Construction of Aerial Ecological Corridors Based on the Concept of Urban Renewal

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Abstract Urban traffic congestion is a significant challenge that contributes to high-density environments in urban areas, adversely impacting the living conditions of urban residents. The concept of urban renewal introduces new requirements and challenges pertaining to urban transportation issues. To mitigate urban traffic congestion, enhance the greening rate of the city, and improve the urban environment, the concept of developing urban aerial ecological corridors is proposed. An analysis of the current state of various urban aerial corridors in different cities indicates that aerial ecological corridors effectively enhance connectivity and accessibility between different spaces, representing a significant strategy for addressing the issue of urban traffic congestion. Aerial ecological corridors have the potential to enhance the vertical space within urban environments, increase the greening rate of cities, and promote the physical and mental health of urban residents. Additionally, these corridors can improve the connectivity of habitat patches and address the developmental needs of biodiversity. Consequently, they serve as a crucial foundation for guiding the future transformation of urban development towards a healthier and greener direction.

Keywords Urban renewal, Aerial ecological corridor, Connectivity, Accessibility

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Since the implementation of reform and opening-up policies, the urban built-up area has experienced significant expansion, accompanied by a growing urban population. This development has led to an increase in high-rise buildings and exacerbated urban traffic congestion, resulting in the emergence of various "urban diseases". The concept of urban renewal has significantly revitalized existing urban spaces and enhanced the innovative capacity of cities. Consequently, urban renewal has emerged as a primary driver of new growth and development within urban environments[1-2]. The concept of urban "organic renewal", proposed by Wu Liangyong, underscores the necessity of implementing urban renewal grounded in sustainable development to enhance urban quality[3-4]. Within this framework, Wu Liangyong asserts that urban renewal can enhance connectivity among regions, mitigate habitat fragmentation, and establish potential ecological corridors by assessing the connectivity index of the area during the construction of these corridors[5-6]. Meantime, the establishment of ecological corridors not only enhances connectivity between regions but also fosters functional connectivity among core biodiversity areas, thereby improving environmental quality[7-10]. The high-density human environment characteristic of urban areas has contributed to heightened stress levels in the lives and work of city residents, adversely affecting both physical and mental health. Urban green spaces offer a range of restorative benefits for these individuals, including stress alleviation and mood enhancement[11-14]. To enhance urban green spaces, three-dimensional space greening has emerged as a significant area of focus. Within this context, the greening efforts in aerial ecological corridors, which function as three-dimensional urban transportation spaces, are of particular significance.

The concept of green health cities has emerged as a significant approach to addressing "urban crowd" diseases and facilitating urban renewal since its introduction in 2020. In the aftermath of the epidemic, there has been a heightened awareness regarding public health, underscoring the critical importance of green space development[15]. In high-density living environments, the development of green health cities can facilitate the maintenance of both physiological and psychological health among residents, thereby decreasing the incidence of various diseases[16]. Recently, the concept of aerial slow corridors has been introduced to improve the green landscape and fully utilize the landscape landmark function of urban aerial slow corridors. Globally, green health cities are also evolving, as the presence of green spaces has been shown to alleviate stress[17]. In Singapore, the development of a garden city incorporates continuous pathways and multifunctional spaces that are strategically integrated between buildings. Research indicates that elevated open green spaces can effectively mitigate life stress and foster tranquil and relaxing environments[18].

In contemporary major cities, the prevalence of pedestrian overpasses, elevated bridges, and aerial corridors connecting buildings is on the rise. Vertical greening, vertical landscaping, and the construction of aerial gardens have emerged as prominent topics. The high-density living environment has attracted considerable interest within the field of green health landscape research, leading to the integration of landscape benefits in numerous public spaces. Despite the fact that most aerial corridors, which are inherently three-dimensional spaces, predominantly fulfill transportation roles, there is a notable lack of focus on ecological research and an even greater deficiency in the consideration of landscape functionality. The ecological functions associated with numerous urban aerial corridors remain inadequately defined. This review seeks to systematically discuss and summarize the developmental trends in the construction of aerial ecological corridors within the context of urban renewal.

1 Research trends of urban aerial ecological corridors

1.1 International research trends

1.1.1 Origins of aerial corridor applications.

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Research pertaining to urban renewal in international contexts can be traced back to the 1950s. The "large-scale demolition and construction" initiatives spearheaded by developers have significantly altered the original urban landscape, but this approach is no longer compatible with contemporary theoretical frameworks of urban renewal. During this period, urban renewal was still in its nascent stages, and the enhancement of urban environments, ecology, and urban greening rates had not yet achieved substantial progress.

1.1.2 Addressing complex urban environmental challenges. As urban areas continue to evolve, developed cities worldwide are encountering challenges including insufficient infrastructure, traffic congestion, environmental pollution, and habitat fragmentation. To address these issues, international efforts have concentrated on the establishment of ecological corridors aimed at enhancing connectivity between patches and improving accessibility across various regions. In 2020, Thorne et al.[19] examined issues such as traffic congestion and resource scarcity. Their findings indicate that open spaces, including vacant lots and the areas surrounding buildings, can not only enhance greening rates but also improve connectivity between different spaces. The study employs the landscape connectivity model Omniscape to model the connectivity of open spaces, specifically assessing the strength of connectivity among urban open spaces, thereby offering essential insights for urban spatial planning. In 2022, Lin Jiqing et al.[20] employed kernel density analysis to identify nodes and constructed ecological corridors and ecological nodes using the MCR model and GIS software, thereby strengthening connectivity across various regions and alleviating the urban heat island effect. In 2023, Zheng Songqing et al.[21] conducted an analysis of the relationship between cooling effects and various influencing factors, employing the Spearman correlation coefficient and the Lowess method. The findings suggest that the transition from compact mid-rise buildings to open high-rise structures yields a significant cooling effect, and the enhancement of vegetation is shown to contribute to the mitigation of the urban heat island effect.

1.1.3 Enhancing the physical and mental health of urban residents. As the scale of population migration into urban areas escalates, individuals are becoming progressively disconnected from the natural environment. Concurrently, urban green spaces are consistently diminishing, which adversely impacts both the physical and mental health of individuals[22]. In order to enhance the quality of life for residents, cities in other countries have initiated vertical development, which has led to an increase in green spaces. The advancement of three-dimensional environments, including aerial corridors, rooftop gardens, and vertical greening, is experiencing significant growth. In 2018, Hadi et al.[17] proposed the integration of high-rise spaces through the use of corridors, drawing upon literature from the field of geography and observational interviews. Their findings suggest that open green spaces situated at elevated altitudes can offer urban residents a tranquil mental environment. To promote the development of urban green spaces, Le Corbusier proposed that "aerial streets" serve the function of integrating public areas, natural landscapes, and community facilities within high-rise structures, thereby augmenting the green spaces available at ground level[23-24]. Researchers and scholars have identified that the incorporation of greenery in three-dimensional environments, such as aerial corridors, possesses considerable potential for enhancing individuals' physical and mental health[25]. The examination of urban renewal in international contexts reveals that the comprehensive development of cities is a progressive process. This evolution transitions from enhancements in urban transportation systems to ecological optimization, ultimately culminating in the promotion of human physical and mental health. When analyzed through the lens of regional connectivity, it becomes evident that urban renewal is intrinsically associated with the establishment of aerial ecological corridors.

1.2 Domestic development

1.2.1 Origins of aerial corridor applications. As urbanization continues to advance, the issue of traffic congestion has intensified significantly. In response to challenges associated with high urban density, a cohort of scholars led by Wu Liangyong in the 1980s proposed concepts such as "organic urban renewal", which aimed to develop a novel planning framework for the analysis of old cities[26]. In accordance with the concept of urban renewal, the implementation of aerial slow corridor systems in urban areas has increased as a strategy to mitigate traffic congestion. In 2007, Guangzhou proposed the interconnection of buildings within Zhujiang New Town, leading to the completion and operationalization of the initial set of aerial pedestrian corridors.

1.2.2 Enhancing connectivity between urban spaces to mitigate habitat fragmentation. Around the 21st century, landscape scholars Yu Kongjian and Zhu Qiang introduced the concept of corridors. In 2014, Wu Dezheng et al.[27] employed GIS and ArcGIS 9.3 software to identify potential corridors by analyzing the connectivity index among urban spaces, employing 3S technology and the minimum cost distance method to improve landscape connectivity and mitigate habitat fragmentation. In the same year, Wang Ling[28] conducted an assessment of urban residents' satisfaction regarding aerial corridors, utilizing indicators such as accessibility, convenience, comfort, and aesthetics. The findings revealed that residents expressed a high level of satisfaction with the aerial corridors, with connectivity and accessibility between spaces identified as critical factors. Building upon international methods for the development of ecological corridors and concepts of urban renewal, scholars in China have made significant advancements in organic urban renewal and ecological corridors in the country.

1.2.3 Enhancing the satisfaction of urban residents. In contrast to international research, domestic studies on urban renewal and aerial ecological corridors have a relatively brief history and a slow rate of development, primarily depending on the adaptation, enhancement, and application of methods developed in foreign research. In 2009, Huang Ying[29] highlighted spatial connectivity and landscape coherence in her research, employing the SD method along with sample photographs to perform psychological assessments of local tourists, thereby evaluating their satisfaction with the spatial environment. The treatment of spatial connection between the five-arch stone bridge in the park and the surrounding environment is crucial for enhancing tourist satisfaction. In 2021, Li Huimin[30] conducted an analysis of the advantages and disadvantages associated with different types of aerial corridors, concluding that aerial slow corridors have the potential to improve the convenience of urban transportation systems and enhance the comfort of citizens. The integration of green spaces within aerial corridors has the potential to enhance urban greening areas, thereby mitigating the adverse emotional effects experienced by residents in high-density environments and offering them supplementary spaces for relaxation.

2 Case analysis

2.1 Inter–building corridor

2.1.1 Aerial corridor between residential areas. Modern aerial corridors in residential areas can significantly enhance accessibility between different floors (Fig.1). These corridors contribute to an improved lighting environment for residents, offering public spaces for viewing and

relaxation. They transcend the limitations of traditional ground-level activities and establish cross-floor social venues that foster community integration. The gardens situated along the aerial corridors provide a restorative viewpoint of the city, fostering a tranquil atmosphere that can promote relaxation among residents and improve their overall living experience. This design element serves to mitigate the psychological stress associated with high-rise living. The incorporation of greening along the corridors contributes to a reduction in surface temperatures in the vicinity of the buildings, thereby enhancing the surrounding environment and local climate.

2.1.2 Aerial corridor between commercial areas. The aerial corridor situated between commercial streets integrates the construction of commercial structures on both sides. Its primary objective is to link the large commercial complexes on either side, thereby dismantling physical barriers to create a "commercial community" that address the needs of shoppers, enhance convenience and accessibility for pedestrian traffic, improve the overall shopping experience, and attract a greater number of customers (Fig.2). This function mitigates pedestrian flow at crosswalks and decreases the frequency of traffic accidents. The incorporation of greenery and the strategic placement of small facilities within the corridor can create resting and viewing areas, thereby improving the overall experience of individuals in the commercial area. When the design of the corridor in the commercial district is more appealing, the aerial corridor, enhanced by green landscapes and modern technology, emerges as a popular destination for visitors, thereby stimulating consumption in the surrounding area.

2.1.3 Aerial corridor between hospitals. The aerial corridor connecting hospitals significantly enhances the interconnectivity of buildings and improves accessibility and connectivity across diverse areas (Fig.3). In emergency scenarios, such as the transfer of critically ill patients, the aerial corridor facilitates a safe and expedited passage, thereby minimizing delays associated with ground traffic. The efficiency of movement for both patients and medical staff will be enhanced, as minimizing the distance and duration of movement is particularly crucial for patients who necessitate frequent examinations or surgical procedures. The corridor serves to connect buildings with diverse functions, including the emergency department, inpatient wards, and laboratories. This configuration effectively reduces transfer time and enhances treatment efficiency. The hospital environment significantly influences patients' psychological well-being. Specifically, the incorporation of natural lighting and green design elements in the corridors facilitates patient recovery. Additionally, the aerial corridor should integrate accessibility features to ensure unobstructed passage for wheelchairs, stretchers, and other mobility aids, thereby improving both accessibility and safety within hospitals.

2.1.4 Aerial corridor between schools. The aerial corridor between schools primarily facilitates connectivity among buildings and enhances accessibility for students commuting to and from classes (Fig.4). The corridor is characterized by the presence of large trees strategically positioned throughout the space, which enhances its aesthetic appeal and ecological significance. Additionally, it functions as an emergency passage, offering a potential escape route during emergencies such as fires or earthquakes. Furthermore, the corridor promotes interdisciplinary communication by facilitating interactions among students from various academic disciplines, thereby fostering project collaboration.

2.1.5 Urban viaduct. The primary objective of urban viaducts is to improve the convenience of inter-regional transportation, thereby enhancing accessibility and connectivity within the surrounding area (Fig.5). The space beneath the viaduct is enhanced with climbing plants to promote greening efforts, thereby improving the urban ecological environment, increasing the urban greening rate, alleviating driver fatigue, and reducing the incidence of traffic accidents. Furthermore, the vegetation situated between viaducts can help mitigate urban noise, pollution, and ecological fragmentation.

2.1.6 Urban overpass. This aerial corridor is located not at the intersection of roads, but rather in the center of the roadway. It is designed to assist residents on both sides in crossing through designated pedestrian crossings, while simultaneously separating motor vehicles from non-motorized vehicles. This particular type of overpass is prevalent, primarily designed to facilitate the movement of urban residents, mitigate traffic congestion, and decrease the frequency of traffic accidents (Fig.6). Certain overpasses have integrated green spaces, and the decorated overpasses have become attractive destinations, improving the overall quality of the urban environment.

3 Discussion and conclusions

3.1 Discussion

Aerial ecological corridors situated between buildings can facilitate accessibility between different areas and decrease walking time for residents. The incorporation of greenery in these spaces can augment the overall green space within the city, enhance the quality of life for residents, offer recreational opportunities for urban inhabitants, and foster communication and interaction among residents.

The segregation of pedestrian and vehicular traffic on aerial corridors, such as overpasses, has the potential to reduce traffic congestion and lower the frequency of traffic-related accidents within urban areas. Additionally, the integration of vegetation on these overpasses can contribute to the mitigation of habitat fragmentation, promote biodiversity, and enhance the overall quality of urban environment.

Aerial corridors constructed as viaducts have the potential to link extensive areas of space. The incorporation of vegetation on these viaducts not only mitigates driver fatigue on highways but also improves the overall environmental quality of the region. Furthermore, the introduction of greenery beneath viaducts serves as an essential strategy for advancing urban vertical greening, thereby expanding urban green spaces and enhancing biodiversity.

3.2 Conclusions

Aerial ecological corridors can effectively alleviate various traffic congestion challenges while simultaneously increasing the proportion of urban green spaces and enhancing biodiversity conservation. These corridors help to mitigate habitat fragmentation and improve spatial accessibility within urban environments. From the perspective of environmental enhancement, the cultivation of plants in aerial corridors can significantly expand greening coverage. This expansion increases the green volume within urban spaces and improves the overall environmental quality of urban areas, thereby effectively promoting the physical and mental health of urban residents. Furthermore, aerial ecological corridors serve as migration, foraging, and habitat pathways for a diverse array of species. These corridors connect fragmented ecological patches, thereby facilitating species exchange and gene flow, which is advantageous for the preservation and enhancement of biodiversity. The implementation of aerial corridors provides an expanded habitat for urban avifauna, insects, and various other organisms, thereby fostering a more stable and robust urban ecosystem. Additionally, these corridors improve connectivity and accessibility among urban blocks, mitigate habitat fragmentation, and significantly enhance the integration of urban

Fig.1 Spatial corridor in residential areas

Fig.2 Aerial corridor between commercial streets

Fig.3 Aerial corridor between hospitals

Fig.4 Aerial corridor between schools

Fig.5 Urban viaduct

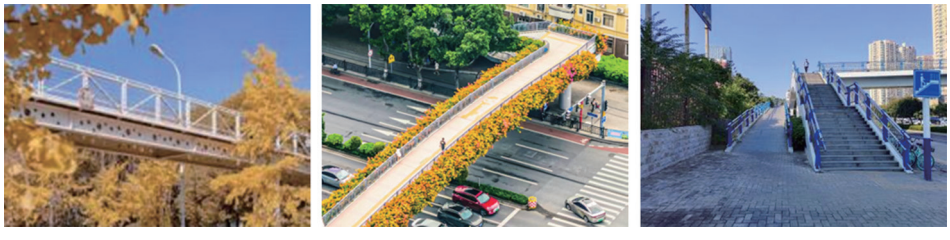

Fig.6 Urban overpass

ecological corridors with green patches.

Aerial ecological corridors represent a crucial element of three-dimensional transportation systems. The implementation of aerial walkway systems can link various commercial centers with transportation hubs, and facilitate movement between buildings. This integration not only alleviates ground traffic congestion but also enhances the efficiency of movement across different regions, thereby enhancing the quality of life and contributing to the increased satisfaction of urban residents. In the future, construction may be approached through the lens of multidimensional urban spaces, thereby offering urban residents a variety of living experiences.

Currently, urban aerial ecological corridors face several challenges. The ecological functions of these corridors are limited, and their connectivity is inadequate. Many of these aerial corridors serve primarily as "decorative landscapes" and do not provide the necessary ecological support for animal migration. The selection of inappropriate plant species, the extensive reliance on monocultures of non-native tree species, and the poor stress resistance coupled with an inability to attract local organisms do not contribute positively to urban biodiversity. The deficiencies in maintenance, the malfunctioning of the irrigation system, and the inadequate measures for the prevention and control of diseases and pests have resulted in the degradation of vegetation. In the subsequent phase of developing urban aerial corridors, it is essential to integrate plant combinations, prioritize the selection of native species, and establish a three-dimensional plant structure comprising trees, shrubs, and grasses. This approach aims to enrich plant diversity and enhance urban biodiversity. It is essential to enhance the frequency of maintenance activities, optimize the extent of green spaces to the greatest possible degree, offer urban residents a conducive environment for both physical and mental relaxation, and establish an aerial ecological corridor.

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representation, which failed to account for the interaction between indoor and outdoor wind environments, particularly in scenarios where windows are open. Consequently, future research should integrate the aforementioned two aspects, building upon the conclusions drawn from existing studies, such as simulations of the wind environment during winter under conditions of high-frequency wind direction. Such an approach will enhance the understanding of how layout factors in courtyards influence the wind environment. The aim is to gather more pertinent data regarding the wind conditions in rural courtyards, which will hold practical significance for the design of future courtyard spaces.

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