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Research on Integrated Architectural and Transportation Design for the Reconstruction of Underutilized Land Surrounding Urban Transportation Hubs

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Abstract: As core nodes where urban passenger flow, logistics, and information flow converge, urban transportation hubs play a pivotal role in optimizing urban space and enhancing urban functions through the efficient utilization of the land surrounding them. However, the majority of urban transportation hubs in China currently face issues of underutilized land use, such as mixed land functions, fragmented spatial layout, and poor transportation connection, which restrict the exertion of the comprehensive efficiency of the hubs. From the core perspective of integrated architectural and transportation design, this paper combines relevant theories of architectural design with principles of transportation planning. By analyzing the design of underutilized land surrounding typical domestic transportation hubs, it proposes integrated design strategies from four dimensions: mixed-use, spatial integration, transportation connection, and ecological coordination. This research provides theoretical and practical references for the high-quality reconstruction of underutilized land surrounding urban transportation hubs in China.

Keywords: Transportation hub; Reconstruction of underutilized land; Integration of architecture and transportation; Mixed-use; Spatial integration

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1. Introduction

With the improvement of China's comprehensive transportation system, hubs such as high-speed rail and metro have become core engines of urban development. Nevertheless, due to the disconnection between architectural and transportation connection in the surrounding land, problems such as mixed functions, inefficient transfer, and ecological imbalance have emerged. This situation not only results in the waste of land resources but also restricts the radiation and driving role of the hubs, becoming a prominent bottleneck in the process of urban renewal. At present, the academic circle has conducted certain research on fields such as station-city integration and Transit-Oriented Development (TOD), but most studies focus on a single hub type or isolated aspects of architectural design and transportation planning. For the specific scenario of "reconstruction of underutilized land", research on the systematic integration of architectural functions, spatial forms, and transportation systems is still insufficient, especially the lack of a multi-dimensional design framework and specific strategies that can directly guide practice [1]. Based on this, this paper clarifies the core research question: How to break through the inefficient problems such as unbalanced land functions, spatial fragmentation, and poor transportation connection around urban transportation hubs through integrated architectural and transportation design, so as to achieve the simultaneous improvement of land use efficiency and spatial quality?

Against this background, this paper focuses on the scenario of land reconstruction surrounding hubs. Through systematically reviewing relevant literature at home and abroad, summarizing the core conclusions and limitations of existing research, and combining the analysis of typical cases, it extracts the key elements of architecture-transportation coordination, constructs an integrated design framework, and proposes targeted strategies. The study clarifies the core connotation, implementation principles, and technical pathways of this design model, providing theoretical support and practical reference for improving the spatial quality and utilization efficiency of areas around transportation hubs, and facilitating the high-quality advancement of urban renewal.

2. Theoretical framework of integrated architectural and transportation design

2.1. Core connotation

Integrated architectural and transportation design refers to the overall coordination of the functional layout and spatial organization of architecture with the streamline design and mode connection of transportation in the process of reconstructing underutilized land surrounding transportation hubs, with "people" as the core, so as to achieve a two-way interactive relationship where "architecture serves transportation and transportation empowers architecture". Functional coordination means the matching of architectural functions with transportation functions, such as the close connection between commercial buildings and bus stops, and between office buildings and metro entrances/exits. Spatial integration refers to the seamless connection between architectural space and transportation space, such as the connection between the underground floor of a building and metro tunnels, and between the second floor of a building and pedestrian corridors. Streamline optimization refers to the separation and guidance of pedestrian flow in buildings from traffic flow and pedestrian flow in transportation systems, such as realizing the passage of motor vehicles on the underground floor and the activities of pedestrians on the ground floor and the second floor through vertical stratification.

2.2. Design principles

2.2.1. People-oriented principle

Centering on the travel and living needs of passengers and residents, priority should be given to ensuring the safety and comfort of walking and non-motorized transportation, and reducing the time and distance of transportation transfer. For example, in the design, it is necessary to ensure the continuous and smooth flow of walkways around the hub, with the walking transfer distance not exceeding 300 meters.

2.2.2. Mixed-use principle

Promotion of the transformation of the land surrounding hubs from "single function" to "compound function" ought to be promoted by integrating functions such as transportation, commerce, office, residence, and leisure to form a "15-minute neighborhood", and realize the convenient connection of "work-living-travel" [2]. For example, within 1 kilometer around the hub, a complex building integrating commerce, office, and apartment is laid out to meet the temporary consumption needs of passengers and the daily needs of residents.

2.2.3. Multi-modal connectivity principle

Through the integrated design of transportation hubs and surrounding buildings, seamless transfer between different transportation modes is realized. For example, metro entrances/exits are set on the underground floor of buildings, bus stops and bicycle parking lots are set on the ground floor, and pedestrian corridors on the second floor connect hub buildings with surrounding commercial buildings.

2.2.4. Ecological priority principle

Integration of ecological concepts into integrated design is needed, and reducing the environmental impact of transportation and architecture through technical means such as green buildings, ecological buffer zones, and sponge cities, so as to improve the ecological quality of the area is crucial. For example, greening is set on the roof of buildings, and ecological isolation belts are set on both sides of traffic roads to reduce traffic noise and exhaust pollution [3].

2.3. Design framework

Based on the above core connotation and design principles, this paper constructs an integrated architectural and transportation design framework for the reconstruction of underutilized land surrounding transportation hubs (**Figure 1**). The framework is guided by the "goals of underutilized land reconstruction", with "mixed-use, spatial integration, transportation connection, and ecological coordination" as the four core dimensions. Each dimension includes specific design elements and technical methods, forming a four-level design system of "goal-dimension-element-method".

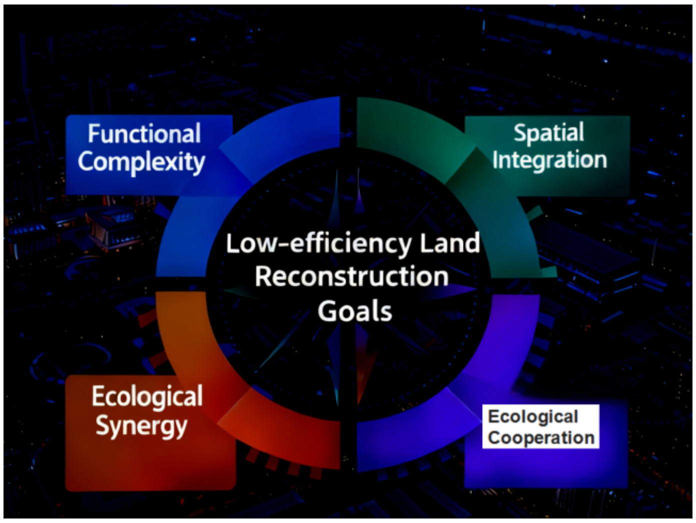

Figure 1. Integrated architectural and transportation design framework.

Note: Figure 1 is displayed in a central radiation structure, with the "goals of underutilized land reconstruction (efficiency, convenience, vitality, ecology)" at the center, and the four design dimensions around it. Each dimension is marked with specific design elements, such as the "mixed-use" dimension includes "functional ratio, functional layout, functional linkage" elements.

3. Integrated architectural and transportation design strategies for the reconstruction of underutilized land surrounding urban transportation hubs

3.1. Mixed-use strategy: Constructing a "transportation-living" integrated functional system

3.1.1. Scientifically determine the functional ratio

Based on the passenger flow of the hub and the surrounding demand, the functional proportion is planned in a differentiated manner (**Table 1**). The core area focuses on passenger services, with the proportion of commercial and transportation facilities exceeding 65%; the influence area takes into account residents' lives, with the proportion of residential and public services exceeding 40%; the extension area (1–3 km) is dominated by ecological residence, with the green space proportion not less than 20%, so as to balance the needs of different groups.

Table 1. Functional ratio table of land surrounding hubs

Area scope	Dominant functions	Functional ratio (reference value)	Service objects
Core area (0–0.5km)	Transportation + Commerce	Transportation facilities 35%, Commerce 30%, Office 20%, Others 15%	Passengers, short-term stay groups
Influence area (0.5–1km)	Office + Residence	Residence 25%, Office 30%, Public services 15%, Commerce 20%, Others 10%	Residents, long-term employed groups
Extension area (1–3km)	Residence + Ecology	Residence 40%, Ecological green space 20%, Public services 15%, Commerce 15%, Others 10%	Surrounding residents

3.1.2. Optimize the functional layout mode

Adoption of the "circle + axis" layout mode is essential (**Figure 2**). It forms three functional circles with the hub as the core, and forms functional axes along metro lines and urban trunk roads, connecting commercial complexes, community service centers and other facilities in series. For example, office and commercial buildings are laid out along metro lines, and residential buildings and schools are laid out along trunk roads to realize continuous and coordinated functions.

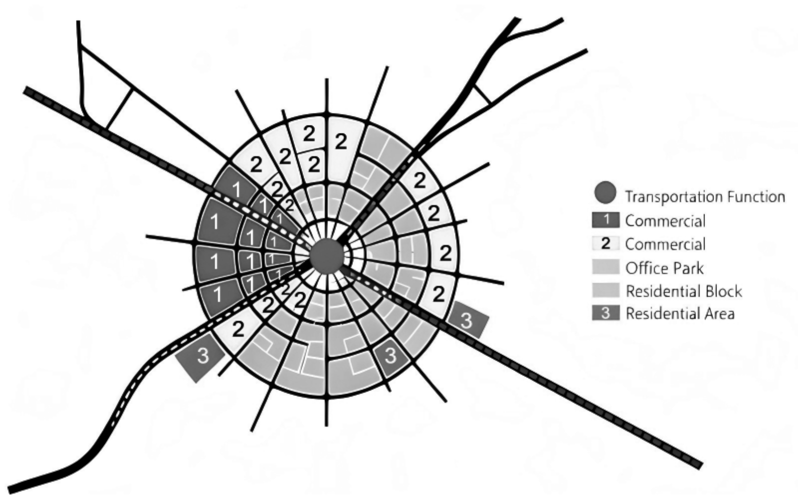

Figure 2. "Circle + Axis" layout mode.

Note: In Figure 2, the dot represents the hub, the solid black line represents the trunk road, the dotted line represents the metro line, and the black area represents the functional area (Area 1 represents transportation; Area 2 represents commerce; gray represents office; Area 3 represents residence), clearly presenting the "circle + axis" structure.

3.1.3. Promote the design of functional linkage

In architectural design, the concept of “functional linkage” is integrated to realize the complementarity and coordination between different functions. For example, in commercial buildings, bus stops and tourist service centers are set to facilitate passengers’ “shopping + transfer”. In office buildings, catering and leisure facilities are supporting to meet the daily needs of office workers. In residential buildings, community service centers and small-scale commerce are set to improve the convenience of residents’ lives. At the same time, through corridors, atriums and other spaces inside the building, convenient connection between different functional areas in the same building is realized [4].

3.2. Spatial integration strategy: Realizing seamless connection between architectural and transportation space

3.2.1. Vertical stratification: Constructing a three-dimensional spatial system of “underground-ground-aboveground”

The underground floor is used for laying out metro, underground parking lots (parking spaces are configured according to 15% of the peak passenger flow) and underground commerce. For example, the underground floor of the West Kowloon Station in Hong Kong connects the metro and commercial blocks, allowing passengers to reach the consumption area immediately after exiting the station.

The ground floor is designed with pedestrian squares (the area is configured at 0.2 m^2 per person), bus stops and 1–2 floors of commerce. The square uses greening to separate the staying area from the passing area to avoid crowding of pedestrian flow. The aboveground floor connects the hub with surrounding buildings through a 2nd-floor pedestrian corridor (with a net width of 3 meters and a rainproof ceiling), such as the Hongqiao Tiandi Corridor in Shanghai, realizing “rain-free transfer in the air” (**Figure 3**).

Figure 3. Hongqiao Tiandi Corridor in Shanghai.

Note: In Figure 3, the corridor connects the hub with commercial buildings, with glass guardrails and sunshades on both sides, and a ground walkway below, reflecting the concept of vertical stratification design.

3.2.2. Interface fusion: Coordinating the vision and function of architectural and transportation space

For the architectural interface, the street-facing interface of buildings surrounding the hub should adopt a "transparent and open" design, avoiding closed walls or solid facades. Glass curtain walls, floor-to-ceiling windows and other designs are used to enhance the visual interaction between the building and the street. At the same time, building entrances/exits should be set close to transportation stations. For example, the main entrance of a commercial building faces the bus stop directly to facilitate the flow of people into the building. For the transportation interface, the design of transportation facilities (such as bus stops, metro entrances/exits) should be coordinated with the style of surrounding buildings, adopting unified materials and colors to avoid abruptness. For example, the ceiling design of metro entrances/exits can draw on the roof shape of surrounding buildings to form a visual echo.

3.2.3. Open space integration: Constructing a multi-level open system

The "hub square–street green space–community park" should be integrated to form an open network. The hub square is equipped with tree-lined greening and rest facilities. The street green space is 5–10 meters wide, adopting a multi-layer structure of "arbor + shrub + ground cover". According to the area of the community park, fitness and amusement facilities are equipped, connected by walkways to enhance spatial vitality [5,6].

3.3. Transportation connection strategy: Constructing a multi-mode seamless transfer system

3.3.1. Optimize the organization of transportation streamlines

The principle of "stratified diversion and one-way circulation" is adopted to separate streamlines. In the design of motor vehicle streamlines, a special channel is set on the underground floor to connect the parking lot with the trunk road, and a one-way auxiliary road is set on the ground floor for temporary parking to avoid interfering with walking. In the design of non-motor vehicle streamlines, a 2.5-meter-wide colored asphalt lane is set along the outer side of the green space on the ground floor, equipped with isolation guardrails, and the capacity of the parking point is configured according to about 15% of the peak passenger flow. In the design of pedestrian streamlines, a three-dimensional network is formed through "underground passages + ground squares + aboveground corridors" to ensure "uninterrupted and undisturbed" passage.

3.3.2. Strengthen the connection of multi-mode transportation

For the five main transportation modes of "high-speed rail–metro–bus–walking–bicycle", targeted connection facilities are designed as follows:

(1) Connection between high-speed rail and metro: Metro entrances/exits are set on the underground floor of the hub building, directly connected with the high-speed rail exit, and the walking transfer distance is controlled within 100 meters. At the same time, clear guiding signs and moving walkways are set in the transfer channel to improve transfer efficiency;

(2) Connection between high-speed rail and bus: A bus hub station is set on the ground floor of the hub building, adopting a "harbor-style" platform design to avoid the impact of bus parking on trunk road traffic. The bus line planning covers residential areas, commercial areas and office areas within 3 kilometers around, with the departure interval not exceeding 5 minutes during peak hours;

(3) Connection between high-speed rail and bicycle: Shared bicycle parking areas and public bicycle rental points are set around the hub square, equipped with charging piles and maintenance stations. At the same time, barrier-free ramps are set between the bicycle lane and the hub entrance to facilitate cyclists to enter

the hub [7,8];

(4) Connection between high-speed rail and walking: A pedestrian square is set at the hub entrance, with the square area configured at 0.2 square meters per person during peak passenger flow. At the same time, the surrounding buildings are connected through pedestrian corridors and underground passages to realize the walking experience of "reaching the destination immediately after exiting the station".

3.3.3. Integration of intelligent transportation systems

Intelligent guidance means setting a certain number of electronic screens in transfer channels and stations to display real-time bus arrival and parking space availability, and developing an APP to provide navigation services. Intelligent parking integrates a certain number of parking spaces to realize sharing, supports APP reservation and license plate recognition for entry and exit, and the utilization rate is increased to more than 80%. Intelligent bus sets electronic station boards at stations and bus priority signals on trunk roads, with the traffic efficiency increased by more than 20%.

3.4. Ecological coordination strategy: Realizing the harmonious coexistence of "transportation-architecture-ecology"

3.4.1. Green building design

Energy conservation is reflected in the use of thermal insulation materials for external walls (thermal conductivity $\leq 0.6W/(m^2 \cdot K)$), heat-insulating glass for windows, and photovoltaic panels on the roof to meet about 15% of the power demand [9,10]. Water conservation adopts a rainwater recycling system, with an annual water saving of ≥ 50,000 tons, and uses low-flow fixtures with a water saving rate of ≥ 30%. Ecological materials use recycled concrete with a proportion of ≥ 20%, and environmentally friendly coatings indoors with a formaldehyde emission of $\leq 0.124mg/m^3$.

3.4.2. Construction of ecological buffer zones

For road buffer zones, a 10-meter-wide green belt is set on both sides of the trunk road, planted with noise-reducing and pollution-absorbing green plants, reducing noise by ≥ 15 decibels. For hub buffer zones, a 20-meter-wide green belt is set between the hub and residential areas, integrating wetlands and walkways to purify exhaust gas and provide leisure space for residents.

3.4.3. Application of sponge city technology

Technologies such as permeable pavement (for walkways and parking lots), rain gardens (accounting for 20% of green space), and green roofs (coverage rate ≥ 50%) are adopted. The rainwater permeability rate of the area is ≥ 40%, and the annual reduction of runoff pollution is ≥ 50%, which can effectively solve the problem of waterlogging [11].

4. Empirical case: Redevelopment project of a typical high-speed rail hub city

4.1. Project overview

Redevelopment project of a typical high-speed rail hub city is a national comprehensive transportation hub, handling 8.2 million passengers annually. Within 1 kilometer of the hub, there were originally 12 hectares of old industrial areas, 8 hectares of urban villages, and 5 hectares of scattered commercial spaces. The floor area ratio (FAR) was only 0.8, the peak congestion index reached 1.8, and the green space ratio was 15%. Covering a total area of 25 hectares, the project adopts an integrated redevelopment strategy, aiming to create a vibrant area integrating "transportation, ecology, and daily life" (**Figure 4**).

Figure 4. Schematic diagram of a comprehensive transportation hub in a high-speed rail area of a certain city.

4.2. Application of integrated design strategies

4.2.1. Mixed-use design

Core area (8 hectares) includes 3 hectares of hub supporting facilities, a 2.5-hectare commercial complex (with 12,000 square meters of underground commerce), and 1.5 hectares of office space. The commercial area is directly connected to bus stations, enabling passengers to make convenient purchases during transfers. Influence area (17 hectares) comprises 8 hectares of residential buildings (including 30% affordable housing), a 1.5-hectare community center, a 2-hectare school, and a 3-hectare park. It forms a "15-minute neighborhood" where residents can reach various facilities on foot.

4.2.2. Spatial integration design

The underground floor connects to the subway and a 2,000-parking-space garage. The ground floor features a 12,000-square-meter pedestrian plaza and bus stations. A 1.5-kilometer skywalk on the above-ground floor links the hub with commercial and office spaces. An 8,000-square-meter hub plaza is equipped with tree-lined greenery. Three kilometers of street green belts (8 meters wide) are laid out along the main roads. A 30,000-square-meter community park incorporates rain gardens, increasing the green space ratio to 35%.

4.2.3. Transportation connection design

Motor vehicles travel underground, while one-way auxiliary roads on the ground are reserved for temporary parking. Non-motorized lanes are arranged along green spaces, and pedestrian traffic is connected in three dimensions. The transfer distance between high-speed railway and subway is 80 meters, bus stations are 50 meters away from the plaza, non-motorized parking can accommodate 500 vehicles, and smart APPs provide navigation coverage. Twenty electronic guide screens are installed, the smart parking utilization rate reaches 85%, and bus priority signals improve traffic efficiency by 20%.

4.2.4. Ecological coordination design

Commercial and office buildings comply with the Green Building Evaluation Standard (Two-Star). The photovoltaic system generates 100,000 kilowatt-hours of electricity annually, the rainwater recycling system saves 50,000 tons of water per year, and recycled materials account for 60% of the total. A 10-meter green belt (with Platanus and Nerium oleander) is planted along the main roads, and a 20-meter wetland green belt separates the hub from residential areas, reducing noise by 18 decibels. 25,000 square meters of permeable pavement, 8,000 square meters of rain gardens, and 12,000 square meters of green roofs are adopted, achieving a rainwater infiltration rate of 40%.

4.3. Evaluation of project implementation effects

Monitoring data one year after completion shows as follows:

(1) Land use efficiency: The FAR has increased to 2.5, and the land output intensity has risen from 500,000 Chinese Yuan per hectare to 3 million Chinese Yuan per hectare;

(2) Traffic optimization: The congestion index has dropped to 1.2, bus speed has increased from 15 km/h to 22 km/h, and transfer time has been shortened to 8 minutes;

(3) Spatial vitality: The average daily passenger flow has increased from 5,000 to 30,000, the commercial occupancy rate reaches 95%, and the park receives an average of 2,000 daily visitors;

(4) Ecological improvement: The proportion of days with good air quality has risen from 80% to 92%, noise in residential areas has decreased from 68 decibels to 50 decibels, and waterlogging issues have been eliminated.

5. Conclusions and prospects

Addressing the underutilized land use problems around urban transportation hubs, such as functional imbalance, spatial fragmentation, and poor transportation connectivity, this study aims to “improve land use efficiency and spatial quality.” It constructs an integrated architecture and transportation design framework, and solves the core issue of “how to address inefficiency through integrated design” via four-dimensional strategies: mixed-use design, spatial integration, transportation connection, and ecological coordination. This research fills the gap in academic studies on the systematic integration of architecture and transportation in the context of “underutilized land redevelopment,” providing a comprehensive solution for hub land renewal. The study holds significant theoretical and practical value. Theoretically, it expands the TOD concept from “single hub planning” to the scenario of “underutilized land redevelopment,” improves the theoretical system of station-city integration, and clarifies the coordination logic of “function-space-transportation-ecology.”

Practically, specific strategies such as functional ratio tables and vertical stratification models can directly provide technical references for planning departments and design units. Methods like the “circle + axis” layout also offer insights for other urban renewal projects. Meanwhile, the study has limitations. The proposed strategies are mainly based on the common characteristics of typical domestic hubs, failing to fully consider the differentiated needs of cities of different sizes (e.g., first-tier cities vs. third- and fourth-tier cities) and different types of hubs (e.g., high-speed railway hubs vs. subway hubs). Additionally, it lacks an economic feasibility analysis of integrated design, such as key issues like construction costs and investment payback periods.

Future research should conduct targeted studies based on specific scenarios and quantitatively analyze the economic and social benefits. In future practice, it is necessary to adjust the details of the strategies according to factors such as hub type, city scale, and regional characteristics. For example, around high-speed rail hubs in small and medium-sized cities, the proportion of commercial and office functions can be appropriately reduced, and residential and ecological functions can be increased; around metro hubs, the connection with ground buses and non-motor vehicles should be strengthened. At the same time, it is suggested to carry out interdisciplinary cooperation, integrate technologies from various fields such as urban planning, architectural design, transportation engineering, and ecology, to further improve the scientificity and accuracy of the design, and help the high-quality development of urban space.

Disclosure statement

The author declares no conflict of interest.

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