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Research on the evolution of spatial morphology and methodology of landscape resilience design in urban waterfront areas

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Abstract: Urban areas are currently at a pivotal stage of renewal and enhancement of the human living environment. Waterfront zones, as critical spaces embodying regional culture and the spirit of place, hold significant practical value for research on spatial morphology evolution and landscape design. Responding to emerging demands for public waterfront spaces amid urban renewal, this study concentrates on the historical evolution patterns of waterfront spatial morphology, the theoretical framework of landscape resilience design, and its practical implementation. The objective is to establish a methodological system for waterfront landscape design that adapts to dynamic urban development, thereby providing theoretical support for improving the quality and sustainability of waterfront spatial environments.

Key words: urban waterfront; spatial morphology evolution; landscape resilience design

1 Introduction

Urban renewal represents an indispensable process in 21st-century urban development worldwide. With the acceleration of urbanization, society has generated new definitions, understandings, and demands regarding urban renewal. In this new era, the construction of urban waterfront public spaces has become a key aspect of urban renewal. These spaces not only function to improve urban ecological environments but also carry the responsibility of preserving historical urban contexts and shaping distinctive urban identities.

2 The value of urban waterfront spatial morphology evolution and landscape resilience design

During the industrial age, numerous factories were established in port areas, discharging untreated industrial wastewater directly into waterfront zones. Consequently, waterfronts were perceived as chaotic, heavily polluted, and functionally monotonous spaces, serving merely as industrial adjuncts disconnected from urban life. In the post-industrial era, waterfronts have gradually transformed into core venues for public engagement with nature and urban vitality. Their functions have diversified from purely industrial to encompass ecological, recreational, and cultural dimensions, becoming crucial carriers for urban image formation and quality enhancement.

3 Current status analysis of urban waterfront spatial morphology evolution and landscape resilience design

Urban waterfronts, characterized by dual natural and urban open space attributes, face the dual challenge of preserving natural qualities while enhancing urban legibility during renewal. Historical development has resulted in spatial disorder and functional imbalance in some waterfronts. Waterfront landscapes often suffer from fragmented planning, ecological vulnerability, and insufficient attention to historical continuity. Current users mainly comprise local residents and tourists; however, the simplistic design of waterfront zones fails to meet the needs of diversified activities, lacking appropriate spaces for water interaction or specialized venues for groups such as anglers. Moreover, the application of landscape resilience design remains inadequate: ecosystem buffering capacity is weak with limited self-repair ability in the face of floods and water pollution, and spatial morphology lacks mechanisms to adapt to dynamic urban changes; Functional updates lag behind renewal demands, and landscape facilities lack durability and adaptability, impeding long-term sustainable spatial value.

4 Methodologies for urban waterfront spatial morphology evolution and landscape resilience design

4.1 Enhancing ecological functional resilience to shape resilient green landscape spaces

Urban waterfront renewal requires micro-level design improvements to green public spaces by limiting unnecessary hardscape to less than 20% of total site area and increasing permeable surfaces to enhance rainwater absorption. For fragmented landscapes, a combined approach of artificial landscaping and ecological restoration is employed by establishing vegetation buffer belts at least 5 meters wide to connect fragmented green spaces, forming a multi-scale (50–100 m grid units), multi-dimensional resilient green network that strengthens ecological connectivity and disturbance resistance [1].

During maintenance, an IoT-based ecological monitoring system tracks soil moisture, vegetation growth, and water quality in real time. When parameters exceed thresholds (e.g., soil moisture below 15% or above 30%), intelligent irrigation or drainage will be automatically activated to maintain ecological balance. Structural assessments and functional optimizations of resilient green spaces occur every five years, including vegetation renewal and infrastructure maintenance to ensure long-term resilience functionality.

4.2 Optimizing road traffic organization and creating water-friendly resilient landscape nodes

As a nexus connecting people, water, and city, urban waterfront spaces must emphasize natural engagement and recreational functions during renewal. Optimizing traffic flow and designing resilient landscape nodes enhance spatial accessibility and waterfront experience [2].

Waterfront nodes and land interfaces use boardwalks 3–5 meters wide with safety railings at least 1.1 meters high and spacing no greater than 0.11 meters. Along the coastline, every 100 meters features a waterfront platform no less than 200 square meters. The platform shall be elevated 0.5–1 meter above normal water level and paved with permeable materials (infiltration coefficient $\geq 1.5\times10^{-3}$ cm/s) supporting both water interaction and rainwater infiltration.

Landscape stitching employs a "terrace–slope–mudflat" three-dimensional transition, with terraces 1.5 meters above design flood level and 8–10 meters wide walkways. Slopes are planted with erosion-control vegetation (e.g., sand couch grass, purple alfalfa) at ratios of 1:3 to 1:4. Mudflats retain natural muddy substrates, with wooden boardwalks every 50 meters, 20 meters long, level with average high tide, supported by adjustable piles (±0.8 meters) to adapt to water level changes.

Functional nodes are arranged every 500 meters with composite features: 300–500 square meter waterfront plazas with seating spaced 1.5–2 meters apart; 80–100 meter ecological interpretive boardwalks with signage every 50 meters; and fishing platforms 50–80 square meters with 2–3 meter spacing between fishing spots. All nodes incorporate resilient boundaries using movable planters and flexible walls, allowing dynamic spatial adjustments. Facilities can be temporarily dismantled during floods exceeding five-year return periods to ensure flood safety.

Diverse circulation paths respect existing networks with hierarchical design: main park roads 4–6 meters wide, slopes under 8%, serving primary traffic; secondary roads 2–3 meters wide, slopes under 12%, connecting nodes; and walking trails 1–1.5 meters wide with natural stepping stones, including steps where slopes exceed 15% (step height 12–15 cm, width 30–35 cm).

Paving uses regionally cultural decorative elements via color combinations. Main roads employ colored permeable concrete (compressive strength ≥30 MPa, infiltration $\geq 2.0\times10^{-3}$ cm/s) with blue-gray wave patterns. Secondary roads combine rust-colored steel plates (3–5 mm thick, etched with industrial gear motifs) and gravel (5–8 mm diameter). Walking trails use local stone slabs (60×60 cm, buried 10 cm) interspersed with durable turf strips (e.g., buffalo grass) 30 cm wide.

4.3 Preserving cultural resilience by extracting historical landscape symbols and revealing place memory fragments

Landscape nodes must highlight the maritime character of coastal cities by deriving cultural genes from natural and human contexts, centering design on "marine culture". Symbol extraction selects place-identifying elements such as "water ripple textures", "lighthouse silhouettes", and "fishing boat forms", abstracted artistically into design motifs. Wave amplitude in water ripple patterns is controlled at 10–15 cm; lighthouse silhouette simplification ratios are maintained between 1:5 and 1:8 to ensure recognizability and landscape integration [3].

Focusing on historical memory carriers in coastal zones, a "linear cultural exhibition belt" is established along the waterfront. Every 80–100 meters features a cultural wall 2.5–3 meters high, constructed from local stone and weathering steel composite materials, etched with marine life motifs and port development history texts (font size 10–15 mm). Every 500 meters, there are interactive installations like "wave piano keys" on the ground (each key 60×80 cm, producing sounds at 500–800 Hz when stepped on), evoking the acoustic imagery of "Piano Island".

Vertical site design preserves original industrial foundations (e.g., dock rails, crane bases), which are repurposed into terraces 0.8–1.2 meters high. Rail spacing remains at 1.435 meters (standard gauge), with bases surfaced with 3–5 thick mm rust-colored steel plates engraved with equipment usage dates and functional descriptions.

5 Conclusion

In conclusion, the evolution of urban waterfront spatial morphology and landscape resilience design must be grounded in ecological, transportation, and cultural perspectives. By constructing resilient green spaces, optimizing circulation, and embedding cultural symbols, dynamic spatial adaptation and sustainable enhancement of landscape functions can be realized, providing a systematic design approach for urban waterfront renewal.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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