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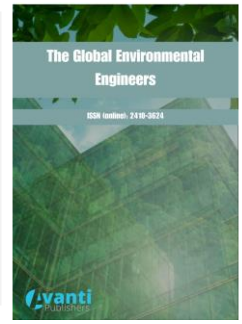

Study on the Function and Planning of Urban River Ecological Corridor

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ABSTRACT

This study investigates the functions and planning principles of urban river ecological corridors, highlighting their vital role in urban ecosystems. Urban rivers, which include both waterways and riparian zones, provide essential ecosystem services such as habitat provision, temperature regulation, pollutant filtration, and flood mitigation. However, rapid urbanization has led to the degradation of these corridors, resulting in habitat fragmentation, reduced biodiversity, and compromised ecological integrity. The paper reviews global efforts and strategies for urban river restoration, emphasizing the significance of ecological methods and public participation in the planning process. A case study of the Yuhangtang River in Hangzhou, China, exemplifies various restoration approaches, including traditional flood control, ecological restoration, and landscape design, all assessed using a multi-criteria decision-making (MCDM) framework. The findings indicate that employing the MCDM tool can facilitate planning that integrates the functions of river ecological corridors. Additionally, plans that achieve a balance of ecological, economic, social, and aesthetic benefits are more likely to gain public acceptance.

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1. Introduction

Rivers have historically been central to the development of cities due to their vital roles as providing resources of food, water, power, and transportation [1, 2]. Rivers play a crucial role in urban ecosystems, significantly contributing to sustainable urban development. Urban rivers and their associated riparian zones, encompassing both aquatic and terrestrial components, constitute complex ecosystems that represent a distinctive integration of urban blue and green spaces. Functioning as essential components of urban ecosystems, these rivers perform critical ecological roles, including providing habitats for diverse species, regulating water flow, filtering pollutants, and acting as natural buffers. Additionally, they offer valuable ecosystem services that enhance the quality of life and well-being of urban residents [3]. However, they also stand as central features in urban landscapes, making them ecologically sensitive areas influenced by both natural processes and human activities [4]. Urbanization is a global phenomenon that poses significant ecological challenges, driving economic, social, and environmental transformations with far-reaching ecological impacts. In highly industrialized cities, river corridors - whose primary waterways support transportation and industrial activities - have undergone extensive modification, often losing much of their natural state [5]. While urban rivers harbor substantial biodiversity, they are also focal points for urban development, making them ecologically sensitive zones shaped by the dynamic interplay of natural processes and anthropogenic influences. Furthermore, the absence of effective urban planning and comprehensive environmental protection strategies has led to severe environmental degradation, leading to habitat fragmentation, reduced connectivity, and compromised ecological integrity and biodiversity [6, 7]. The unprecedented growth rate of cities and towns across the country has made it urgent to understand the impact of urbanization on natural ecosystems and the services they provide [8]. This issue has become the focus of numerous studies assessing the effects of urbanization on biodiversity and human quality of life [9, 10]. Among these natural forms, rivers have historically provided numerous opportunities for direct and indirect interactions between humans and nature, contributing to the well-being of all organisms through multiple ecosystem services [11-13]. However, as urbanization leads to the continuous expansion of impervious surfaces, rivers experience channelization, loss of riparian habitat, and increased pollution from runoff [14]. This degradation causes rivers to gradually transform into inanimate "pipes" that fail to facilitate interaction between humans and nature.

Urban rivers significantly enhance landscapes by offering opportunities for visual enjoyment, leisure, entertainment, and cultural education [15]. A review of existing literature and data indicates a strong correlation between urban rivers and urban biodiversity [16-18]. Serving as essential habitats for numerous aquatic and water-dependent species, urban rivers are pivotal in supporting the survival and reproduction of various animal and plant populations, thus fostering urban biodiversity [19]. However, the process of urbanization has progressively disturbed these river habitats through anthropogenic activities, leading to a gradual degradation of hydrosystems.

Although the degradation of the ecological corridor functions of urban rivers has garnered some attention from society, the discussion of their corridor functions and the study of planning principles at the planning level require further exploration [20]. Therefore, conducting relevant research has significant theoretical and practical value. At the same time, this study plans to include some indicators that characterize river ecological functions into the expert scoring index system and integrate river ecological functions into the planning target system through the TOPSIS method in the multi-criterion decision-making (MCDM) method.

2. Development and Challenges of Urban River Ecological Corridors

2.1. Development and Importance of Urban River Ecological Corridors

In his book *Landscape Ecology*, Forman proposed that corridors can integrate into the landscape pattern in various ways, summarizing their applications in landscape transportation, protection, and aesthetics into five major functions of corridors [21]. This work laid the foundation for the creation and development of corridor theory, making it an essential component of modern landscape ecology. Since the turn of the 21st century, scholars have conducted extensive research on ecological corridors. In recent years, with awakening of ecological awareness, the protection and restoration of river ecological corridor has become a focal point of urban development [22]. The development of river corridors worldwide began in 1881 with the Emerald Necklace Park in Boston, USA. Since the 20th century, many cities have undertaken the planning and establishment of blue and green infrastructure networks. Projects like the Miami Greenway, Plan de Renaturalización del Rio Manzanares, and the Bishan-Ang Mo Kio Park in Singapore reflect the significant development of river corridors [23-25].

Currently, global temperatures are rising, and due to the urban heat island effect, urban ecosystems are experiencing more severe impacts than other ecosystems [26]. Urban river ecological corridors play a crucial role in delivering essential ecosystem services within urban environments. These services include temperature regulation, increased air humidity, mitigation of extreme weather events, and filtration of air, soil, and water pollutants. Additionally, as integral components of urban aquatic ecosystems, urban rivers contribute to the mitigation of urban heat, functioning as significant cooling islands [27, 28], thereby supporting public well-being and health [29]. However, most urban water bodies are in poor ecological condition concerning water quality integrity, nutrient concentration, and riverbank interference, as well as riverbank vegetation, riverbed sediments, enterococci, and dissolved oxygen levels [30]. The ecological quality and species richness of urban rivers are declining due to urbanization [31]. In China, according to a report released by National Environmental Protection Agency, 69.1% of the 94 river urban sections evaluated were polluted to varying degrees, rendering them unsuitable for any practical use [32]. To make matters worse, among China's 295 cities at or above the prefectural level, a total of 216 cities identified 1811 black and smelly water bodies [33].

In response to these challenges, numerous countries have undertaken initiatives to reintegrate multiple uses of urban rivers. A variety of ecological methods have been employed to restore the ecological functions of these waterways while minimizing management interventions along riverbanks. Consequently, urban river restoration efforts have been progressively implemented worldwide, aiming to enhance the ecological quality of urban rivers and reestablish the connection between humans and the natural environment [34]. In particular, the restoration and enhancement of urban rivers have been employed as solutions to address various social and environmental challenges through the design of "blue-green" infrastructure [35, 36]. In 2001, the Chinese government officially initiated a comprehensive restoration and management program for the Tarim River Basin, which included ecological water transportation and vegetation restoration projects. This initiative successfully rehabilitated the damaged ecosystem, gradually transforming the area into a green corridor. Since the early 21st century, extensive scholarly research has focused on ecological corridors. Recently, as the construction of ecological civilization has gained momentum, the development of river corridors has emerged as a central theme in urban planning. Over the past few decades, China has implemented several initiatives aimed at restoring and enhancing urban river conditions, including efforts to control black river pollution, the garden city movement, and the sponge city plan [37-39].

However, these top-down initiatives frequently prioritize technology-driven methods for river restoration, often neglecting critical social dimensions and the importance of public participation. In addressing this gap, Bonthoux's research team utilized behavioral mapping and questionnaire surveys to uncover that urban residents possess a profound perception and attachment to their local wild environments. Their findings offer valuable insights for the design of urban river spaces, aimed at enhancing urban biodiversity and enriching natural experiences [40]. Increasingly, degraded urban river waterfront spaces have been transformed into public open spaces, thereby enhancing the ecological functions of rivers, improving flood control capabilities, and offering citizens recreational opportunities [41]. Empirical evidence suggests that the restoration of urban rivers can change people's perceptions of rivers, enhance interactions with them, and rebuild the connection between humans and nature [42].

2.2. Role of Urban Rivers as Functional Carriers of Ecological Corridors

Maintaining and restoring watershed vegetation corridors in urban landscapes is essential for safeguarding freshwater biodiversity [43, 44]. Campos's research team identified urban rivers as novel ecosystems predominantly composed of non-native species, finding that urbanization negatively affects riparian vegetation. Their findings emphasize that river water quality plays a critical role in shaping both aquatic and terrestrial communities. The natural structure of riparian zones is closely linked to biodiversity conservation, suggesting that minimizing human disturbances to these areas can significantly enhance biodiversity [31]. Despite their ecological importance, rapid urbanization has fragmented wildlife habitats, creating isolated patches that function as ecological islands. This fragmentation reduces connectivity among populations, disrupts genetic flow, and intensifies inbreeding depression, increasing the risk of species degradation and extinction.

Urban river habitats function as wildlife corridors, providing ecological benefits that extend beyond traditional recognition. These rivers supply essential water resources to organisms and serve as key routes for the movement and foraging of coastal animals, particularly in the absence of precipitation [45]. Growing awareness of the ecological significance of urban rivers has led to the emergence of "wildlife-inclusive urban design," a concept that promotes the integration of biodiversity-oriented strategies into urban planning. This approach enhances the value of blue-green spatial design by recognizing urban rivers as vital elements for biodiversity protection and ecosystem services [46].

River ecological corridors play a vital role in reestablishing connectivity among fragmented habitats, enabling the migration, interaction, and reproduction of wildlife. These corridors promote gene flow, ensuring population survival and species resilience. By providing suitable living and migration pathways for diverse species, river corridors mitigate the adverse effects of habitat fragmentation and enhance ecosystem functionality. They support the recovery of endangered and rare species while maintaining genetic diversity, contributing to the stability, balance, and resilience of natural ecosystems [47].

2.3. Planning Process Integrated into River Ecological Corridors

The integration of river ecological corridors into urban planning is essential for promoting sustainable development, enhancing biodiversity, and improving community well-being. Integrating river ecological corridors into urban planning requires a comprehensive framework that encompasses various phases:

1) Defining spatial scope. Understanding the spatial scope of river corridors is critical for effective planning. This includes defining boundaries based on ecological needs and human activities, ensuring that both conservation and development goals are met [22].
2) Multi-objective involvement. Engaging local communities, government agencies, and other stakeholders in the planning process fosters collaboration and ensures that diverse perspectives are considered. Public involvement can enhance the legitimacy and effectiveness of implementation strategies [48].
3) Ecological Assessment. Conducting thorough ecological assessments helps identify the current status of river ecosystems, including hydromorphological conditions, water quality and biodiversity levels. These assessments inform decision-making by highlighting areas in need of restoration or protection [48, 49].
4) Ecological functions driven Planning. Clarify the goals of ecological corridor construction, such as protecting biodiversity, improving water quality, and providing leisure and entertainment space. Select specific indicators based on ecological function goals and then integrate them into the regular technical path. Its core includes ecological function planning and connectivity planning. Ecological planning includes functional spatial planning such as ecological revetment, wetland restoration, and ecological greenways. Connectivity planning is to ensure the connectivity of ecological corridors in different dimensions.

3. Case Study

3.1. Material and Methods

3.1.1. Study Area

Yuhangtang River is in Yuhang District of Hangzhou City, China, the main downstream of the Tiao River (119.92◦ E – 120.05◦ E, 30.26◦ N – 30.31◦ N) with a total length of 19.8 km, an average width of 34.9 meters and an average water depth of approximately 1.6 meters. Over the long history, many riverside wetlands have been transformed into urban construction land, rivers have been straightened, and riverbanks have hardened. Thus, water quality has declined, and biodiversity has been seriously lost. In recent years, the Yuhangtang River has become a transportation-oriented river course. In recent years, due to the needs of the development of Hangzhou Third City

Center, i.e. Hangzhou Future Sci-tech City, some basic water quality treatment and river regulation work of Yuhangtang River have been launched. However, water ecological restoration work in other aspects other than water quality is still progressing slowly, and there are still many problems that hinder the ecological functions of the Yuhangtang River, including the river's role as an urban ecological corridor. This case is an in-depth work based on this (Fig. **1**).

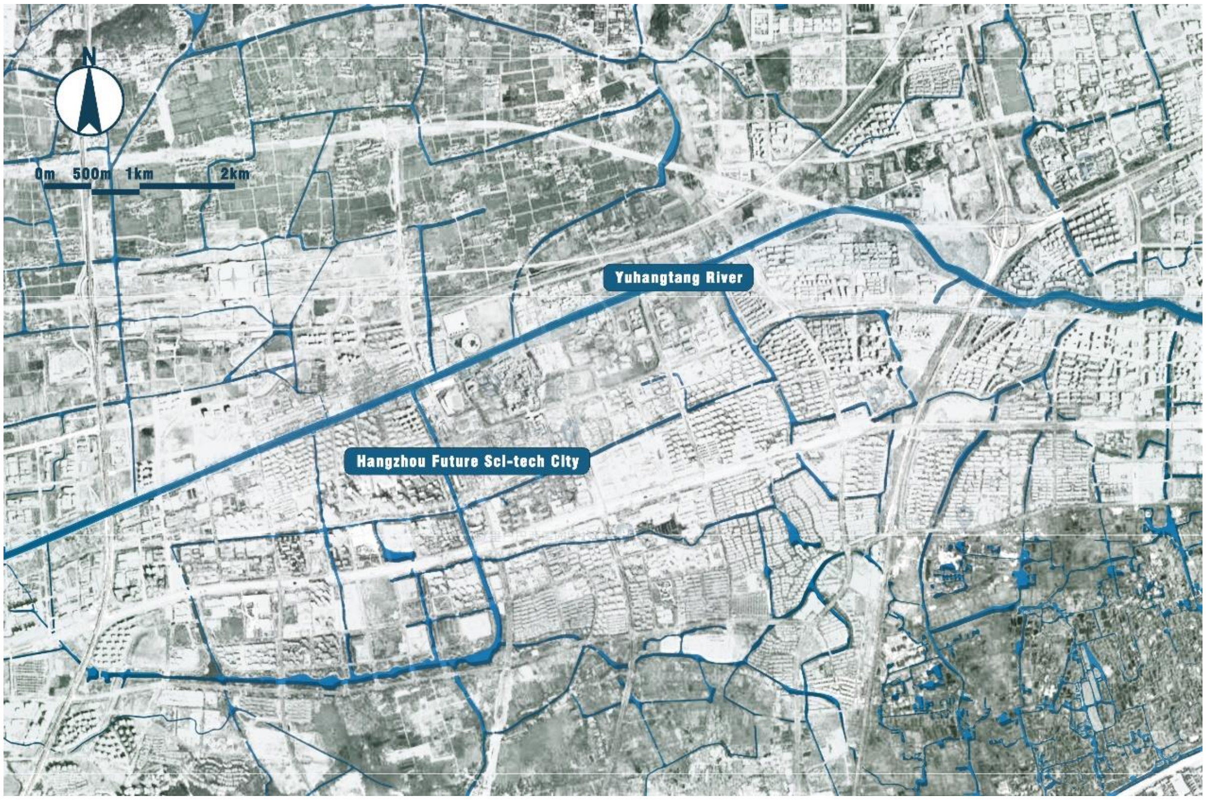

Figure 1: Location of study area.

3.1.2. Method

Generally, the planning method that integrates the ecological corridor function of rivers is similar to conventional planning methodologies. However, the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution), a technique within the realm of multi-criterion decision-making, is incorporated into the planning process [50, 51]. The expert scoring system includes specific indicators that characterize the ecological functions of rivers. Experts evaluate the weights assigned to each indicator and score them, accordingly, ultimately determining the planning strategy that aligns comprehensively with the established evaluation criteria.

3.2. Process of Planning and Evaluation

3.2.1. Plannig Goals and Criteria

Based on relevant literature and through exchanges with experts, the final project goals include the following aspects: water quality, habitat, connectivity, flood mitigation capabilities, landscape aesthetics and public acceptance, and economics. Since drawings are only theoretical solutions, the final actual effect cannot be directly inferred. Therefore, the indicators related to ecological corridors in the expert scoring plan mainly screen two indicators: improve habitat and increase connectivity.

The evaluation criteria for these six aspects are as follows:

- Improve water quality: Based on the current situation of water quality indicators such as COD, NH_3-N, and TP.

- Improve habitat: Based on the current situation of the number and distribution uniformity of different habitat types.
- Increase connectivity: based on patch connectivity index, ecological network analysis, etc.
- Flood mitigation capacity: Based on flood risk simulation results.
- Landscape aesthetics and public acceptance: Based on landscape design scores and public questionnaire survey results.
- Project cost: Construction and maintenance costs based on each plan.

3.2.2. Data Collection and Weight Setting

The different categories of data are collected by different methods.

- Water quality data: Relevant data collected through water quality monitoring stations.
- Habitat data: Remote sensing images and field surveys.
- Connectivity data: GIS analyzes the connectivity of ecological corridors, using connectivity indices and ecological network tools for analysis.
- Flood mitigation data: Flood risk simulation using hydrological models.
- Landscape and public feedback: public questionnaires and landscape expert ratings.
- Cost data: project design and budget reports.

The analytic hierarchy process (AHP) is used to determine the standard weights and integrate the opinions of 5 experts and stakeholders. The weighting results are as follows: water quality improvement 25%, habitat diversity index 22%, corridor connectivity 18%, flood mitigation capacity 10%, landscape aesthetics and public acceptance 18%, project cost 7%.

3.2.3. Proposal Generation and Evaluation

Three teams designed three alternative plans based on different focuses, namely Plan A, Plan B and Plan C.

Plan A: The river management method of traditional water conservancy projects is mainly based on, hardening riverbanks and standardized drainage, with a focus on improving flood control capacity (Fig. **2-3**).

Figure 2: Plan of one typical reach of Plan A.

Figure 3: Perspective renderings of one typical reach of Plan A.

Plan B: Emphasizes ecology and combines ecological restoration with connectivity improvement. The main planning focuses include ecological slope protection, vegetation restoration, and blue-green space connectivity (Fig. **4-5**).

Figure 4: Plan of one typical reach of Plan B.

Figure 5: Perspective renderings of one typical reach of Plan B.

Plan C: Emphasizes the beauty and leisure and entertainment of the waterfront landscape, and combines appropriate ecological restoration. The planning focuses include adding leisure facilities and vegetation restoration (Fig. **6-7**).

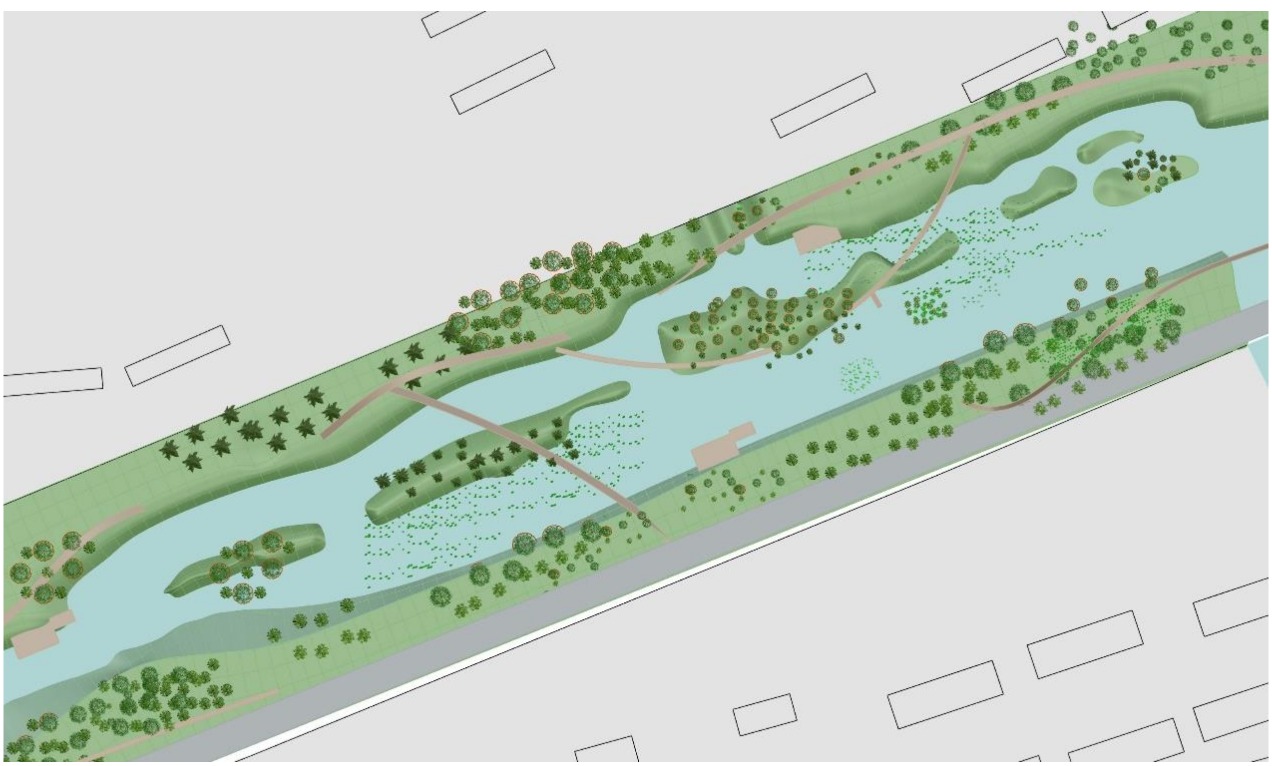

Figure 6: Plan of one typical reach of Plan C.

Figure 7: Perspective renderings of one typical reach of Plan C.

3.2.4. Plan Evaluation

The experts' evaluation is grounded in the interpretation of relevant indicators, an assessment of the current situation, and an examination of proposed plans. This includes analyzing information presented in master plans, elevations, and perspective renderings, as well as incorporating subjective scoring based on personal experience. Based on the rating status of 5 experts and stakeholders, the score for each item ranges from 1 to 10, TOPSIS method was used to evaluate the total score of each plan.

Calculate Closeness Coefficient Ci.

$$Ci = \frac{D^-}{D^+ + D^-} \tag{1}$$

The result is as follows (Table **1**):

Table 1: Scores of three plans based on TOPSIS.

Indicators	Plan A	Plan B	Plan C
Water quality improvement	6	8	7
Habitat diversity index	5	9	6.5
Corridor connectivity	4	8.5	6
Flood mitigation capacity	7.5	6	7
Landscape aesthetics and public acceptance	3.5	7	8
Project cost	8	5.5	6.5
Ci	0.3166	0.6714	0.5036

Plan A focuses on flood control and cost management but has low ecological benefits, poor connectivity, and high project costs. Plan B scored the highest in terms of ecological connectivity and habitat diversity, while Plan C scored higher in landscape design and public acceptance. Ultimately, Plan B was recommended as the best option due to its outstanding performance in enhancing ecological connectivity and biodiversity. Plan B has the largest Ci value (Closeness Coefficient), and its performance in various indicators is relatively balanced and close to the ideal solution, so it is the optimal plan.

3.3. TOPSIS Method in River Ecological Planning

TOPSIS method is a widely used multi-criteria decision-making (MCDM) tool. Its application in urban planning allows decision-makers to evaluate and prioritize various projects or alternatives based on multiple criteria, facilitating more informed and effective planning outcomes [52, 53]. In the case of Yuhangtang, expert scoring led to the identification of a plan that effectively balances ecological, social, economic, and aesthetic functions, satisfying the requirements of multiple stakeholders. This approach is expected to save considerable time and costs in subsequent in-depth design phases. While we maintain a cautiously optimistic outlook regarding the actual outcomes of post-completion, it is important to note that all evaluations are contingent upon the information provided in the plan and the subjective judgments of the experts involved. Consequently, this planning initiative, which integrates ecological functions, serves as a quantitative specification for ecosystem functionality. Thus, the impressive ecological functions demonstrated may merely reflect a superficial appeal rather than a robust underlying efficacy.

4. Conclusion and Discussion

This study suggests that the planning of urban river ecological corridors is primarily developed through subjective quantitative analysis of indicators such as ecological, economic, and social values, based on strategies that balance human needs with natural systems. A plan is recommended as the best performance in ecological connectivity and habitat diversity. The TOPSIS method effectively supports multi-criteria decision-making in urban planning, helping to prioritize projects based on diverse criteria. In Yuhangtang's case, this approach led to the selection of a plan that balances ecological, social, economic, and aesthetic functions, saving time and costs for future design phases.

It can reference the suitability analysis developed by McHarg to quantitatively evaluate various components within an ecosystem, which can be used to assess different development options, such as restoring and maintaining natural ecosystems and protecting biodiversity; using vegetation and water purification functions to reduce pollutants entering rivers, thereby filtering contaminants; reducing soil erosion through vegetation coverage and riverbank reinforcement; and mitigating the impact of floods on cities through the natural regulation function of river corridors, among others, to propose the most appropriate planning strategy. However, some scores are subjective and depend on experts' interpretations of the simulation results, which carry significant uncertainties, and the accuracy of the scheme simulations requires further verification. By adhering to these concepts and principles, planning and implementing ecological corridors along urban rivers can significantly contribute to creating more resilient, sustainable, and livable cities.

Conflict of Interest

The authors declare no conflict of interest.

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