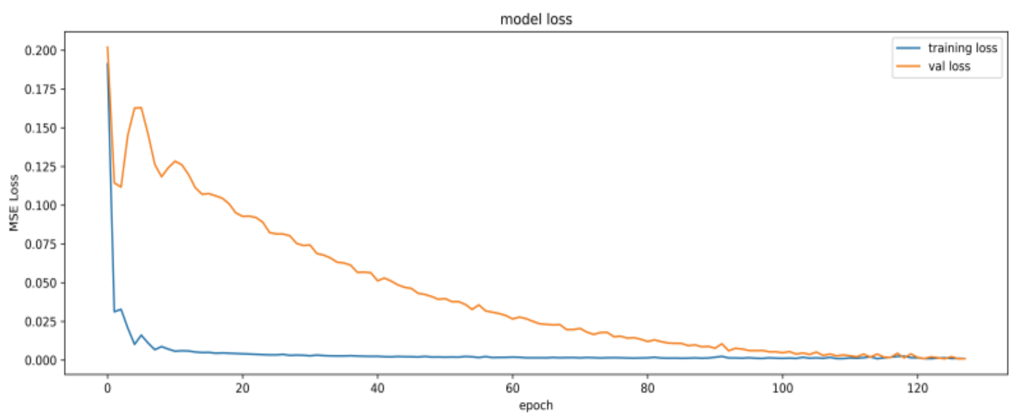
3.1. Unit price forecast

Following the extraction of prefabricated component reinforcement bar data, this study expanded its predictions by incorporating historical market prices, exchange rates, international iron prices, domestic oil and coal prices, regional GDP, and fixed investment in transportation. Daily data from 2012 to 2023 was utilized, with the model undergoing 150 iterations. The training and validation data were split in an 8:2 ratio. The training process, loss function, and prediction outcomes are depicted in **Figure 3.1**. Similarly, this approach was applied to estimate the costs of other foundational projects within the construction, enabling the derivation of stage-specific costs and overall lifecycle costs based on the CSIs principle, thereby achieving intelligent estimation.

(a) Neural network training process



(b) Model loss function



(c) Comparison of predicted and actual values

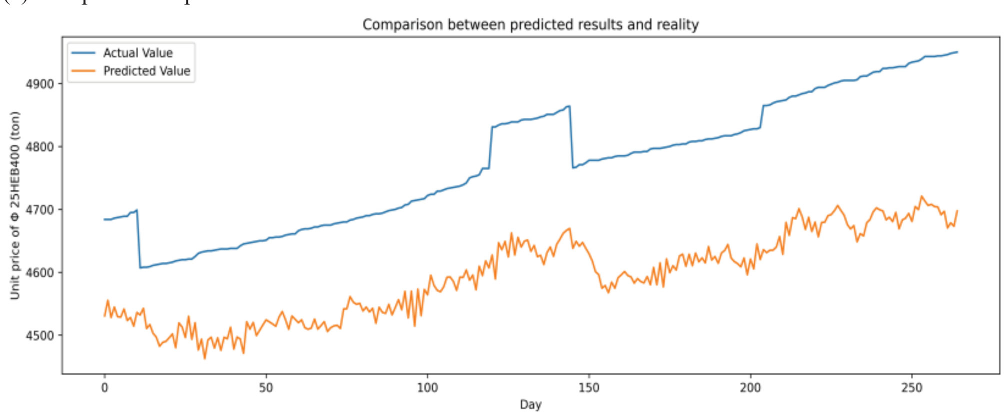


Figure 3.1. Effectiveness of Φ25HRB400 unit price prediction model

According to the unit price prediction results of Φ25HRB400, the average price error is 50 yuan (RMB), with a maximum error of 78 yuan and a minimum error of 20 yuan. The error rate is 1.1%, which meets the requirements of high-precision measurement of engineering cost in the new era and can be applied in practical engineering.

3.2. Engineering cost estimation

In the study, by referring to historical similar engineering cases and the actual design and construction of this project, the WBS-WLC-CSIs method was used to extract significant projects (including bridge pier foundation construction, bridge pier construction, production and installation of prestressed concrete beams, bridge deck laying, etc.) and conduct key material cost and demand analysis. Furthermore, based on the cost prediction of key materials (such as predicting the unit price of Φ25HRB400 and calculating demand), the proportion of significant costs, and the proportion of cost in different stages of the entire life cycle of the project, accurate and intelligent prediction of the entire life cycle cost of the project can be achieved.

In practical applications, taking the # 15, # 16, and # 17 pier (abutment) sections as an example: the span of this area is 30.5 m, and the predicted cost of each pier (including pile foundation, support system, etc.) is 3.2913 million yuan, 3.4928 million yuan, and 3.3135 million yuan, respectively. The actual cost is 3.3298 million yuan, 3.5027 million yuan, and 3.3469 million yuan, with an average prediction error of 0.77%. Within this range, the predicted cost per square meter of the bridge deck is 38,200 yuan (including prestressed box girders, bridge deck paving, drainage and waterproofing, expansion joints, asphalt, and railings, etc.). The actual cost per square meter is 38,900 yuan, with a prediction error of 0.18%. The total cost within this range is predicted to be 3.485 billion yuan, with an actual total cost of 3.497 billion yuan and a prediction error of 1.12%. The predicted total life cycle cost is 3.602 billion yuan, and the prediction error of the executed part is 1.96%.

In summary, by calculating the total cost of each sub-project (unit price multiplied by demand), and then adding up the costs of all sub-projects, the significant project cost is obtained, and the estimated total cost of the entire project is obtained. These predicted results are very close to the actual costs, with an error that meets the high-precision cost estimation requirements of engineering (< 3%), which can help project managers more effectively control costs and budget execution, and improve project management efficiency and engineering cost accuracy.

4. Conclusion

This study successfully achieved intelligent estimation of project foundational costs by integrating CSI theory with advanced neural network technology. Focused on a viaduct construction example in a specific area of Shijiazhuang, the integration of historical data and relevant economic indicators proved beneficial for accurately predicting project costs. This validation underscores the practical application value of intelligent estimation methods in construction projects. With ongoing technological advancements and richer data resources, intelligent estimation methods based on the CSIs theory hold promise for broader application, revolutionizing engineering project management by enhancing cost accuracy and efficiency. This advancement is poised to significantly propel sustainable development and innovation within the construction and infrastructure sectors.

Disclosure statement

The authors declare no conflict of interest.

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Discussion on Influencing Factors of Water Resources Environment and Strategies for Protecting Water Ecology

Wangzi Zhou[1]*, Jing Dong[2], Qianyi Zhao[1], Qianxun Li[1]

[1]Changjiang Survey, Planning, Design and Research Co., Ltd., Wuhan 430014, China
[2]Changjiang River Scientific Research Institute, Wuhan 430010, China

***Corresponding author:** Wangzi Zhou, zhouwz_work@163.com

Abstract: At present, the major problems facing the water resource environment worldwide include water pollution, water resource shortage, and water ecosystem degradation. The discharge of industrial wastewater, agricultural non-point source pollution, and the discharge of urban sewage lead to a serious decline in water quality, which directly affects the safety of human drinking water and the living environment of aquatic organisms. Additionally, the unbalanced distribution and excessive exploitation of water resources lead to the problem of water shortage in many areas, which then leads to social and economic contradictions and ecological crises. In terms of ecosystems, the phenomena of water ecological degradation and reduction of biodiversity are increasingly obvious, and the carrying capacity of aquatic ecosystems are gradually declining. This paper aims to analyze the natural, social, and economic factors affecting the water resource environment, and propose effective strategies to protect the water ecology. To provide a theoretical basis and practical guidance for the sustainable utilization of water resources and the long-term development of the water ecosystem.

Keywords: Water resources; Environmental impact; Water ecology; Protection strategy

Online publication: November 1, 2024

1. Introduction

As the basis of human survival and development, water resources are related to the stability of the ecosystem and the sustainable development of the social economy. However, with the intensification of global climate change, the acceleration of the industrialization process, and the continuous improvement of urbanization level, the water resource environment is facing more severe challenges. Especially in areas with water shortage, problems such as water pollution and ecosystem degradation have become more prominent, which seriously affects the local ecological balance and the quality of life of residents. Simultaneously, the unreasonable development and utilization of water resources also exacerbate the deterioration of the water ecological environment and threaten ecological diversity and environmental health. Therefore, it is of great practical significance to study the influencing factors of the water resource environment and propose effective protection strategies [1].

2. The importance of water ecological protection

Water ecological protection is of vital significance because it is directly related to the stability of the ecosystem and the sustainable development of human society. As an important carrier of life on the earth, the water body not only provides a living environment for living things but also participates in the process of global material cycle and energy exchange [2]. A healthy water ecosystem can maintain water purification, flood regulation, climate regulation, and play an irreplaceable role in maintaining biodiversity, improving environmental quality, and preventing natural disasters. However, with increasing human activity, aquatic ecosystems face unprecedented threats such as water pollution, ecological degradation, and destruction of aquatic habitats [3]. These problems not only affect the ecological function of water bodies but also have a direct impact on human drinking water safety, agricultural irrigation, fishery production, and other effects. By restoring and maintaining the health of the water ecological environment, water ecological protection can effectively reduce water pollution, restore the ecosystem, and promote the harmonious coexistence between man and nature. Concurrently, the protection of water ecosystems also plays an important role in coping with global climate change and preventing environmental damage caused by extreme weather events [4].

3. The influencing factors of water resources and environment

3.1. Climate change

Climate change not only affects the amount of water resources but also has an important impact on water quality. Heavy precipitation events can lead to increased surface runoff, bringing more pollutants into rivers and lakes, and thus exacerbating water pollution [5]. Under drought and high temperatures, the evaporation and concentration effect of water increases the concentration of pollutants in the water and deteriorates water quality. At the same time, climate change also harms aquatic ecosystems, and rising water temperatures may lead to the decline of aquatic biological populations, causing ecosystem imbalance [6].

3.2. Industrial and agricultural production

Industrial and agricultural production is the key factor affecting the water resources environment. With global industrialization and the scale of agricultural production, the consumption and pollution of water resources are becoming increasingly serious [7]. In the process of industrial production, a large amount of water is used for cooling, cleaning, and processing. When some of the water is discharged back to the natural environment, it often contains a large amount of harmful chemicals, such as heavy metals, waste acids, waste alkali, etc. These pollutants pose a great threat to the ecosystem of water bodies and can lead to water eutrophication, reduced biodiversity, and death of aquatic organisms. Moreover, the untreated or improperly treated sewage discharged by factories not only pollutes rivers and lakes but also pollutes groundwater resources through infiltration, which may have long-term adverse effects on agricultural water use and drinking water for residents [8].

4. Specific manifestations of water resources and environmental problems in China

4.1. Water pollution

Water pollution is mainly reflected in industrial wastewater, agricultural non-point source pollution urban sewage discharge, and other aspects. The discharge of industrial wastewater has caused serious pollution to the water environment. Many industrial enterprises in China, especially heavy industries such as chemical, steel, and textile industries, often discharge a large amount of undertreated wastewater in the production process [9]. These types of wastewater contain harmful substances such as heavy metals, ammonia nitrogen, and organic pollutants, which are directly discharged into rivers and lakes, causing deteriorating water quality. For example, in the water pollution incident of the Songhua River, the benzene pollutants discharged by a chemical plant caused a large area of water pollution, seriously affecting the safety of drinking water of residents along the river [10].

4.2. Water resource shortage

The water shortage is primarily caused by the uneven distribution of water resources, over-exploitation, and waste. The spatial distribution of water resources is extremely uneven, particularly between the north and south. Southern China experiences abundant precipitation and plentiful water resources, while northern regions face significant water shortages. For example, the Yellow River basin, an important water source in northern China, supports extensive agricultural, industrial, and domestic water needs. However, in recent years, due to water scarcity, the Yellow River has frequently experienced dry spells, especially in its downstream regions. This water shortage has severely impacted local economic development and the lives of residents [4].

4.3. Water ecological degradation

Water ecological degradation is mainly manifested by the destruction of aquatic ecosystems and the reduction of biodiversity. The destruction of aquatic ecosystems is widespread throughout the country, especially in areas where water resource development and utilization are concentrated. Engineering activities such as reservoir construction, river reconstruction, and excessive sand mining have led to a change in the natural form of rivers and destroyed the original ecological balance. For example, although the construction of the Three Gorges Dam on the Yangtze River has brought a positive effect on power generation and flood control, its impact on the downstream river ecosystem cannot be ignored. The storage and regulation of the reservoir changed the hydrological cycle of the Yangtze River and affected the habitat of aquatic organisms, especially the spawning place of fish, leading to the sharp decline of the fish population.

5. Water ecological protection strategy

5.1. Rational development and utilization of water resources

Rational development and utilization of water resources aim to minimize the negative impact on the environment and ensure the sustainable supply of water resources through scientific planning and sustainable management methods. Strengthen the planning and management of water resources development, reasonably formulate the priority of all kinds of water demand, and ensure the balance between water resources development and natural supply. In areas rich with water resources, rainwater, and floods can be stored through the construction of reservoirs and reasonable water conservancy projects to meet the needs of agricultural, industrial, and domestic water use, but the scale of development must be controlled to avoid excessive interference to the water ecosystem. In areas with water resource shortages, restrictive development measures should be taken to give priority to domestic water use and promote water-saving technologies in agriculture and industry.

5.2. Effective control of pollution sources

The effective control of pollution sources focuses on the comprehensive treatment and prevention of industrial, agricultural, and domestic pollution sources, and reduces the chance of pollutants entering water bodies. Industrial pollution is one of the main sources of pollution. To control industrial pollution needs to start from the pollution source and strengthen the supervision and environmental protection requirements of enterprises. Enterprises should strictly abide by the national discharge standards in the production process, especially for highly polluting industries, such as chemical, paper, steel, etc., and should strengthen the supervision of pollutant discharge to ensure that the wastewater is discharged after full treatment. The construction of efficient sewage treatment facilities and the implementation of clean production technology can significantly reduce the toxic and harmful substances in water bodies. For example, in chemical enterprises, advanced wastewater treatment technologies such as biological treatment and physical and chemical treatment can be used to ensure that heavy metals and organic pollutants meet the discharge standards.

5.3. Develop and optimize sewage treatment and reuse technology

Effective sewage treatment can not only reduce the pollution to water bodies but also maximize the utilization efficiency of water resources through reuse technology, to reduce the pressure on natural water bodies. Improving sewage treatment technology is the basis of optimizing sewage management. Traditional sewage treatment methods mainly include primary treatment, secondary treatment, and tertiary treatment, but with the improvement of water quality requirements and the increase of pollutant types, a single treatment method has been unable to meet the needs of modern environmental protection. Therefore, advanced wastewater treatment technologies, such as membrane bioreactor (MBR), advanced oxidation technology (AOP), and biological filters, must be introduced. By combining the membrane separation technology with the traditional activated sludge process, the membrane bioreactor can achieve more efficient sewage purification and solid-liquid separation, and the treated water quality is close to the drinking water standard. Advanced oxidation technology uses strong oxidants such as ozone and hydrogen peroxide, which can effectively remove refractory organic matter and micro-pollutants in sewage. The biological filter uses specific microbial groups to decompose pollutants, which can effectively remove nutrients such as nitrogen and phosphorus in the water and prevent water eutrophication.

6. Conclusion

Looking into the future, the protection of water resources environment and water ecological restoration will face more challenges, but it also contains new opportunities. With the acceleration of climate change and the industrialization process, the problem of water shortage and water pollution will become more and more serious, and we urgently need to adopt comprehensive solutions. Future research and practice should pay more attention to technological innovation and application, especially in the aspect of sewage treatment and reuse technology. The new treatment process and reclaimed water utilization scheme will further improve the use efficiency of water resources and reduce the pressure of water pollution. Simultaneously, the development of ecological restoration technology will make the effect of water restoration more significant. Through scientific and reasonable restoration measures, a healthy water ecosystem will be rebuilt, and biodiversity protection will be brought into the core of water resources management. Additionally, public participation and policy support will become an important force in promoting water ecological protection.

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Seismic Performance of Prefabricated Continuous Girder Bridge

Hongyuan Xiong*

China University of Geosciences (Beijing), Beijing 100083, China

***Corresponding author:** Hongyuan Xiong, zlybns@163.com

Abstract: Bearings are the weak link in the seismic design of bridges. Using a continuous girder bridge as an example, it is demonstrated that bearing damage should be considered under large earthquake conditions. The bearing, acting as a fuse-type unit, can be designed to be preferentially damaged to effectively control the displacement of the beam and the response at the base of the pier during an earthquake.

Keywords: Cable-stayed bridge; Seismic analysis; Dynamic performance; Structural design

Online publication: November 1, 2024

1. Introduction

In recent years, there have been many strong earthquakes around the world, which not only caused heavy casualties but also damaged urban infrastructure, especially bridge structures, resulting in huge property losses. The research work on the problems related to the seismic resistance of bridge structures has become particularly urgent.

2. Project overview

Using a five-span prestressed concrete continuous girder bridge as the engineering background, the span configuration is 96 + 3 × 160 + 90 m. The superstructure consists of a prestressed concrete variable-height straight web continuous girder with a single-box, single-cell section. The top plate of the box girder is 13.50 m wide, the bottom plate is 7 m wide, and the cantilever is 3.25 m wide. The beam height varies from 8.5 m at the main pier to 3.5 m at the mid-span and the ends of the side span. The substructure's main pier is a cylindrical solid pier with a cap beam, with a diameter of 5 m. The upper box girder uses C55 concrete, while the pier cap and pier body use C40 concrete.

The bridge's seismic performance was analyzed using the finite element program MIDAS Civil, which was used to create a 3D model of the entire bridge. The analysis focused on the effects of bearing damage and the nonlinearity of the limit device on the elastic-plastic seismic response. A comprehensive element hysteresis curve model, considering bearing damage, contact with the limit device, and material nonlinearity, was proposed. It was found that when the movable support loses its sliding capacity (due to damage and contact with the limiting device), it not only restricts the displacement of the beam but also effectively reduces the seismic response at the fixed pier.

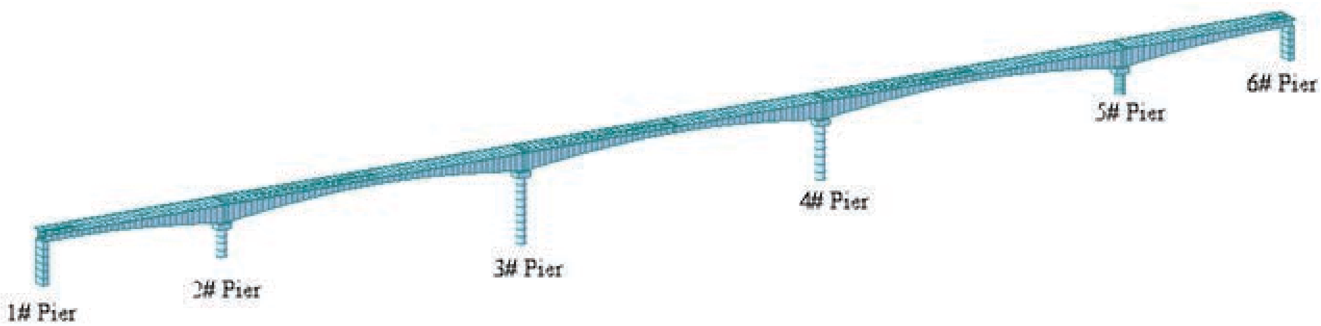

Figure 1. Structural calculation finite element model

3. Structural finite element modeling

In the calculation and analysis, the interaction between the foundation, the pile foundation, and the pile-soil structure is not considered. The pier base is assumed to be fixed to the ground, and a limit device is applied to simulate the bearing damage (see **Table 1**) [1]. The piers are modeled using nonlinear elastic-plastic elements, and the nonlinear deformation behavior follows the Modified Takeda model (Modified Takeda Type). The piers have a circular cross-sectional design. To simplify the analysis, the effects of collision forces are omitted in the finite element model. The limit devices are arranged along the transverse direction of the bridge, and the study focuses solely on the seismic response in this direction.

Table 1. Bridge model boundary conditions

Location	DX	DY	DZ	RX	RY	RZ
Pier 1#	1	1	1	1	1	1
Pier 2#	1	1	1	1	1	1
Pier 3#	1	1	1	1	1	1
Pier 4#	1	1	1	1	1	1
Left end of beam	0	1	1	1	0	1
Right end of beam	0	1	1	1	0	1

Note: "0" represents free, "1" represents a constraint

Following the establishment of the finite element model for the continuous girder bridge, various seismic analysis cases are considered to assess the bridge's response under different assumptions. These cases explore the influence of support friction, limit device behavior, and nonlinear effects, as outlined below:

(1) Case 1: Pier elastoplastic scheme – In this scenario, friction at the support is ignored, and the analysis focuses on the elastoplastic behavior of the piers, which is a standard approach for continuous girder bridges in elastoplastic seismic analysis [2].
(2) Case 2: Support friction scheme – This case considers the friction of the active support, but the limit device's role is not included. The support is modeled as an ideal elastoplastic element, with a friction coefficient of μd = 0.02, a yield displacement of xy = 0.005, and zero stiffness after the support slides.
(3) Case 3: Elastic limit device scheme – In this case, after the support slides a certain distance, the limit device restricts further sliding, assuming no failure of the limit device (elastic behavior). The initial displacement of the support's limit device is set at 0.1 m.
(4) Case 4: Nonlinear limit device scheme – This scenario accounts for the limit device entering a plastic state or the support undergoing shear failure. The nonlinear behavior is introduced by adjusting the critical yield force and stiffness of the limit device in the model.

4. Model of the movable support unit of the finite device

Under seismic action, the movement range of the support with the limit device is restricted. When the longitudinal deformation of the girder bridge becomes significant, it may lead to collision contact issues. This can cause connecting components, such as the support and limit device between the main girder and the substructure pier, to enter a nonlinear state. This process can be described in the following five points:

(1) The movable support does not begin to slide; it remains in an elastic state, and the bridge pier is elastically connected to the main beam [3].
(2) The movable support starts to slide, but its stiffness is negligible, leading to only friction acting between the pier and the main beam.
(3) When the displacement reaches a certain threshold, the movable support continues to slide, activating the limit device. At this point, the bridge pier and the main beam are connected through the limit device, and the transmitted force is the sum of the friction force from the movable support and the force exerted by the limit device.
(4) As the movable support slides further, the limit device enters a nonlinear state, and the transmitted force remains the sum of the friction force of the movable support and the force of the limit device.
(5) The main beam shifts in the opposite direction, resulting in unloading.

A sliding friction element (ideal elastic-plastic model) simulates the movable support. Additionally, a bearing element is established to consider both the friction of the bearing and the dual nonlinear effects of the limit device, in accordance with the characteristics of the sliding friction and collision contact elements [4].

5. Dynamic characteristics calculation and analysis

Select the El Centro wave (peak acceleration 0.3569 g, duration 53.72 s) and apply a factor of two to simulate large earthquake conditions. Input the combination of horizontal + vertical (2/3) and vertical + vertical (2/3) combinations of the earthquake. By calculating the dynamic characteristics of the bridge, as shown in **Figure 2** and **Figure 3**:

(1) When Scheme 1 is adopted, the bending moment and curvature at the bottom of each bridge pier are the largest, entering a fully plastic state, which significantly increases the likelihood of damage. In contrast,

when Scheme 2 is adopted, the bending moment and curvature at each pier bottom are the smallest.

(2) In Scheme 3, when considering the friction of movable supports and the elastic effect of the limit device, the bending moment and curvature at each pier bottom are compared with Schemes 2 and 4, revealing significant changes in the internal forces of movable piers 2# and 5#.

(3) In Scheme 4, while considering the friction of movable supports and the nonlinear effect of the limit device, the section bending moment and curvature at the bottom of each pier are reduced compared to Scheme 3. However, the curvature of the plastic middle movable pier bottom hardly changes, while the curvature of the fixed pier bottom decreases by 22.8%, indicating a significant reduction. This demonstrates that when the limit device enters a nonlinear state, more ground motion energy is dissipated, effectively reducing the seismic response at the fixed pier bottom.

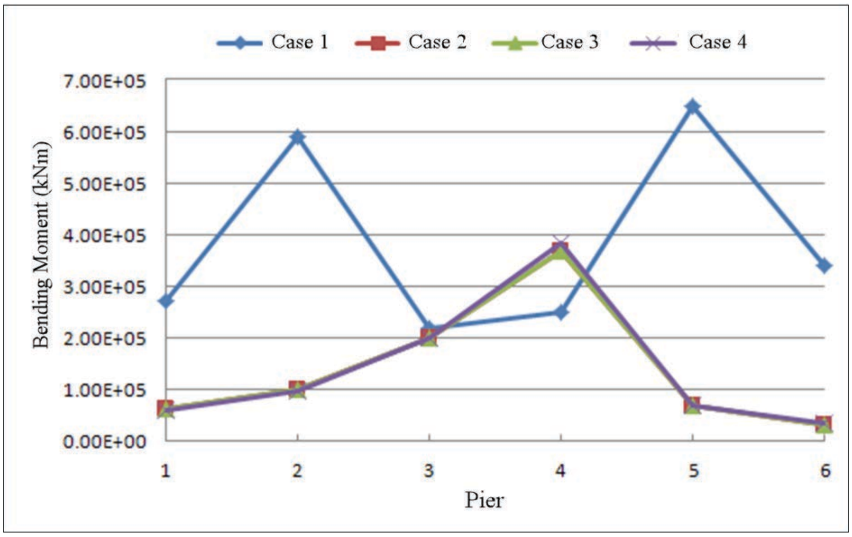

Figure 2. The bending moment at the pier bottom in longitudinal and vertical ground motion

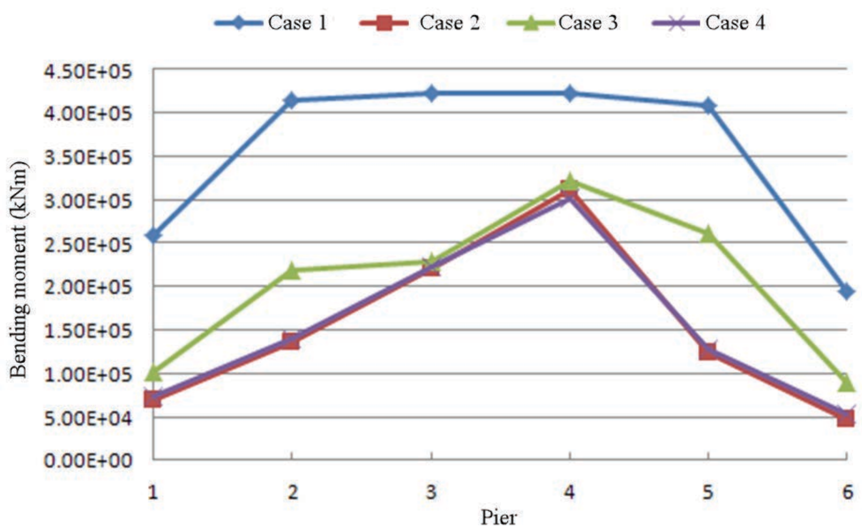

Figure 3. The bending moment at the pier bottom in horizontal and vertical ground motion

6. Conclusion

In this paper, a finite element model is established for the overall calculation of the bridge, considering the elastoplasticity of the bearing, the limit device, and the pier body, and a seismic response analysis is carried out. The results show that:

(1) Under large earthquake conditions, when the movable bearing loses its sliding performance, it is highly likely to cause damage to the bridge pier. Therefore, it is necessary to configure a certain amount of steel reinforcement in the bridge pier to ensure its ductility.

(2) The use of limit devices can effectively limit the displacement of the beam body, reduce the seismic response of the fixed piers, and simultaneously balance the distributed seismic force among the piers.

(3) When the movable support loses its sliding performance and comes into contact with the limit device, it can not only limit the displacement of the beam body but also effectively reduce the seismic response of the fixed pier.

(4) For different bridge structures, by adjusting the initial distance between the limit device and the movable support, as well as modifying the stiffness and yield strength of the limit device, and the friction coefficient and stiffness of the support, it is possible to effectively prevent excessive structural displacement. This approach aims to reduce the seismic response of the fixed piers and achieve a balanced distribution of the input energy from ground motion among the piers.

Disclosure statement

The author declares no conflict of interest.

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Research on Landscape Design of Waterfront Public Space in Mountainous Cities Based on User Experience — Taking the Waterfront Landscape Design of Art Peninsula in Chongqing as an Example

Haiyan Tang*, **Miaoqing Zhang**

Chongqing Institute of Engineering, Chongqing 400056, China

***Corresponding author:** Haiyan Tang, tanghaiyanxinxin@126.com

Abstract: Mountainous cities are dominated by mountainous, hilly, and steep terrain, which brings certain complexity and particularity to the planning and construction of waterfront spaces in these cities compared to plain cities. Waterfront spaces, often serving as the core areas of city development, possess favorable location advantages and special attributes of water-land intersection, giving them more possibilities for functional transformation [1]. However, the ultimate goal of design is to provide users with a vibrant waterfront area. The design of waterfront spaces should focus more on people's behavioral needs, allowing users to feel a good interaction between the place and their behavioral needs during space usage [2]. Therefore, the design incorporates human environmental behavior, increases interactive experiences, and enriches spatial interest.

Keywords: User experience; Interaction; Waterfront landscape design

Online publication: November 1, 2024

1. Introduction

The concept of user experience was introduced to China around the year 2000 and gradually developed in 2008. In recent years, due to the rapid development of the Chinese market and the rapid growth of mobile internet, user experience has penetrated into people's daily lives, especially in network products. When focusing on the research of landscape facilities, public spaces, and landscape environmental experience design, user experience is mainly manifested in experiential design in landscape design.

2. Interactive experience between humans and space

The transportation hub pocket park at the intersection of Hanjiang North Road and Xinhua Road in Wuhan creates various spaces with different functional categories to facilitate social activities between individuals and teams, promote interactive experiences between people, plants, and objects, and enhance people's experience. Designers adopt visual experience design and behavioral experience design to promote sensory and behavioral experiences among people. The space is divided into three parts, distinguished by step heights, creating a stepped space that forms a progressive feeling and stimulates people's curiosity to explore [3]. The use of circular seating provides a sense of privacy, creating a relatively quiet resting space that can accommodate people's long-term stays. The park's lighting system reduces energy consumption and improves the pedestrian experience through light-sensing and pedestrian-sensing street lights. Regular horticultural activities are held in the park, which not only increase participation but also allow people to learn about horticultural appreciation and professional knowledge. People can prune flowers and trees, plant flowers and water, and fertilize them according to their preferences, turning them into artworks and stimulating their creative passion. When touching plants and flowers, people can get the most direct sensations, as different plants have varying textures and smoothness, providing diverse stimuli to humans (**Figure 1**).

Figure 1. Wuhan Pocket Park

3. Interactive experience between people and facilities

In 2013, Italian designer Dario Pompei completed the Italian Interactive Forest project in degli Angeli Square. In this landscape, when visitors walk through the interactive forest composed of more than 100 synthetic Information Technology (IT) trees. Each IT tree is equipped with an ultrasonic proximity sensor to detect changes in human position. These sensors transmit information to the control center of the lighting system through an open-source microprocessor, where a computer controls the brightness of the lights [4]. Whenever a visitor passes by, it triggers the IT trees to illuminate the path, and the more active the visitors are, the stronger the IT trees' response [5]. The area has become a prominent space due to the Italian Interactive Forest, which responds to the movement of people passing through. The designer indicates that such an experience can evoke locals' association with participating in the protection of the local Lake Vico (**Figure 2**) [6].

Figure 2. Glowing IT trees

4. Interactive experience between people and themed areas

The Marina Bay Sands in Singapore is a masterfully designed project by the world-renowned architect Moshe Safdie. Covering a vast area of 101 hectares, it has become one of the largest city gardens in the world. Upon entering Marina Bay Sands, visitors are immediately captivated by the diverse plants and flowers. Here, rare species from around the globe are displayed in their most pristine and beautiful forms, thanks to the ingenious arrangements of the designers. Wandering through the garden feels like being immersed in a colorful natural world, providing a sense of tranquility and relaxation. Moreover, Marina Bay Sands seamlessly integrates multiple themed areas such as the mysterious Cloud Forest, the enchanting Flower Dome, and the majestic Super Trees. Each area offers unique landscape designs and interactive experiences, allowing visitors to appreciate the beauty while also experiencing the charm of different regions (**Figure 3**) [7].

Figure 3. Marina Bay Sands Garden Park, Singapore

5. Analysis of the waterfront landscape design proposal for the Art Peninsula in Chongqing

During the design process, by studying the concept of "user experience" and applying interdisciplinary approaches such as interactive experience, environmental psychology, and landscape design, we aimed to address the existing issues of the Art Peninsula's public space, which included a lack of interaction and a monotonous landscape hierarchy. We focused on human perception and experience within the landscape environment, improving the environment and promoting interaction between "people and people, people and the landscape." This was done to foster advanced emotional interactions, strengthen people's sense of identity with the public space, and increase the enjoyment of visiting.

5.1. Children's play area

In planning the children's play area, we deeply understood children's pursuit of fun and incorporated this philosophy into every aspect of the design. Our goal was to create a comprehensive and enjoyable space that children would find irresistible. In selecting play facilities, we introduced a variety of innovative and interactive play equipment. Beyond traditional slides, swings, and climbing frames, we added creative elements like sand pits and painting walls. These brightly colored and variously shaped facilities not only stimulated children's curiosity and desire to explore but also encouraged physical activity.

The layout of the play area emphasized creating rich and diverse spatial experiences. By installing play facilities at different heights, winding paths, and hidden play spaces, we encouraged children to discover new joys through exploration. This design not only exercised children's bodies and minds but also nurtured their imagination and creativity.

Within the play area, we set up multiple interaction points, such as parent-child interaction zones, allowing children to engage with their parents or other children while playing and enhancing their emotional bonds. Additionally, we could regularly host various themed events like parent-child sports days and children's festival celebrations, providing children with more diversified entertainment experiences.

The sandpit area was the highlight of the design. Here, children could freely dig and build with sand, experiencing its flow and transformation. This natural and intimate play method not only allowed children to unleash their innate playfulness but also fostered their love for and curiosity about nature (**Figure 4**).

Figure 4. Children's Dream World

5.2. Music Plaza

In the center of the plaza, a set of interactive dry fountains are designed. The fountains dance along with people's steps. The faster the steps, the higher the water splashes off the fountains, as if playing a moving piece of music. The pleasant sound of water is like the whispering of a natural stream in your ear, bringing a unique sensory feast to every visitor (**Figure 5**).

Figure 5. Music Plaza

5.3. Land Skateboarding Area

In planning the Land Skateboarding Area, emphasis was placed on enhancing the sports experience and creating a challenging yet smooth space for skateboarding and cycling enthusiasts. The area is equipped with diverse facilities to cater to different skill levels, ensuring that every participant can find suitable challenges and enjoyment. The design pays special attention to the harmonious integration of sports elements with the natural environment. Through clever use of terrain and careful selection of vegetation, the Land Skateboarding Area forms a natural connection with surrounding public spaces, creating a vibrant and harmonious environment for sports enthusiasts. This design not only reduces interference for sports enthusiasts but also allows other visitors to feel the vitality of this area.

Safety and accessibility were paramount in the planning process. The ground is covered with anti-slip materials, effectively reducing the risk of falls during sports activities and ensuring people's safety. Additionally, rest areas and viewing areas are provided for sports enthusiasts to take breaks and enjoy natural scenery. Beyond meeting the functional needs of sports, the design of the Land Skateboarding Area fully considers the possibilities of social and cultural exchange. This area will become a link that promotes vitality in public spaces and enhances interaction among people from different backgrounds and interests, allowing them to share the joy of sports together (**Figure 6**).

Figure 6. Land Skateboarding Area

6. Summary

In summary, this project represents a comprehensive and in-depth design attempt for the public space of Chongqing Art Peninsula. Through innovative design techniques and a user-centered philosophy, we aim to create a public space that embodies both artistic beauty and humanistic care. This space is envisioned as a venue for cultural experiences and artistic enjoyment, where people can find pleasure and enjoy the good life.

By promoting "human-landscape interaction," we seek to transform the public space of Chongqing Art Peninsula into a culturally and socially interactive public arena. This not only pursues the harmonious coexistence with nature but also deeply explores the fun in life. It encourages people to discover the beauty of life and enjoy every moment full of interest through interactions with nature. Along the pathway, various interactive installations are set up to guide the surrounding population through water elements and nature, emphasizing the interactive experience between "people and people, people and nature" from multiple perspectives such as visual, tactile, and auditory senses. Interactive landscapes such as waterfront platforms and smart interactive facilities are established to encourage citizens to explore and participate, thereby stimulating community vitality. Through the language of landscape design, we integrate natural ecological elements and the city's vitality into citizens' daily lives, creating a modern and cozy leisure place. Additionally, modern technology is incorporated into the design, utilizing smart navigation and environmental monitoring systems to enhance the space's intelligence level and provide convenient information services to citizens.

Disclosure statement

The authors declare no conflict of interest.

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Practice Exploration of Green Building Design in Prefabricated Residential Building Design

Yonghui Yu*

Hebei University of Engineering Science, Shijiazhuang 050000, China

***Corresponding author:** Yonghui Yu, 812623992@qq.com

Abstract: Prefabricated residential building design fully embodies the concept of green building and aligns with China's strategic plan for sustainable development. However, there is a need to further optimize green building design methods, enhance the design quality of prefabricated residential buildings, and improve energy and resource utilization. Compared to traditional construction methods, prefabricated residential building design still faces several challenges during the actual construction process. These challenges include difficulties in design, material selection and processing, and the high demands for construction coordination. To strengthen the application of green building concepts in prefabricated residential design and effectively promote the sustainable development of the construction industry, this paper discusses practical measures for implementing green building design in prefabricated residential projects for reference.

Keywords: Green building design; Prefabricated housing; Architectural design

Online publication: November 1, 2024

1. Introduction

At present, the construction industry is in a critical period of rapid economic development, transformation, and high-quality construction. To further improve the living conditions of the people, solve the common problems of prefabricated residential buildings such as low performance of the whole life cycle of buildings, the large energy consumption of residential construction, large impact on the construction environment, and unbalanced green and low-carbon development, it is necessary to comprehensively promote the green, low-carbon, livable and high-quality development of prefabricated residential buildings. Furthermore, it is essential to strengthen the practice and application of green building design in prefabricated residential construction. Accordingly, the primary focus of this paper is to analyze and study the implementation of green building concepts in the design of prefabricated residential buildings, with the aim of promoting sustainable construction practices in this sector.

2. Green environmental protection characteristics of prefabricated residential buildings

From the perspective of green environmental protection, prefabricated steel structure residential buildings have natural advantages in green building design [1]. Currently, prefabricated buildings mainly include prefabricated concrete structure buildings and prefabricated steel structure buildings, among which prefabricated concrete structures have good durability and stability, and occupy a large proportion in practical applications.

Specifically, prefabricated concrete structure residential buildings have the following advantages. Firstly, quality control, as the components are produced in the factory, which allows for better control of the quality of concrete and the precision of the components. Secondly, the construction efficiency is high. The prefabricated components can be directly transported to the construction site for assembly, reducing the time required for formwork construction and maintenance compared to on-site pouring. Thirdly, for economic and environmental protection, especially large-scale projects, the cost of prefabricated components is often lower than the cost of traditional cast-in-place structures, and many prefabricated components can be reused to reduce waste.

Following this, prefabricated steel structure residential buildings have the following advantages. Firstly, the steel structure has recycling characteristics, allowing the steel used in the building to be recycled at the end of its life cycle. After professional treatment, it can be repurposed for other engineering projects, including production and manufacturing. According to statistics, the recovery rate of steel in steel structures can be up to 90% [2]. This not only reduces the consumption of resources in other areas during production but also reduces the waste generated after the dismantlement of the building.

Secondly, since steel has the characteristics of structural stability, high hardness, strong corrosion resistance, and many more, the solid waste and ecological waste generated during the building service cycle are less and the maintenance frequency is lower, which effectively reduces the impact of the building itself on the surrounding ecological environment. Thirdly, it emits less carbon. Compared to traditional reinforced concrete buildings, prefabricated building design has shown advantages in many aspects, such as water saving, environmental protection, energy saving, and carbon emission reduction, with carbon emission reduction being the most significant. Statistically, the expected carbon emissions of prefabricated steel structure buildings are about 450 ± 20 kg/m^2, while the carbon emissions of traditional reinforced concrete buildings are about 800 kg/m^2.

Finally, based on the high efficiency and modular production characteristics of prefabricated steel structures, the time and material waste of on-site construction can be effectively reduced during the actual construction. In the production process, resource use can be optimized through precise design and control, thus reducing unnecessary energy consumption [3]. Simultaneously, most of the prefabricated components can be processed in the factory, thus reducing the noise pollution and dust pollution of the construction site, and further improving the effect of environmental protection [4].

3. Practical application of green building design in prefabricated residential building design

3.1. Building site selection and site green design

Building site selection and site design are critical steps before building design and construction. Effective site selection and design can significantly ensure the overall quality of the building [5]. Under the framework of green building design, construction and design parties should actively explore the path of organic integration between architectural design schemes and the surrounding ecological environment based on the site's actual conditions. They should coordinate the relationship between humans and nature, as well as between humans and ecology, through scientific and reasonable construction methods and techniques, ensuring economic benefits while also prioritizing ecological benefits.

Therefore, during the site selection process for prefabricated residential buildings, relevant staff must conduct a thorough investigation of the surrounding environment in advance. This includes identifying the characteristics of the surrounding area, such as the presence of residential areas, commercial zones, campuses, or any special pipelines and their specific underground locations at the construction site. Subsequently, effective measures should be adopted to minimize the impact on the surrounding environment during actual construction, ensuring harmonious coexistence between humans and nature [6]. Simultaneously, the construction party should also ensure the scientific and rational location of the residential building, taking into account construction technology, construction standards, environmental characteristics, human conditions, climate conditions, and many more, to ensure that the structural design and exterior design of the residential building meet the environmental requirements and technical requirements [7]. For example, if the residential building is located in a remote area, it will reduce the travel convenience of the current residential building users, increasing carbon emissions. If it is a low-lying area, the phenomenon of cold winter and hot summer may occur, resulting in increased dependence of residents on heating facilities, air conditioning, and other equipment, and thus a serious waste of resources, which does not meet the design standards of green buildings [8].

3.2. Selection of residential building materials

The design of prefabricated residential buildings under the concept of green building design requires the use of new roofing materials and wall materials, which are made of composite and fibrotic materials and have the characteristics of a simple installation process, low environmental pollution, lightweight, etc., which can greatly reduce the demand for human resources in construction and effectively enhance the thermal insulation effect of residential buildings [9]. Additionally, in the design of prefabricated residential buildings in green building design, many factors such as heat insulation, sound insulation, fire prevention, lighting, and ventilation should be comprehensively considered. Materials such as aluminum alloy and plastic steel alloy can be selected during actual construction, which can not only meet the design requirements of green buildings but also bring certain economic benefits to the builders and constructors [10].

For example, when applying aluminum alloy doors and windows, it is necessary to fill an appropriate amount of waterproof mortar between the energy-saving frame and the wall based on the local climate characteristics, and the thickness of the mortar should be less than the thickness of the energy-saving frame, so as not to affect the stability of the energy-saving frame after the mortar swelling. After the waterproof mortar is filled and air-dried, professional acceptance should be carried out, and the installation of the aluminum alloy main frame can be carried out after acceptance. In the design of doors and windows, insulating glass, heat reflection coated glass and other materials with excellent insulation and energy-saving characteristics can be selected. This not only improves the sealing of doors and windows, but also increases the shading, and achieves an indoor adjustable heat control effect, to achieve summer insulation and winter insulation. During the design period, insulation materials with strong water absorption should be avoided as much as possible, because such materials will absorb water and moisture seriously in areas with frequent rainfall, which will increase the internal humidity of the wall and easily cause damage to the building.

3.3. Green design for ventilation and lighting

Ventilation and daylighting are important items to be considered when designing the interior space layout of prefabricated residential buildings. In the actual design process, designers need to rationally design and utilize natural light, ventilation windows, new technologies, and new materials according to the requirements of natural ventilation and lighting, combined with indoor orientation and lighting conditions [11]. In particular, the design of the building ventilation system must conform to the concept of energy saving, make full use of natural wind, and strengthen indoor ventilation and exhaust. Generally speaking, indoor natural ventilation mainly uses the characteristics of building space layout, temperature difference effect, and air pressure. For example, the temperature difference and pressure difference between the indoor and outdoor parts of the building are different. By opening the doors and windows of the building, outdoor air can enter the room to achieve the role of ventilation. If the architectural design uses the concept of windward side to leeward side, it can further improve the indoor ventilation effect of the building. Although the reasonable design of residential doors and windows has a good ventilation effect, it also needs to carefully consider the ventilation area. According to the design requirements of conventional prefabricated residential buildings, the ventilation area ratio between the opening area of the bedroom and the ground should not exceed 19:20, the ventilation area of the kitchen should be greater than 0.6 m^2, and the opening angle of the windward side should be 90°.

Ventilation and lighting in the interior of the building not only need to meet the relevant architectural design and building energy conservation requirements but also need to ensure that users can get a good visual experience. Therefore, designers also need to optimize the ventilation and lighting of the building according to the specific building type and make the indoor lighting have a certain uniformity by improving the indoor lighting indicators. For example, insulating glass and adjustable shutters can be used to match the design. Adjustable shutters can freely adjust the indoor light area according to user needs, improving the quality of life and comfort of users. Not only that, adjustable shutter types, product appearance, color, and other options, according to the overall layout and color collocation of the interior, not only to meet the daily lighting needs but also to create a livable, comfortable atmosphere. Moreover, according to the indoor lighting design standards, the lighting uniformity of class I to IV lighting levels should not be less than 0.7 when lighting the top, and the distance between the midline of two adjacent skylights should not be greater than two times the height from the working face to the lower edge of the skylight [12].

3.4. Green design of indoor environment

Air quality is directly related to human health and living comfort, so designers need to pay attention to the optimization of air quality when designing the interior environment of prefabricated residential buildings. Furniture materials, decoration materials, indoor ventilation, and other comprehensive factors will affect the indoor air quality index [13]. Therefore, when decorating, we should try to choose non-toxic, green, and environmentally friendly materials, and after the decoration is completed, we should do a good job of ventilation to reduce formaldehyde levels. At the same time, the selection of furniture materials should also choose low-volatile organic building materials, and set up air cleaners or green plants in a reasonable area to help purify indoor air, to effectively optimize indoor air quality.

Moreover, it is essential to design and select the fresh air conditioning system thoughtfully. This involves fully considering the spatial layout of the building's interior, choosing the appropriate installation location, and adhering strictly to construction standards and specifications. In particular, it is important to seal the fresh air intake on the building wall to prevent rain, outdoor mosquitoes, reptiles, and other pests from entering the room. It should be noted that during the process of interior decoration construction, attention must also be paid to the air-tightness transformation and optimization of key areas such as doors, windows, and structural gaps. By improving construction quality and standardization, prefabricated residential buildings can achieve good air-tightness, which helps reduce the impact of cold air in winter on indoor temperatures and plays an important role in lowering building energy consumption. Additionally, good air tightness can minimize outdoor noise, reduce outdoor air pollution, prevent mold growth, and protect against structural corrosion.

3.5. Green design of residential building insulation

The wall is an important part of the residential building structure, and its quality is directly related to the safety of the residential building. Under the concept of green building design, the construction quality and stability of the wall should be ensured, and the environmental protection and energy saving of the wall should also be comprehensively considered [14]. To this end, the composite wall can be applied to the building's thermal insulation design according to the actual situation. The composite wall can effectively enhance the thermal insulation performance of the wall itself, achieve the effect of heat insulation and cooling in summer and cold insulation and warmth in winter, and then reduce the dependence of residential users on temperature control facilities such as air conditioning thus reducing resource consumption. Furthermore, with the continuous development of science and technology, a variety of green building materials have gradually appeared in the construction market. Some new organic materials with biodegradable performance, good thermal insulation performance, etc., can effectively meet the current era of green building in the context of energy conservation, insulation, and other aspects of the design standards.

Taking silicon ink as an example, it is a new type of external wall insulation material, which has the advantages of one-time pouring molding and permanent non-demolition convenience in actual construction and can integrate the main body of the building structure with the thermal insulation layer. The surface layer of the silicon ink exterior insulation material is a decorative layer, which can be flexibly adjusted according to building standards or user requirements, including but not limited to surface texture, color, and shape. Additionally, the silicon ink mold-free insulation board also has excellent weather resistance, water resistance, and crack resistance, which can significantly improve the stability and firmness of the external wall structure of residential buildings. In actual application, it is necessary to reserve about 500 mm space on the top of the non-removable thermal insulation template and use wooden boards to temporarily fix it to prevent pulp leakage on the top surface. Planks can be removed after concrete placement is completed [15].

4. Conclusion

To sum up, incorporating the concept of green building into the design of prefabricated homes can enhance the environmental performance of the building and greatly improve the health and comfort of the occupants. By fully integrating the concept of green building into the site selection and site design of prefabricated residential buildings, building materials selection, ventilation and lighting design, interior environment design, and other links, not only the goal of energy conservation and emission reduction is achieved, but also the operating cost is reduced, and the overall value of the building is enhanced. In the future, the application of green building design in prefabricated housing design needs to be further explored in terms of carbon reduction, livable, and sustainability, to create long-term excellent housing.

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The "Digital" Approach Impact Today: Modularity in Interior Architecture

Xinyi Tian*

University of College London, London WC1E 6BT, United Kingdom

Corresponding author: Xinyi Tian, tianhrpr@gmail.com

Abstract: Understanding digital technology requires a shift in mindset that takes into account the broader implications of design, social dynamics, environmental factors, and cultural influences. Acknowledging the fact that technology is not confined to the virtual domain but rather has a tangible influence on our daily lives and the surrounding environment, the extensive integration and potential of digital technologies offer a distinctive prospect to fundamentally transform our shared comprehension of architecture. Digital technologies are revolutionizing design practices, manufacturing processes, and our engagement with and understanding of the built environment, by fostering the development of novel models that promote equity and inclusivity. The application of "digital technologies" can function as a methodology for examining and expressing the possible paths of emerging digital technologies. Extrapolate the expected impact of digital technologies on the design, development, and occupancy of the environment to achieve a more sustainable future in the long run. This paper will examine the potential connections and origins of digital technology concerning modularity, as well as the implications of modularity on forthcoming architectural developments in customization.

Keywords: Modularity; Modular architecture; Interior architecture; Customization

Online publication: November 1, 2024

1. Introduction

The integration of digital technologies, including machine learning, artificial intelligence, big data, and manufacturing processes, is progressively gaining prominence within the construction sector. The pervasive integration of digital technology has permeated global society and all facets of human existence, particularly since the advent of the new millennium in the early 2000s [8]. A wide array of products, encompassing video equipment, cameras, computers, mobile phones, televisions, watches, medical devices, laser gauges, electronic kitchen utensils, and air conditioners, have gained widespread usage in daily existence owing to their dependence on digital technology [8]. The primary objective of this relationship was to augment and complement, while simultaneously engaging in a critical analysis of the established viewpoints regarding the societal implications of technology [6]. The incorporation of digital technologies, such as augmented reality, 3D printing, and artificial intelligence, has become a crucial aspect of the architectural design process. Interior architecture is one of the areas of usage [26]. Digital systems have seamlessly assimilated into the fabric of our everyday existence, assuming a pivotal role in facilitating a myriad of functions, including the conveyance of personal sentiments and ideas, as well as the facilitation of transportation.

2. The theory of modularity

2.1. The emergence of the concept of modularity in architecture

Ever since Henry Ford introduced the production line technique to assemble the Ford Model T in 1913, the construction industry has been actively seeking ways to enhance resource utilization by adopting standardized construction methods and components [23]. The architecture resulting from these procedures can be described as modular architecture; the foundation of modular architecture lies in the conceptualization and implementation of systems composed of discrete repetitive components, commonly known as standard units, and these units demonstrate consistency in terms of their dimensions, configuration, and inherent [22]. These entities can form connections with each other, undergo substitution, or undergo addition. From a theoretical standpoint, the adoption of this architectural approach offers clear competitive advantages, despite acknowledging certain negative connotations. The current architectural challenge in the 21st century pertains to the contemporary modular approach, which aims to facilitate individualized customization of residential dwellings, while simultaneously maintaining cost-effectiveness and upholding high standards of quality.

2.2. What is modularity and modularity in architecture?

A formal definition of a module in the technical context of this paper is an independent unit that can be combined with others and easily rearranged, replaced, or interchanged to form different structures or systems. Modularity combines similar elements or components into independent modules. By doing this, the modules can be modified separately, and in this way, a modular system can quickly adapt to changing requirements and new technology.

A modular architecture refers to a structure that consists of multiple modules, which must adhere to compatible and consistent behaviors and boundary conditions to be integrated. It includes at least two modular functions and two interfaces, which can be either input/output or bidirectional. The size and complexity of the architecture can vary, as the boundaries of the modules are scalable. The merging or joining of modules occurs through interoperable interfaces, which can be unique, selective, or universal. Additionally, functional content can be transferred or shared within the architecture, with the functionality being additive [9]. It is important to note that the potential to form modular entities exists before the actual formation of the modules.

2.3. Why modularity?

Modular systems are easily modified to address future needs. Modularity is the engineering equivalent of a financial option: pay a premium today to exercise an option in the future. Modularity offers different levels of options for the end user to respond to new requirements [3]. Modular designs offer advantageous system design elements that are economically appealing and contribute to the improvement of product support and reliability. Modular designs have the potential to yield cost savings. The subsequent enumeration outlines the anticipated advantages of modularity, contingent upon its successful implementation: The achievement of efficient and uncomplicated integration facilitated by interfaces designed for ease of use. Efficient and streamlined processes for reconfiguration and integration, aimed at facilitating the prompt incorporation of diverse capabilities. Considering the ease of maintenance and the speed at which problems can be resolved, it is of utmost importance to consider these factors across all levels of maintenance. The goal is to maximize the utilization of spare parts while concurrently minimizing the consumption of resources and the frequency of maintenance required for replacement components [9].

2.4. The example of modularity

Consider the following example of modular systems: a Swiss Army Knife. The example will highlight the fundamental advantages and drawbacks of modularity, as well as provide some real instances of the differences between the modularity of design. The versatile design of the Swiss Army Knife enables its owner to better prepare for whatever the future may bring. Because it has so many different tools, the Swiss Army Knife can be used for a variety of purposes, which is better for the person who ultimately uses it. The Swiss Army Knife is therefore a good example of a fundamental trade-off that must often be made when adopting modular design. This trade-off involves enhanced flexibility in exchange for less-than-ideal performance. Because each tool within the knife can function independently, knife designers must manufacture each component individually, tailoring the design of each tool to the volume constraints of the knife chassis. This approach exemplifies modularity in the design process. During manufacturing, all tools might be manufactured on different assembly lines and then combined into a single device on another assembly line.

3. Modularity in architecture and urban planning

3.1. Relationship between modularity and architecture and urban planning

Because its component elements are inherently related to one another, there are relationships to be found at every level. According to Slife, the concept of technology did not spring fully formed from nowhere, as the author of the essay titled "Sociomateriality of Information Systems and Organizing" makes clear [21]. This is an essential point. A relational ontology, on the other hand, holds that "the social and the material are inherently inseparable" [19]. The concept of technology did not spring fully formed from nowhere, as the author of the essay titled "Sociomateriality of Information Systems and Organizing" makes clear. This is an essential point [21].

3.2. Modular in customization

Vitruvius defines proportion as "the correspondence between the members of the whole work" and "the correspondence of the whole with a certain part chosen as a criterion" in the first chapter of his Ten Books of Architecture [25]. The concept of modularity, or "customization," was applied in the early years.

After a period of flagging interest from the 1970s into the 1990s, design interest in housing is again on the rise, particularly in terms of innovative materials and production systems, "green" buildings, and an activist interest in providing for a broader spectrum of people [1]. Recently, "mass customization" or "modular customization" has become a term used to describe housing production, long used by industrial designers, suggesting a production system that has the stability of quantity (mass) and the flexibility of custom design (customization). This systematic approach to housing, which emphasizes the mass production of shelter to accommodate numerous individuals, predominantly emerged during the Industrial Revolution.

During the early 20th century, the artistic movement known as Neue Sachlichkeit, along with other related movements, focused on the establishment of standardized dimensions for minimal housing units, as well as the effective utilization of emerging materials and technologies. Le Corbusier's Maison Dom-Ino was also conceived as a cost-effective and adaptable system for the mass production of housing, employing contemporary materials and production methods.

3.3. Modular in interior design

The challenge of addressing the increasing complexity of technical systems and the growing interplay between technical and societal aspects necessitates the utilization of appropriate engineering design approaches [10]. According to Lindemann *et al.*, as mentioned by Nambisan *et al.,* as the level of complexity in technical systems rises, there is a corresponding increase in both the level of uncertainty and the number of resources needed during the development process. Due to this rationale, numerous projects rely on legacy systems that undergo modifications across generations as they navigate the delicate balance between incorporating novel functionalities and leveraging established components [17]. Modular solutions provide a notable level of flexibility and can be seamlessly incorporated into diverse architectural structures, including residential complexes, rental properties, purpose-built student accommodations, hotels, communal living spaces, office buildings, and educational institutions.

It is imperative to acknowledge that in the context of co-living and student housing, each module represents an autonomous unit that is furnished with its own set of bathroom amenities. The modules possess the capacity to be constructed in advance at a location separate from the final site, encompassing all necessary components, including windows, flooring, walls, electrical outlets, furniture, and window coverings [15]. The measurements exhibit a high level of accuracy, with precision extended to the nearest millimeter. The integration of corridors into module design is a viable and practical choice. Uniform dimensions for every room are not a prerequisite. Certainly, the integration of modules in a specific location can be employed to attain larger and more expansive areas. After the floors and other interior components have been installed, the integration of supplementary modules within the premises results in a final product that is indistinguishable from conventional rooms. As mentioned earlier, it is important to highlight that the achievement of efficiencies was based on the modular concept of an overarching "end goal," regardless of the size of each specific space or room.

3.4. Modular in urbanism

The modular urban is to increase the quality of community life while reducing housing costs and environmental impact. The strategy for its implementation is detailed below. An accommodating environment fulfills personal needs, adapts to the cadence of everyday life, and provides access to the community and relationships the residents want. To achieve this goal, modular urban seeks to unleash the many advantages of living in compact communities by providing choice and encouraging a feeling of belonging. Humans possess an intrinsic need for interpersonal connection, a modularity strategy entitled for creating multigenerational shared-living spaces in urban cores. People may have both their own space and the benefits of living in a close-knit community thanks to this innovative approach to housing.

"No one size fits everyone." For this reason, rather than conventional single-family houses, we advocate for a variety of apartment buildings. Everyone from a single person to a family of four, from retirees to a group of students, has choices. Staying in the same neighborhood even if you need a new place to live means you can easily trade flats with others in a similar situation.

4. Conclusion

The process of digitization has been characterized as a transformative shift in human behavior and perception. The discipline of architecture and urban is influenced by the progressions in digital technologies, as well as the evolving demands of society. The rise of this phenomenon can be ascribed to the successful incorporation of digital technologies within the domain of intelligent architectural structures, as supported by scholarly investigations and real-world implementations.

The emergence of advanced technologies has enabled individuals to engage in the public sphere within the digital media realm, particularly through the utilization of cyberspace, thereby bypassing the limitations imposed by physical space. The utilization of digital technologies in the realm of space has been acknowledged as an increasingly urgent necessity. The notion of digital development encompasses various dimensions, including economic prosperity, adequate standards of living, convenience in daily life, and spatial needs for habitation. The objective is to improve the user experience through the promotion of comfort, convenience, safety, and the facilitation of work and leisure activities.

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Study on Durability of Recycled Aggregate Concrete in High-Temperature and Complex Environments

Xiaoqing Hu*, **Yao Tong**, **Xuan Min**, **Rongchong Xu**

Chongqing Institute of Engineering, Chongqing 400056, China

Corresponding author: Xiaoqing Hu, hu812255201@hotmail.com

Abstract: Recycled aggregate concrete refers to a new type of concrete material made by processing waste concrete materials through grading, crushing, and cleaning, and then mixing them with cement, water, and other materials in a certain gradation or proportion. This type of concrete is highly suitable for modern construction waste disposal and reuse and has been widely used in various construction projects. It can also be used as an environmentally friendly permeable brick material to promote the development of modern green buildings. However, practical applications have found that compared to ordinary concrete, the durability of this type of concrete is more susceptible to high-temperature and complex environments. Based on this, this paper conducts theoretical research on its durability in high-temperature and complex environments, including the current research status, existing problems, and application prospects of recycled aggregate concrete's durability in such environments. It is hoped that this analysis can provide some reference for studying the influence of high-temperature and complex environments on recycled aggregate concrete and its subsequent application strategies.

Keywords: Recycled aggregate concrete; Construction engineering; High-temperature and complex environment; Durability

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1. Introduction

With the continuous aging of reinforced concrete buildings and the increasing amount of construction waste generated by demolition and renovation due to urban construction, the annual output of construction waste in China accounts for 30% to 40% of the total urban waste. According to the latest plan announced by the Ministry of Housing and Urban-Rural Development, China will build 30 billion square meters of new housing by 2020, resulting in at least 5 billion tons of construction waste. Targeted utilization of construction waste and the preparation of recycled aggregate concrete not only conserves overall resources but also prevent environmental pollution caused by piles of waste concrete. It is a sustainable and green concrete that aligns with the scientific development goals concept proposed by the country [1].

During the casting, molding, and curing processes of recycled concrete, a large number of initial defects such as micro-cracks and micro-pores are generated, which affect the strength of the recycled concrete. These are referred to as initial damage [2]. Later, under the influence of external factors (corrosion, load, temperature, etc.), these initial defects continue to expand and connect, forming macro cracks that ultimately lead to the failure of components and even structures.

2. Analysis of current research status both domestically and internationally

Currently, experts and scholars both domestically and internationally have achieved fruitful results in the durability research of recycled aggregate concrete from both experimental and theoretical aspects. These studies mainly focus on establishing damage evolution equations for recycled aggregate concrete under different conditions and analyzing the mechanical performance parameters that characterize concrete damage. Among them, established damage equations include thermal-hydro-mechanical coupling damage evolution equations, chemo-mechanical coupling damage evolution equations, and compression-shear coupling damage evolution equations. However, due to differences in curing and working environments, it is difficult to use a single model to reflect the coupled damage situation of recycled aggregate concrete in high-temperature and complex environments. Therefore, this paper proposes research on the durability of recycled aggregate concrete in high-temperature and complex environments.

2.1. Analysis of the international research status

In foreign countries, research on the durability of ordinary concrete in high-temperature and complex environments began in the 1950s to 1960s. With the continuous development of the construction engineering industry, recycled aggregate concrete has also begun to be gradually put into use and has become popular in multi-story and high-rise buildings. Based on this, the durability of recycled aggregate concrete, especially in high-temperature and complex environments, has become a focus of research for many foreign scholars.

Weide *et al.* studied the changes in cement paste in recycled aggregate concrete under different temperatures using differential scanning calorimetry [2]. The study found that the cement paste undergoes significant changes when exposed to different temperatures. When the temperature rises to about 120℃, the free water within the paste evaporates completely and when the temperature increases from 120℃ to 172℃, the hydrated calcium carboaluminate dehydrates. At 180℃ to 300℃, hydrated calcium silicate dehydrates and at 450℃ to 550℃, calcium hydroxide dehydrates and decomposes.

Lucia *et al.* conducted high-temperature environmental tests on cylindrical samples of recycled aggregate concrete and compared them with ordinary concrete [3]. They evaluated cracks, mass loss, porosity, and thermomechanical properties. The study revealed that, compared to ordinary concrete, the cubic compressive strength of recycled aggregate concrete decreases more significantly under high-temperature conditions, with a reduction range typically reaching 15% to 42%.

Belen *et al.* proposed that the water absorption rate of recycled aggregates in recycled aggregate concrete directly affects its compressive strength in high-temperature and complex environments [4]. Specifically, if pre-water absorption treatment is performed before completing the subsequent preparation of recycled aggregate concrete, even with a 100% replacement rate of recycled aggregates, the reduction in compressive strength under high-temperature and complex environments will not exceed that of ordinary concrete by much.

2.2. Analysis of the domestic research status

Although the application and related research of recycled aggregate concrete in China started slightly later than in foreign countries, with the continuous development of the domestic construction engineering industry in recent years, as well as the continuous innovation of construction engineering materials and technologies, recycled aggregate concrete with advantages such as energy saving, environmental protection, and economy has begun to be widely used. Meanwhile, research on its durability in high-temperature and complex environments has increasingly attracted the attention of relevant domestic scholars.

Xiao Jianzhuang *et al.* conducted experimental research on recycled aggregate concrete in high-temperature and complex environments [5]. They found that when the ambient temperature is between 100℃ to 300℃, the elastic modulus of this type of concrete loses 10% to 20% compared to normal temperature conditions. When the ambient temperature exceeds 700℃, the loss of elastic modulus of this type of concrete reaches 45% to 50%.

Yao Guohuang *et al.*, based on the study of high-temperature thermal and mechanical properties of recycled concrete, used ABAOUS software to establish analysis models for the temperature field, fire resistance limit, and residual mechanical properties after standard heating and cooling fire exposure of reinforced recycled concrete components (slabs, beams, columns) under ISO 834 standard fire conditions [6]. The reliability of the models was also verified. By dividing the one-dimensional and two-dimensional heat transfer areas of the components, a simplified calculation formula for the temperature of reinforced recycled concrete components under fire was proposed. The focus was on analyzing the influence of the replacement rate of recycled coarse aggregates on the temperature field, fire resistance limit, and residual bearing capacity of reinforced recycled concrete components under fire conditions.

Li Weina researched the loss of ignition, compressive strength, bearing capacity, and bonding performance of recycled concrete with different proportions of old materials [7]. The results showed that as the proportion of old materials increased from 0% to 100%, the compressive strength of recycled concrete decreased by 22.3%. Higher burning temperatures led to a greater mass loss rate of recycled concrete and more significant color changes. Higher proportions of old materials and higher fire temperatures resulted in lower strength of recycled concrete. The load-displacement curve of recycled concrete columns exhibited a three-phase trend: an approximately linear increase, then a slow increase, and finally a decrease. The relative slip curve of steel-reinforced recycled concrete columns showed a trend of rapid increase, followed by a rapid decrease and then a rapid increase, with two significant peaks. When the temperature increased from 300°C to 600°C, the peak displacement of steel-reinforced recycled concrete columns increased by 16.7%, and the final slip increased by 9.5%. Under 600°C conditions, compared to conventional concrete columns, the peak displacement of steel-reinforced recycled concrete columns with a 100% proportion of old materials increased by 115.4%, and the final slip increased by 35.3%.

3. Analysis of existing problems and application prospects

3.1. Analysis of existing problems

Based on the research results of domestic and foreign scholars regarding the durability of recycled aggregate concrete in high-temperature and complex environments, it is evident that recycled aggregate concrete has poorer durability compared to ordinary concrete under such conditions. High-temperature environments can lead to the evaporation of water in structural materials, resulting in increased porosity and affecting the internal crystal structure of the materials. As the temperature rises, the evaporation of water within the structural materials leads to greater porosity, reducing the compactness and strength of the materials. Additionally, high-temperature environments can alter the chemical properties within the structural materials, such as promoting carbonation reactions, which can lead to a decrease in material strength [8]. However, compared to ordinary concrete, the performance degradation of recycled aggregate concrete structural materials is more significant under the same high-temperature and complex environmental conditions.

Through existing research and practical applications, the following differences in durability have been observed between recycled aggregate concrete and ordinary concrete:

(1) As the ambient temperature gradually rises, recycled aggregate concrete begins to experience increasing mass loss, its color gradually turns to grayish-white, and surface cracks become more prominent. During this process, the higher the proportion of waste material in the recycled aggregate concrete, the more pronounced these changes are. Experimental data comparisons show that, compared to concrete without waste material, the loss on ignition of recycled aggregate concrete is always higher after adding waste material, and the increase is proportional to the amount of waste material added.

(2) The impact of high-temperature and complex environments on the compressive strength of recycled aggregate concrete is not significantly different from that of conventional concrete. This is because, after exposure to high temperatures, all types of concrete exhibit a significant decrease in compressive strength, making the variations in compressive strength among different types of concrete less significant. However, comparisons of compressive strength among different types of concrete within the same temperature range reveal that, as the proportion of waste material in the concrete increases, the compressive strength of coarse aggregate concrete decreases significantly in high-temperature and complex environments.

(3) Recycled aggregate concrete with added waste material always exhibits greater displacement and faster failure rates than conventional concrete without waste material, indicating a more severe reduction in bearing capacity. Especially in complex environments where the ambient temperature exceeds 600°C, the reduction in bearing capacity of recycled aggregate concrete steel structures becomes more significant as the proportion of waste material increases.

(4) As the proportion of waste material in recycled aggregate concrete increases, the slip of the recycled aggregate concrete steel structure also increases under the same high-temperature and complex environment conditions [9]. Especially in high-temperature and complex environments, this type of concrete steel structure will have a greater amount of slip.

Therefore, it can be seen that in high-temperature and complex environments, the higher the proportion of waste material in recycled aggregate concrete, the lower its fire resistance, bearing capacity, and anti-slip performance will be, resulting in poorer overall structural durability.

3.2. Application prospect analysis

Recycled aggregate concrete is a green concrete strongly promoted by the country. Its performance has similarities and differences compared to ordinary concrete, posing new technical challenges for its application in high-temperature environmental engineering. Based on this, in the construction of building engineering projects, engineering units should reasonably apply recycled aggregate concrete based on actual engineering conditions and application requirements. Typically, engineering units can use this type of concrete material in conditions such as road construction or underwater construction to avoid adverse effects on its durability from high-temperature and complex environments.

To apply recycled aggregate concrete in ordinary building construction projects, engineering units need to consider the actual fire resistance level of the building structure, concrete bearing capacity, concrete-steel structure bearing capacity, and anti-slip design requirements to properly formulate this type of concrete. The proportion of concrete waste should be reasonably determined to ensure the performance of the overall building structure [10]. During the specific formulation process, engineering units should not arbitrarily increase the amount of waste material in recycled aggregate concrete to save costs, as this may adversely affect its durability.

Through the reasonable implementation of the above application schemes and measures, the performance of recycled aggregate concrete can be well guaranteed, minimizing the adverse effects of high-temperature and complex environments on its basic properties and further enhancing the durability of recycled aggregate concrete structures. This will be very beneficial for the rational application of recycled aggregate concrete materials, thereby effectively promoting the sound development of the modern construction industry.

4. Conclusion

Currently, research on the time-varying laws of recycled aggregate concrete performance, damage evolution mechanisms, and constitutive models under the coupled effects of multiple factors in high-temperature and complex environments remains a gap. Therefore, researching the damage evolution mechanism of recycled aggregate concrete in high-temperature and complex environments not only has important scientific significance but also holds significant promise for engineering applications.

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Disclosure statement

The authors declare no conflict of interest.

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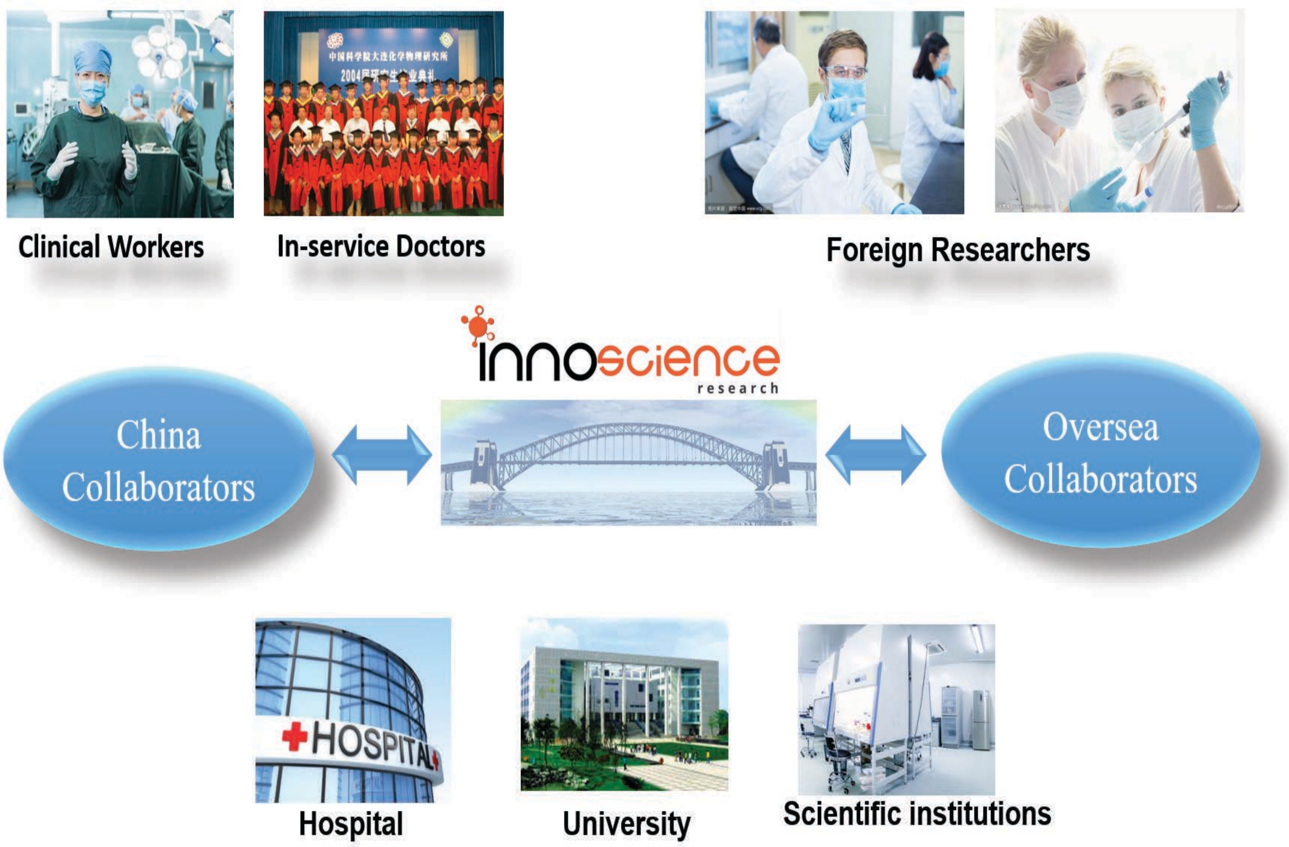

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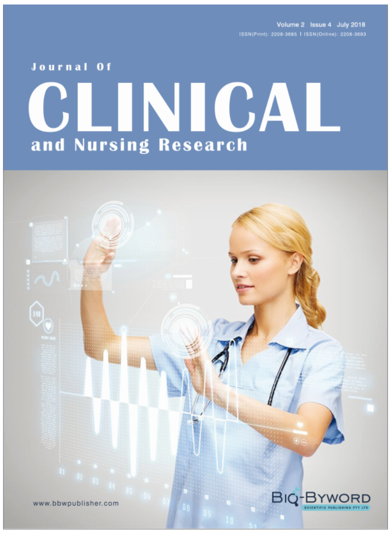

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