Research on the Modular Transformation Method of Xi'an Bridge Space under the Background of Sustainable Development

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Abstract: In order to improve the problems of insufficient utilization efficiency of space under the bridge in Xi'an, lack of public service functions and difficulties in facility maintenance, this paper takes the space under the viaduct of the construction section as the research object, combines field investigation and site condition analysis, constructs a transformation system composed of sports, culture, commerce, education and other service modules, and proposes module combination, assembly structure, low-carbon material utilization and ecological environment optimization methods. The research shows that the module standardization and functional elastic configuration can improve the site adaptability and reduce the construction demand of fixed facilities. The functional configuration, component recycling and age-friendly design scheme based on bridge span conditions are formed, which provides technical reference for the renewal of space stock under Xi'an Bridge.

Keywords: Sustainable Development; Space Under the Bridge; Modular Transformation; Urban Renewal

1. Introduction

As urban development gradually shifts toward the renewal of existing built environments, underutilized land beneath elevated bridges has become an important resource for public space regeneration [1,2]. Xi'an has an extensive network of urban roads and elevated transportation infrastructure. Some under-bridge areas are constrained by bridge structures, traffic organization, and environmental conditions, resulting in inadequate functional facilities, insufficient maintenance management, and conflicts among different spatial uses. The traditional transformation method relies on the construction of fixed facilities, and the cost of space use adjustment and component renewal is high, which is difficult to adapt to the changes in the needs of residents ' activities [3-6]. Modular design provides technical conditions for low-intervention update of existing sites through component standardization, functional unit combination and detachable assembly. Studying the module adaptation, low-carbon construction and ecological improvement methods of the space under Xi 'an Bridge is of practical significance for improving land use efficiency, improving community public service facilities and reducing long-term maintenance costs.

2. Overview of Engineering Examples

Select the space under the viaduct of Xi 'an construction section as an example. The site is located in the urban built-up area, surrounded by residential areas, commercial facilities and urban roads. The daily traffic and public activities of residents are relatively concentrated. The satellite map of the site status is shown in Figure 1. The elevated bridge forms a continuous linear space with sheltered conditions and potential for redevelopment. However, the distribution of bridge piers, road traffic, and existing facilities has resulted in considerable spatial fragmentation. Field investigations revealed irregular vehicle parking, unauthorized roadside commercial activities, and insufficient public facilities in some areas. Interference between pedestrian routes and vehicular activity areas affects circulation efficiency and user safety. Existing activity facilities within the under-bridge space do not adequately meet surrounding residents' needs for recreation, exercise, and cultural interaction, while landscaping and public service functions require further improvement. Based on the bridge structure and site conditions, modular retrofitting is adopted to optimize spatial functions and the organization of activities.

3. Overall Approach to Modular Retrofitting of Under-Bridge Spaces in Xi'an

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The space reconstruction under the viaduct of Jiangong Road in Xi 'an is based on public service demand, site adaptation and resource recycling. A total of 200 questionnaires were distributed in the preliminary survey, and 185 valid questionnaires were recovered, with an effective rate of 92.5 %. The space under five typical bridges in Xi 'an was observed in different time periods. Considering that the survey data comes from multiple points, the specific function configuration of the construction section still needs to be determined according to the site conditions. Before the transformation, the bridge maintenance area, traffic channel and facility safety control range should be delineated, and the bridge span space with independent use conditions should be used as the module layout unit to form a functional system with sports, culture, business, education and other service modules as the main body.

The module configuration is adjusted according to the activity characteristics, space conditions and use period. The sports module arranges health and fitness and small-scale event activities ; the cultural module sets up opera performances and cultural exhibition facilities ; the commercial module adopts movable market and retail facilities ; the education module is configured with popular science interactive devices and open-air classrooms. Rest, guidance and public health facilities are included in other service modules, and the specific layout requirements are shown in Table 1.



Figure 1. Satellite Image of the Existing Conditions at the Jiangong Road Elevated Bridge in Xi'an

Table 1. Adaption of Spatial Function Modules Under Viaduct Bridge of Construction Road

Module type	Site adaptation conditions	Space Organization and Use Arrangement	Key points of engineering control
Motion module	It has continuous activity venues and maintains a safe distance from the vehicle area	Healthy fitness is used normally, and small events are open for appointment	Check the net height, active clearance and ground anti-skid conditions
Cultural module	It has walking accessibility and viewing space	The exhibition is open daily, and the opera performances are organized on time	Control noise, number of audience and evacuation channel occupancy
Commercial module	Proximity to pedestrian entrances and exits, with adequate space for temporary gathering	Movable stalls with designated operating hours	Verify fire safety, electrical installations, and catering operation requirements
Educational module	Limited pedestrian–vehicle interference and adequate conditions for group activities	Science exhibits open regularly; open-air classes by reservation	Install protective facilities and ensure the safety of teaching areas
Other service modules	Pedestrian nodes and areas serving public facilities	Rest areas, wayfinding, and convenience services provided as needed	Reserve space for facility maintenance and accessible routes

Standardized components and demountable connections are adopted for the modules, with priority given to existing paved surfaces to reduce foundation construction and building material consumption. Shared lighting, power supply interfaces, and activity facilities reduce redundant installations across different functional units. The spatial arrangement combines fixed service facilities with movable functional modules. On weekdays, the space accommodates daily

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recreation, science education, and community activities. On weekends, it can be converted into areas for markets, cultural exhibitions, or small-scale sporting events according to actual demand. Specific module dimensions and installation quantities should be determined through on-site surveying and verified against bridge-span headroom, available area, fire safety requirements, and pedestrian circulation arrangements.

4. Design of Space Function Module Under Bridge

4.1 Development of the Modular Retrofitting Unit System

According to the span distribution and ground use conditions of the viaduct on the construction road, the available space is divided into independent layout units, as shown in Figure 2. Each unit adopts a three-level structure of ' basic components-functional facilities-auxiliary facilities '. The basic components bear the support and connection functions. The functional facilities are classified according to sports, culture, business, education and other modules. Configuration, auxiliary facilities provide lighting, guidance and power supply interfaces. The module preferentially adopts the ground independent support structure to avoid directly changing the stress state of the bridge. The net width of the public barrier-free channel is controlled by the " General Specification for Accessibility in Building and Municipal Engineering " (GB 55019-2021), not less than 1.20 m, and the densely populated area is not less than 1.80 m. The specific module size is determined according to the measured clearance of the bridge span.

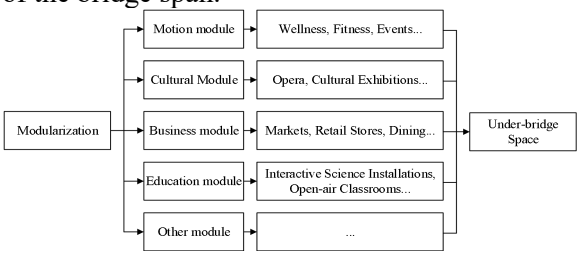


Figure 2. Classification and Frame Diagram of Spatial Function Modules Under The Bridge

4.2 Motion Module Design

The sports module is mainly used for health and fitness and small events, and is preferentially arranged in the bridge span area with flat ground and away from the motor vehicle channel. The health care unit is equipped with low-intensity stretching, balance training and rest facilities. The fitness unit adopts an independently installed device combination to reduce the attachment to the bridge components. Small events use movable equipment and temporary venue identification, and the activity area reserves personnel distribution space. A buffer area is set between the sports facilities and the walking channel to avoid the use of equipment to encroach on the public space.

4.3 Cultural Module Design

The cultural module combines Xi 'an local opera and regional cultural resources to set up small opera performances, cultural exhibitions and community art activities. The exhibition unit adopts replaceable panels and combined display frames, and uses the space between piers to form a continuous visit route. The opera activities adopt removable stage and mobile seats, and adjust the performance area according to the scale of the activities. The exhibition facilities and bridge components maintain maintenance spacing, the performance area avoids motor vehicle channels, and controls the impact of sound reinforcement equipment on surrounding residents.

4.4 Business Module Design

The commercial module sets up three types of units : market, retail and light catering, which are preferentially arranged in areas near pedestrian entrances and easy to transport goods. The market adopts foldable stalls, and the retail unit adopts independent cabinets to reduce the proportion of fixed facilities in the site. The main direction of light catering is prepackaged food and simple sales. The facilities involved in on-site processing must complete fire fighting, smoke exhaust, drainage and verification of operating conditions. Each business unit organizes space according to the needs of operation, queuing and replenishment, so as to avoid business activities occupying the main channel.

4.5 Education Module Design

The education module is composed of popular science interactive device and open-air classroom, which is arranged in the bridge span area with less traffic interference. The popular science device adopts low-voltage power supply or mechanical interaction to set up replaceable display content ;

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the open-air classroom is equipped with mobile tables and chairs, teaching panels and simple projection facilities, and the community science popularization activities are carried out by using the bridge shielding conditions. The educational unit is adjacent to the cultural display area to facilitate the sharing of display equipment and activity venues, and the children 's activity area is provided with necessary boundary protection.

4.6 Other Module Design

Other modules undertake the functions of rest, guidance and basic public services. The rest unit adopts a combination seat and a movable flower box, which is arranged at the main walking node ; the guide facilities indicate functional zoning, entrances and exits, and emergency channels ; garbage classification facilities are set up in a convenient location. The configuration of public health facilities is determined according to the distribution of existing facilities and the conditions of takeover. Each auxiliary module adopts replaceable components, which is convenient for maintenance, movement and reuse.

5. Technology and Ecological Strategy of Modular Transformation of Space Under Bridge

5.1 Modular Structure Design

The modular facilities under the viaduct of the construction road adopt independent support and bolt assembly structure, the main body is mainly light steel members, and the seats, exhibition frames and activity facilities are installed by standard connectors. According to the Technical Standard for Maintenance of Urban Bridges (CJJ 99-2017), the distance between the structure under the bridge and the bottom of the bridge, the pier and the abutment should not be less than 1.5 m, and the bridge inspection and maintenance channel should be retained. Module foundations are designed according to the load-bearing conditions of existing ground surfaces. Electrical conduits are installed independently, and sufficient space is reserved at connection points for disassembly and replacement of individual components.

5.2 Low-Carbon Materials and Circular Reuse Strategies

Reusable steel components are preferred for the main modular structures. Rest facilities employ recycled wood–plastic composites or recyclable metals, while exhibition panels use materials that can be readily removed and replaced. Existing pavement is retained selectively following inspections of its load-bearing capacity and physical condition, reducing the extent of ground demolition. A component identification and numbering system is implemented during material procurement, processing, and installation to record material types, component mass, and installation locations. Dismantled modules are sorted for recovery according to their condition. The quantities of recovered and reused steel and newly installed materials are calculated using the engineering bill of quantities.

5.3 Ecological Environmental Improvement Strategies

Shading caused by the bridge structure creates localized low-light conditions along the Jiangong Road site. Plant species should therefore be selected according to bridge-span locations and measured sunlight conditions. Existing trees and shrubs are retained in areas near the outer edges of the bridge structure, while shade-tolerant groundcover plants and movable planting containers are used in areas with limited sunlight. Permeable paving is installed along the boundaries between activity areas and landscaped zones. Shallow drainage channels and water collection facilities are arranged according to existing surface gradients to prevent drainage from the bridge deck from affecting public activity spaces. Modular lighting employs zoned controls, with separate lighting circuits for sports and circulation areas to reduce electricity consumption during periods of non-use.

Table 2. Technical Control Requirements for Modular Retrofitting of the Jiangong Road Under-Bridge Space

Technical aspect	Control parameters
Safety clearance for structures	Determined according to bridge structural conditions and relevant management requirements
Module foundations	Independent support, with foundation types determined according to ground load-bearing conditions
Material circularity	Quantification of the mass of reused components and newly added materials
Ecological paving	Permeable paving areas determined according to existing surface drainage gradients

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Accessible ramps	General longitudinal gradient not steeper than 1:12 and cross slope not steeper than 1:50

Note: Safety clearance requirements are based on the Technical Standard for Maintenance of Urban Bridges (CJJ 99—2017), while ramp parameters are based on the General Code for Accessibility of Buildings and Municipal Engineering (GB 55019—2021). The remaining items represent design control requirements, and specific values must be determined through on-site testing or engineering calculations.

5.4 Age-Inclusive and Accessible Design

Accessible facilities are designed in accordance with the General Code for Accessibility of Buildings and Municipal Engineering (GB 55019—2021). Wheelchair ramps generally have a maximum longitudinal gradient of 1:12, a maximum cross slope of 1:50, a maximum rise of 750 mm per ramp run, and a minimum clear width of 1.20 m. Children's activity areas employ slip-resistant surfaces and facilities with rounded edges, while resting areas for older adults are equipped with seating that includes armrests. Continuous wayfinding signs are provided at major entrances and exits, and physical barriers are installed in areas with insufficient overhead clearance beneath the bridge to ensure safe passage for users of different age groups.

6. Conclusion

Taking the under-bridge space along the Jiangong Road elevated bridge in Xi'an as an engineering case, this study proposes a modular retrofitting scheme consisting of sports, cultural, commercial, educational, and other service units based on site functional requirements and bridge structural constraints. Through bridge-span subdivision, functional module combinations, and standardized component assembly, the layout conditions and usage requirements of different activity facilities are established. The technical design adopts independent structural supports, demountable connections, and recyclable materials, together with shade-tolerant planting, permeable paving, zoned lighting, and accessible facilities to improve site conditions and control resource consumption. The module configuration still needs to be deepened according to the measured clearance, ground bearing capacity and bridge safety management requirements. At present, the preliminary design path of engineering transformation has been formed, and its actual material saving effect, environmental improvement degree and facility utilization efficiency still need to be verified by project implementation and operation monitoring.

References

[1] Zhang L, Wan Z R, Wei Z J, et al. Adaptive retrofitting of vernacular architecture and residential space planning for seasonal workers from the perspective of production–living–ecological integration: A case study of Qiankengqiao Village, Anji, Zhejiang Province[J]. Development of Small Cities & Towns, 2026, 44(3): 38–45.

[2] Tian Z Y. Optimization strategies for the spatial network of public service facilities in traditional villages under the guidance of coordinated development[D]. Jinan: Shandong Jianzhu University, 2024.

[3] Wang L. Research on market space design based on modular thinking: A case study of Shanggang Market[D]. Shanghai: Donghua University, 2024.

[4] Li S Y. Analysis of design strategies for converting old industrial buildings into creative cultural spaces[C]//Proceedings of the 2025 Smart City Construction Forum. 2025: 656–657.

[5] Kong J H. Research on the landscape design of festival cultural spaces at Huabuzhu Mountain in Jinan[D]. Jinan: Shandong Jianzhu University, 2025.

[6] Xu X Q. Research on waterfront landscape renovation and design in cold regions from the perspective of urban renewal: A case study of the South Canal waterfront landscape belt in Shenyang[D]. Shenyang: Lu Xun Academy of Fine Arts, 2025.

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