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Planning heritage in flood-prone zones: Planning responses and urban morphological evolution in the Ancient City of Linhai, China

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A R T I C L E I N F O

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A B S T R A C T

The integration of historical flood adaptation strategies into contemporary resilience planning remains a critical challenge for heritage cities in flood-prone areas. This study addresses this gap by proposing 'Planning Heritage' as a key analytical lens, conceptualizing it as the cumulative outcome of evolving planning paradigms and flood response strategies. Employing a mixed-methods approach that combines historical document coding, GIS mapping, Space Syntax analysis, and fieldwork, the research examines how chronic flood pressures have shaped the urban form of the Ancient City of Linhai, China, over centuries. The findings reveal that Linhai's flood mitigation capacity relies on a synergistic system of tangible elements (city walls, street networks, and water systems) and intangible wisdom (defence and diversion strategies, alongside community participation). Crucially, the urban morphology has co-evolved with flood risks, resulting in spatial configurations that inherently support evacuation efficiency, drainage, and adaptive land use. However, qualitative evidence suggests that the contemporary functional relevance of this heritage is currently threatened by fragmented management. Consequently, this study concludes that planning heritage constitutes a vital resilience resources and advocates for its active integration into modern flood mitigation planning. This necessitates a paradigm shift from passive preservation to functional revitalization, performance enhancement, and institutional coordination, effectively linking cultural heritage conservation with sustainable flood risk reduction.

1. Introduction

In the context of global climate change and increasingly frequent flood hazards, enhancing urban flood resilience has become a critical issue for sustainable development (Prashar et al., 2023). Of particular significance are historic cities situated within floodplains. These settlements have withstood repeated flooding over centuries, or even millennia, while preserving relatively intact historical relics. Their continued presence demonstrates the efficacy of enduring, adaptive strategies employed in historical urban planning to manage flood risk (Moccia and Sgobbo, 2016). The urban form and heritage shaped by these strategies embody resilient knowledge that is deeply rooted in local contexts and accumulated over long historical trajectories (Itsukushima et al., 2021). Therefore, fully exploring and utilizing this wisdom is essential for protecting urban heritage while mitigating modern flood hazards.

Existing research on historic cities in flood-prone areas falls primarily into three categories. First, technical studies focus on

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applying modern methods, such as GIS, hydrological modelling, and remote sensing, to assess the vulnerability of historic cities under current climate scenarios (European Commission, 2010; Ginzarly et al., 2024; Maio et al., 2012; Perez-Alvaro, 2016). Second, research on urban morphology and historical adaptation interrogates the temporal evolution of form and practice, demonstrating how street networks, plot patterns, and settlement choices reflect successive responses to environmental pressures (Swinkels, 2016; Kropf, 2017; Ikemoto et al., 2021). Third, literature on heritage-based resilience highlights the value of cultural assets, community practices, and adaptive reuse within contemporary resilience strategies (Chapagain, 2023; Fontanella Pisa et al., 2025). While each perspective offers valuable insights, they exhibit certain limitations. Technical studies often treat historic cities as relatively static objects, paying limited attention to the long-term processes that shaped their urban forms and practices (Thomas et al., 2025). Morphological analysis tends to prioritize the documentation of spatial patterns over the examination of the generative planning and governance frameworks behind them (Scheer, 2017). Finally, heritage-resilience research often frames heritage in instrumental terms as a resource for adaptation, without deeply interrogating its co-evolutionary relationship with environmental change and planning over time (Head, 2017).

To address these gaps, this study conceptualizes 'Planning Heritage' as the historically accumulated and continuously evolving assemblage of planning paradigms, practices, regulations, physical infrastructures, and institutional routines. This framework highlights that planning heritage encompasses both tangible dimensions (e.g., canals, embankments, street layouts, land use) and intangible dimensions (e.g., design norms, governance practices, community coping strategies). The accumulated knowledge embodied in these practices has consistently shaped urban form to manage flood hazards (Chmutina et al., 2019). Embedded in both historical planning strategies and the resulting urban forms, this heritage continues to inform contemporary flood mitigation, offering a dynamic alternative to the static approaches prevalent in many engineering-led risk management strategies (Okubo, 2016).

Consequently, this study addresses the following primary research question: In what ways has urban planning heritage in flood-risk zones mitigated flooding throughout history? The study examines the Ancient City of Linhai, a national historical and cultural city in China located in a high-risk flood zone. By tracing nearly two thousand years of planning history, the research extracts Linhai's planning heritage regarding flood response and explores its potential role in contemporary urban flood mitigation. Specifically, the study investigates three sub-questions:

RQ1: What are the core elements of 'planning heritage' in Linhai, and how have they evolved from historical flood mitigation practices?
RQ2: How has the urban morphology of Linhai co-evolved with historical flood events and their corresponding planning responses?
RQ3: What opportunities and challenges does this 'Planning Heritage' present for the capacity of contemporary communities to respond to flood risk?

The remainder of this paper is organized as follows: Section 2 constructs the theoretical framework for planning heritage in historic flood-prone cities through a literature review. Based on this framework, Section 3 outlines the methodology, detailing the data collection and analysis methods applied to the case study of Linhai. Section 4 presents the development of Linhai's planning heritage under the influence of repeated floods, alongside the city's morphological evolution. Finally, Section 5 explores the role of planning heritage in historically accumulated flood control practices and discusses how this heritage can be leveraged to achieve sustainable development in historic cities facing flood risks.

2. Theoretical framework

In this section, the theoretical framework is developed with 'Planning heritage' as the central concept. This framework highlights the dual role of planning heritage as both a record of historical flood responses and a resource for contemporary resilience. To articulate this framework, the study integrates perspectives from flood mitigation planning and urban morphology. The former clarifies how planning heritage embodies adaptive strategies for disaster management, while the latter demonstrates how these

Fig. 1. The development of 'planning heritage' concepts.

strategies are concretized in the evolution of urban form.

2.1. Planning heritage

2.1.1. The development of 'Planning Heritage' concepts

The concept of 'Planning Heritage' first emerged in response to early twentieth-century reflections on the limitations of heritage protection strategies that focused solely on individual buildings (Fig. 1). In 1931, while discussing the revival of Europe's historic towns, Giovannoni introduced the notion of 'Urban Heritage.' He argued that a city's heritage value derives from the internal coherence imparted by its planning, and that the object of protection should extend from standalone buildings to the urban form (Zucconi, 2014). The U.S. National Historic Preservation Act of 1966 subsequently extended legal protection to 'Historic District,' thereby placing the entire urban form under protecting measures.

In the 1970 s, the publication *Britain's Planning Heritage* was the first work to explicitly coin the term 'Planning Heritage,' defining it through significant examples of urban and rural development in British history. Through this exposition, the authors sought to foster public understanding of planning wisdom, the planning process, and historical case studies (Taylor et al., 1975). Scholars of planning history, practitioners in historic urban conservation, and professional planning associations soon adopted the term to describe paradigms and projects that embody planning wisdom, bear witness to historical processes, and possess universal value. In 1978, UNESCO formally recognized 'Town-planning' among the criteria for Outstanding Universal Value (UNESCO World Heritage Centre, 2025). This marked the first acknowledgment of the intrinsic worth of planning activity within the field of heritage studies. Regional initiatives in the United States, Europe, Australia, and beyond followed to identify and protect planning heritage (Freestone et al., 2008; Lazareva et al., 2018; Nakajima et al., 2015).

The Historic Urban Landscape (HUL) approach, introduced by UNESCO in 2011, reframed heritage as a socio-cultural resource and a key component of sustainable urban development, moving beyond static physical preservation (UNESCO, 2011). While this approach established a critical framework involving value layering and community engagement, over a decade of practice has revealed limitations in providing actionable pathways for specific implementation. This is particularly evident regarding fragmented governance and inclusive participation (Pereira Roders and Bandarin, 2019). Historical urban planning and construction were fundamentally active, problem-solving practices that deliberately shaped morphology, infrastructure, and governance to mitigate environmental and social challenges. However, within prevailing frameworks, the local wisdom and adaptive strategies inherent in these interventions are often relegated to a passive background context rather than being recognized as a vital knowledge reservoir for contemporary needs (Chapagain, 2023). Therefore, this study argues that while the HUL approach is essential for general conservation, integrating the 'Planning Heritage' perspective is necessary to bridge intangible planning wisdom with tangible urban forms. By reactivating the agency of historical planning, this research aims to derive operational insights that enhance flood resilience and support sustainable development goals in contemporary cities (Hein, 2020).

2.1.2. The composition of planning heritage

Given that urban planning encompasses both theoretical and practical dimensions, the concept of planning heritage implies a synergy between two dimensions: intangible and tangible elements (Fig. 2).

Intangible planning heritage, as a form of culture heritage, consists of a system of knowledge and wisdom (UNESCO, 2003). This comprises both formally documented planning theories and the planning wisdom embedded in traditional practices. Crucially, such knowledge is dynamic rather than static, as it is continually reshaped by communities in response to their environment. This dynamism is essential to understanding historical planning responses to flood risk. Over prolonged interaction with natural hazards, cities devised localized adaptive strategies, such as settlement siting or customary practices governing street layout, that reflect an evolving collective intelligence regarding environmental challenges.

Intangible heritage further encompasses the governance mechanisms of planning institutions. Written regulations constitute formal instruments that translate abstract planning wisdom into operational procedures, thereby creating the built environment. Decades of municipal administration have yielded extensive experiential knowledge, including infrastructure maintenance protocols, risk

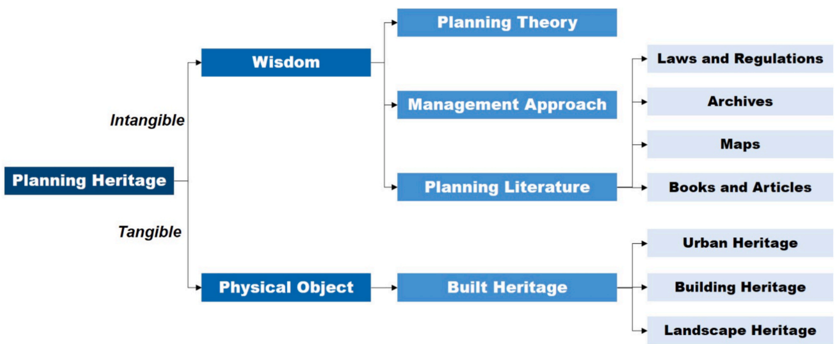

Fig. 2. The composition of 'planning heritage'.

mitigation measures in land development, and effective community engagement methodologies. Together with statutory frameworks, these practices constitute a database guiding long-term strategic planning and underpin identifiable planning achievements.

Finally, intangible planning heritage manifests in material records. Planning literature documents theories, policies, strategies, and governance methods. It encompasses a wide range of materials, including graphic and textual documents that direct design and construction, as well as books, articles, archival sources, and legal statutes. Whereas modern planning archives are abundant, historical sources are often fragmentary and dispersed among local gazetteers, chronicles, and cartographic materials.

Tangible heritage is embodied in the built environment as the spatial expression of planning wisdom. This perspective transcends isolated monuments by considering the city in its entirety as a heritage entity, encompassing not only urban form, architectural ensembles, and landscape features but also the interrelations among them (Pinnegar and Freestone, 2007).

In summary, planning heritage is defined not by isolating its intangible and tangible dimensions, but by the synergy between them. Without the intangible knowledge embedded within it, the physical forms lose their substantive significance. Conversely, the full import of intangible heritage can only be appreciated through the examination of its physical expressions.

2.2. Flood mitigation planning

Urban planning plays a pivotal role in mitigating flood impacts through spatial resource allocation, land use regulation, and infrastructure configuration. The arrangement and design of buildings, street networks, drainage systems, and other urban infrastructure create barriers against flood hazards, facilitate water diversion, and provide temporary storage. These measures reduce the exposure of vulnerable populations and critical facilities(Kaiser and Akter, 2025; World Bank, 2017). Simultaneously, comprehensive public participation and governance mechanisms reduce overall vulnerability and contribute to flood risk mitigation (Moon et al., 2017). A carefully considered urban plan not only diminishes the probability of inundation but also enhances urban resilience and secures a sustainable built environment for future generations. This reasoning explains why historic cities located in flood-prone areas have survived for centuries.

This endurance cannot be fully explained by a static concept of 'heritage-based resilience.' Under prolonged flood pressure, water-related heritage is often damaged and subsequently repaired, adapted, or reconfigured. This means these places do not necessarily act as fixed drivers of resilience. Instead, it is the continual processes of transformation and adaptation themselves that constitute resilience (Chapagain, 2023). What drives this process is the enduring urban planning wisdom that blends flood mitigation with adaptation. Thus, the long-term coexistence of historic cities with floods reflects not only physical heritage but also the accumulated wisdom embedded in adaptive planning strategies and responses.

Flood mitigation planning generally involves three strategic categories (Fig. 3). First, spatial intervention, referred to as 'Choose Change,' aims to avoid risk by relocating sensitive functions outside floodplains or by changing land use within hazard zones to lower vulnerability. Second, engineering and management measures, known as 'Reduce Losses,' focus on limiting damage through structural defence measures such as levees and embankments, as well as through event modification via reservoir operation and diversion canals. Third, 'Accept Losses' relies on mechanisms for sharing losses, including flood insurance and government compensation, or on bearing losses directly to build post-event recovery capacity (Klein et al., 2003). These strategies reflect an evolution from reliance on 'hard' structural approaches to the incorporation of 'soft' institutional resilience and adaptive management, fostering an ethos of coexistence with water (Swinkels, 2016). By integrating spatial intervention, technical defence and mitigation, and institutional assurance, urban

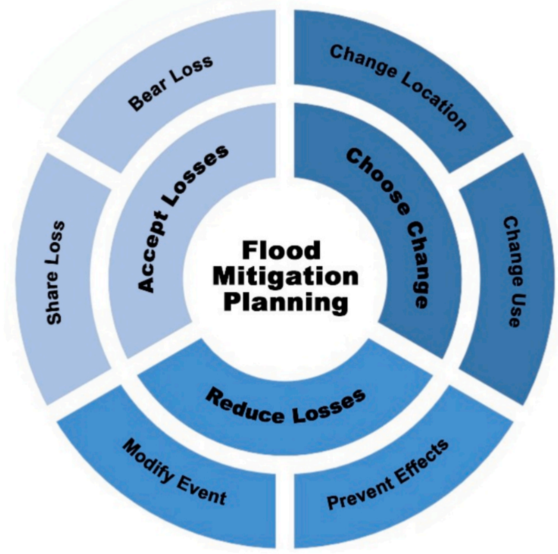

Fig. 3. Three strategies for flood mitigation planning.

flood mitigation planning forms a comprehensive framework that strengthens the long-term resilience of cities.

2.3. Urban morphological evolution

Urban morphological evolution is essentially a process of spatial accumulation in which events or forces leave identifiable traces on the urban form that gradually layer and integrate over time (An and Ochiai, 2025). For example, a major disaster event or a profound social transformation will prompt the reshaping of city boundaries, the reconfiguration of street networks, or changes in land-use patterns (Vale and Campanella, 2005; Whitehand, 1987). These morphological elements accumulate along historical trajectories and with preexisting structures, generating a multi-layered and readily interpretable urban framework at the macro scale (Conzen, 1960). This framework not only records spatial changes but also reflects the enduring influence of past planning responses and adaptation strategies. Because key components such as urban boundaries and main thoroughfares have remained relatively stable for centuries, they serve as durable carriers of collective urban memory (Rossi, 2007). Even when frequently changing details have been lost or obscured, the city's past can still be deciphered through these persistent structural cues. Therefore, urban morphology provides a methodological framework for examining the historical adaptation processes of physical space from the integrated perspective of planning heritage.

In the absence of detailed spatial data, the topological configuration of a street network offers a crucial perspective for understanding the evolution of urban morphology and the flood adaptation wisdom it embodies. Recent studies have underscored the significance of street networks in enhancing urban flood resilience and recovery capacity (Prashar et al., 2023). For instance, space syntax metrics, such as integration, choice, and intelligibility (Penn, 2003), can be employed to characterize network accessibility, connectivity, and comprehensibility, and to assess their impacts on flood risk (Table 1).

On one hand, the topology of the street network profoundly influences water flow management and drainage efficiency. Streets with high connectivity often form principal drainage corridors that can rapidly channel floodwaters away from core areas, although such concentration of flow may exacerbate localized risk (Leta et al., 2024). At the same time, highly accessible segments provide more direct shortest paths to urban drainage infrastructure, thereby significantly improving the efficiency of drainage operations (La Rosa and Pappalardo, 2020). On the other hand, the street network topology is critical for emergency evacuation and rescue coordination. During flooding events, nodes of high accessibility serve as assembly points and distribution hubs for relief supplies, enabling swift gathering of people and rapid material delivery (Gangwal et al., 2023). Moreover, corridors exhibiting high connectivity can function as main evacuation routes (Farahmand et al., 2021). Districts with high intelligibility ensure that residents and rescue teams can quickly identify evacuation routes based on the local street pattern, thus reducing decision-making time (Hillier and Hanson, 1984).

Therefore, this study not only focuses on the evolution of macro-scale morphology but also pays particular attention to the diachronic changes of the street network. In the context of historic cities, historical maps allow a clear reconstruction of early street configurations and establish a foundation for evaluating the spatial resilience of street networks across different periods.

2.4. Planning heritage as a resource for flood mitigation

The theoretical framework of this study is built on the dynamic interaction of four key elements shown in Fig. 4. First, planning heritage not only encompasses the broad and gradual process of human adjustment to environmental threats described by historical adaptation (Doeffinger and Siders, 2025), but it also highlights the consolidated outcome of this process. This outcome specifically comprises the flood mitigation strategies, traditional ecological knowledge, and concrete urban morphological expressions that have been successfully transmitted over time. Within the built environment acting as a dynamic interface, the evolution of urban morphology reflects the efficacy of planning heritage in mediating the relationship between human settlements and the natural environment. By decoding this relationship, planning heritage reveals itself as an active and methodological resource rather than a passive relic, offering specific, actionable, and historically informed strategies. These strategies are crucial for achieving a broader goal of resilience beyond heritage itself in contemporary flood-prone historic cities.

3. Methodology

3.1. Research area

The Ancient City of Linhai was selected as the case study due to its dual significance as a nationally recognized planning heritage

Table 1
Space syntax core metrics in flood risk contexts.

Metric	Core definition	Significance for flood risk & resilience
Integration	Measures topological accessibility of a space to all others, reflecting potential for destination-oriented movement.	Identifies easily accessible post-disaster safe zones and relief distribution points; measures critical facility accessibility within urban networks.
Choice	Measures a space's potential to be traversed by shortest paths, reflecting through-movement potential.	Pinpoints streets likely to become major flood drainage channels during events, serving as evacuation routes while simultaneously posing high-risk flood corridors.
Intelligibility	Measures the ability to infer global spatial structure from local cues, reflecting cognitive legibility.	Impacts wayfinding efficiency during emergencies; low-intelligibility areas may cause evacuation delays/disorientation, increasing population vulnerability.

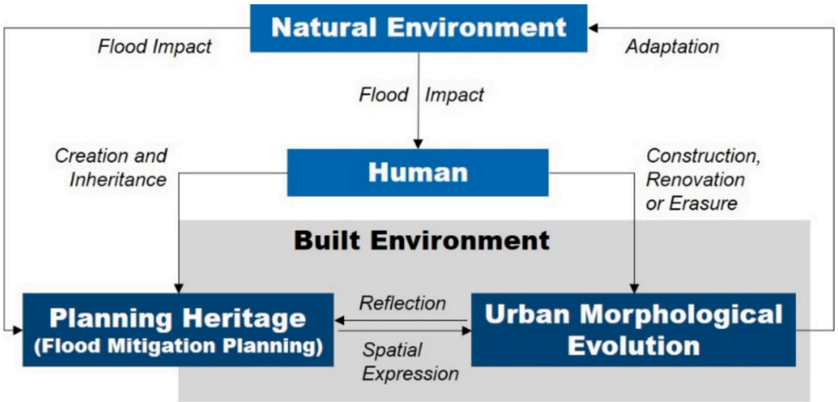

Fig. 4. Theoretical framework of planning heritage and urban morphology in flood risk zones.

site and a region subject to chronic flooding. Located in Taizhou City, Zhejiang Province (28°50′N, 121°06′E), this historic city is situated on the banks of the Ling River in Eastern China. Its topography is characterized by surrounding mountain ridges, a relatively flat interior, and hills to the north and southeast. Covering an area of 3.12 square kilometres and housing approximately 30,000 residents (Fig. 5), the city has faced cyclical flood threats since its establishment in the Jin Dynasty (266–420 CE). Its well-preserved city walls exemplify historical defence strategies, while the integrated canal system and adapted urban morphology reflect wisdom regarding flood adaptation. The continuous evolution of the city under flood pressure offers an ideal context for analysing how planning heritage influences flood resilience. As extreme weather events intensify, leading to recurrent flooding, Linhai serves as a critical case study for bridging historical planning responses with contemporary flood mitigation practices.

3.2. Data collection

This study employed multi-source data, including maps, historical documents, and field surveys (Fig. 6). The aim was to identify Linhai's planning heritage and analyse its role in flood mitigation through data triangulation.

First, textual archives such as chronicles and biographies provided historical context and identified key morphological elements. Document collection focused on official records regarding urban planning and governance, disaster events, and engineering projects. These were primarily drawn from the Linhai County Chronicles, accessed through the Beijing Erudition Digital Research Centre. Based on legibility and availability, three main local chronicles (shown in Fig. 7) were selected. Additionally, biographies of key figures were collected as supplementary material. These figures, namely officials and local gentry, were identified through chronicle records as having significantly influenced Linhai’s early urban planning and flood mitigation systems.

Second, map data formed the basis for reconstructing the urban morphology across different historical periods and provided a quantitative interpretation of the content recorded in historical documents. This study collected both historical and modern maps to trace the morphological evolution of Linhai. To ensure representativeness and availability, maps from four key historical periods were selected: the Jin, Tang, Song, and Qing Dynasties. Historical maps were sourced from the Linhai City Museum, which preserves a rich

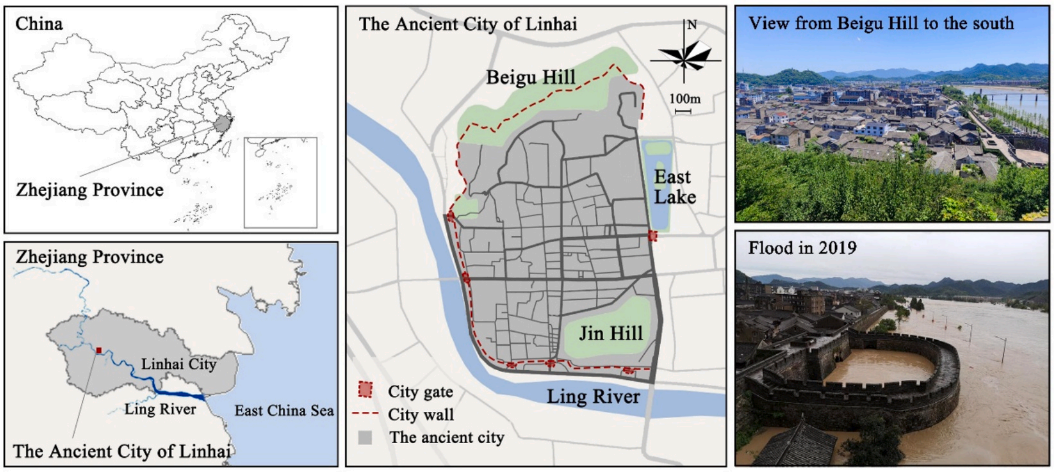

Fig. 5. Study area: the Ancient City of Linhai, Zhejiang Province, China.

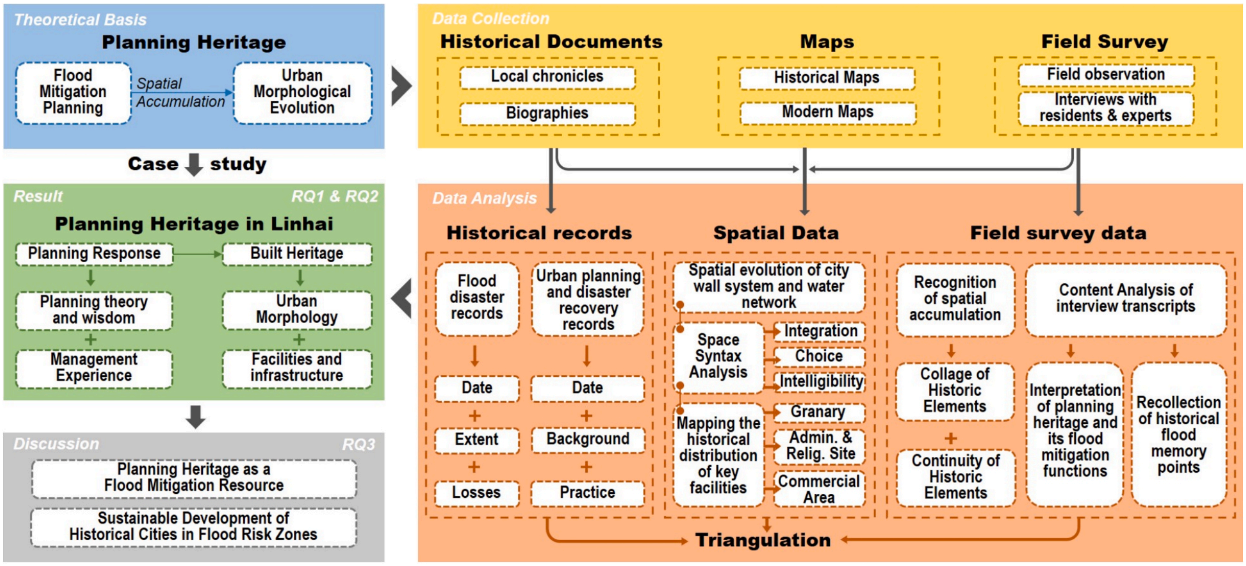

Fig. 6. Research framework for the case study.

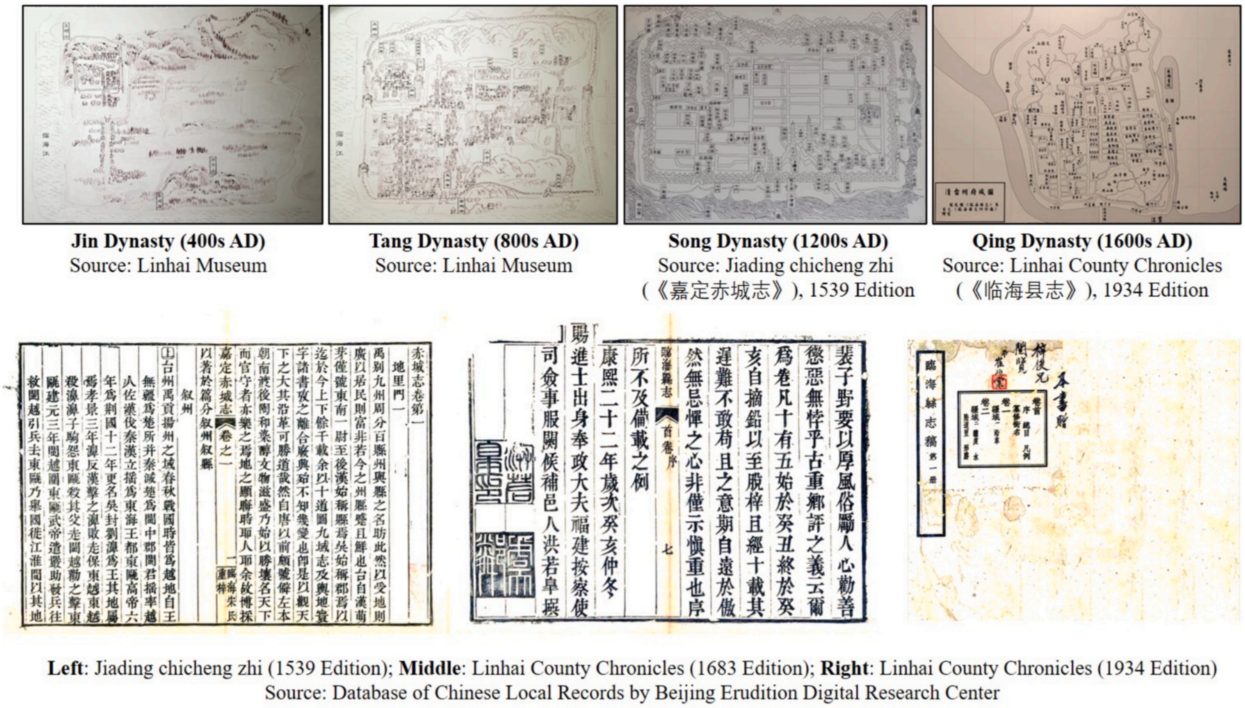

Fig. 7. Historical maps and documents used in this study.

collection of local cartographic materials dating back to 85AD, and from illustrations in local chronicles that systematically document urban form and governance (Fig. 7). Modern maps were sourced from the Linhai Historic and Cultural City Protection Plan, supplemented by Google Earth satellite imagery.

Finally, data from field surveys were used to verify and enrich information derived from maps and documents. Surveys were conducted from June to July 2024 and from January to February 2025, focusing on the spatial accumulation of morphological elements and local flood memory. Traces of former city walls, the street network, and the water system were located on-site based on historical maps and textual records. Furthermore, oral histories, collective memories, and expert insights were captured through interviews. Interviewees included long-term residents of the ancient city, who recounted flood experiences, memories, and perceptions of the mitigation functions of planning heritage. Interviews were also conducted with local government staffs, historians and cultural heritage specialists, who provided official narratives, management practices, and perspectives on the continuities between historical flood control facilities and modern systems.

3.3. Data analysis

This study adopts a mixed-methods approach based on data triangulation, integrating historical record coding, GIS and Space Syntax analysis, and field surveys. These methods are organised into a coherent analytical sequence to examine how planning heritage has actively shaped urban responses to flood risk over time. Historical records are first analysed to reconstruct the planning rationales and decision contexts surrounding major flood events. GIS-based morphological analysis then identifies corresponding spatial changes in the urban form, while Space Syntax is used to evaluate the flood-relevant spatial performance of these configurations. Finally, local knowledge and disaster memory collected through field surveys are employed to cross-validate the interpretations derived from the preceding analyses. This comprehensive approach confirms the extent to which early planning intentions were translated into resilient practices.

First, historical texts were coded to identify associations among recurrent flood hazards, urban morphological evolution, and underlying planning and governance concepts. Key coding themes included records of flood hazards (time, type, extent, and damage) and records of urban planning and post-disaster recovery (time, political and technical background, main strategies, and practices). Based on the extracted data, a detailed time-series matrix was constructed to elucidate these correlations.

Second, GIS and Space Syntax were used to analyse Linhai's urban morphological evolution. Given that many historical maps are topological sketches or artistic renderings rather than geometric surveys, we applied a three-stage reconstruction framework prior to digitization to mitigate geometric distortions and improve comparability across periods. The framework comprised: (1) identification of stable morphological anchors (enduring landscape features and persistent urban structures) on modern satellite imagery to establish a precise geometric base; (2) correction of visual and proportional distortions by cross-referencing local chronicles and archival measurements to convert historical notations into modern distances and supplement missing features; and (3) georeferenced validation through field verification. These steps follow established method in historical urban morphology (Conzen, 1960) and historical GIS integration (Knowles and Hillier, 2008; Gregory and Ell, 2012). Based on these reconstructed historical layers, spatial features were digitized, and maps from different periods were overlaid to visualize the co-evolution of defence and water systems.

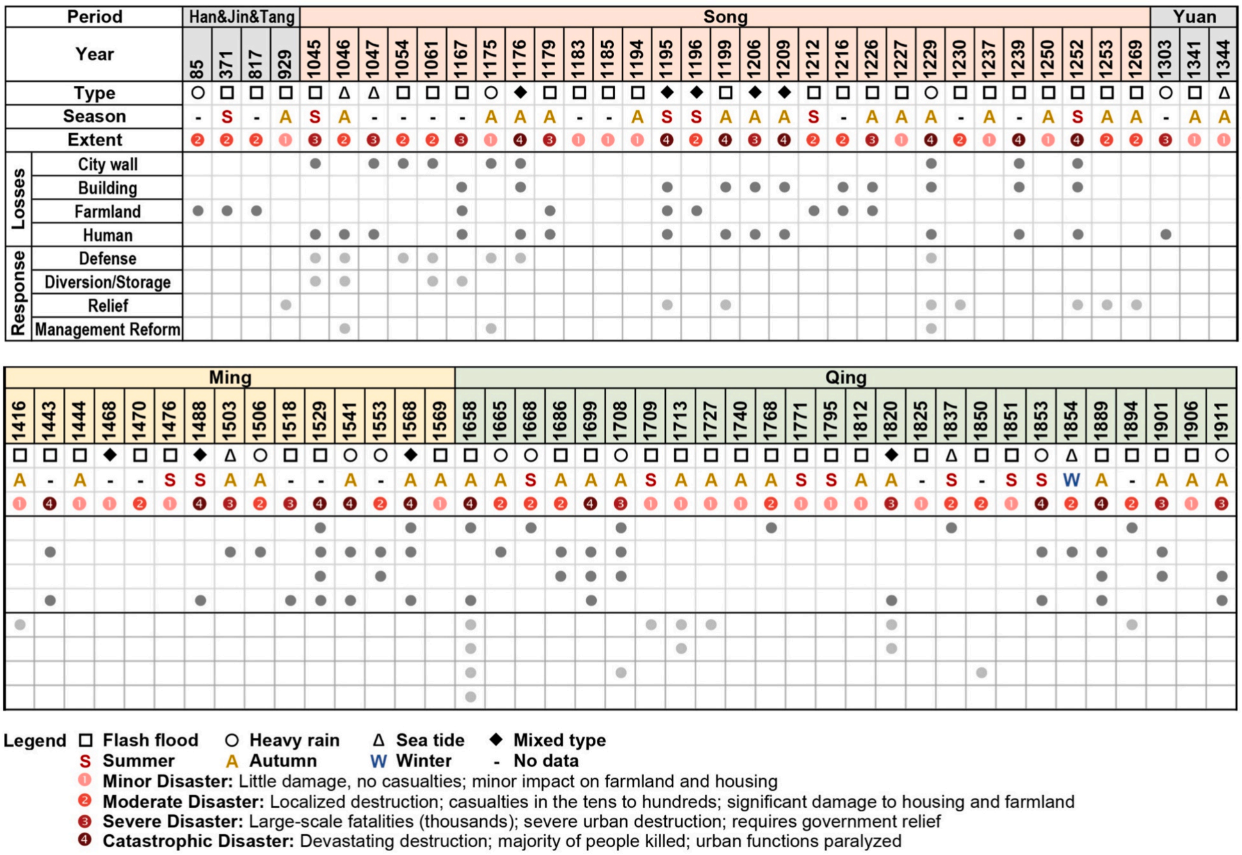

Fig. 8. Historical disaster chronicle of the Ancient City of Linhai.

Subsequently, Depthmap + Beta 1.0 was used to generate axial maps of the street network, from which integration, choice, and intelligibility metrics were calculated to evaluate changes in flood resilience over time. Axial maps were adopted for two main reasons. First, this study conceptualises flood resilience in terms of network legibility and wayfinding capacity under emergency conditions. In flood evacuation scenarios, residents rely primarily on immediately perceivable visual and configurational cues rather than on metric or angular optimisation. Axial lines represent the longest continuous sight and movement paths and therefore correspond more closely to how urban morphology is cognitively interpreted and navigated under stress (Penn, 2003; Hillier and Iida, 2005). Second, segment-based and angular analyses depend heavily on precise geometric and angular measurements, which are difficult to obtain reliably from historical maps characterised by scale inconsistency and drawing distortion. In contrast, axial analysis captures the fundamental topological structure of the street network and is methodologically more robust to such geometric uncertainties, making it highly suitable for longitudinal comparison across historical periods.

Finally, qualitative field surveys and interview data supplemented the spatial and textual information. The data aided in identifying the authenticity of the urban form, highlighting the continuity of historical elements and their interpretation as flood mitigation functions within the planning heritage. Interview transcripts were analysed to identify core themes, capturing residents' and experts' contemporary interpretations and evaluations. This analysis bridged the gap between objective historical records and subjective local experience.

4. Results

4.1. Planning responses

Historical records indicate that Linhai has experienced varying degrees of flood exposure over the centuries. Between 85 AD and 1911 CE, 77 flood events were documented (Fig. 8), most of which were sudden, highly destructive flash floods occurring during the summer and autumn months. Flood severity intensified significantly when high tides or heavy rainfall coincided. Consequences ranged from damage to city walls, buildings, and agricultural land to substantial loss of life. While minor floods inundated fields and structures with relatively few casualties, major events in 1045, 1229, and 1658, destroyed large sections of the city walls and claimed thousands of lives. In response to these recurring hazards, Linhai developed a body of planning wisdom encompassing both theoretical strategies and practical management measures.

4.1.1. Planning strategy and wisdom

Linhai's flood mitigation strategies evolved from avoidance to defence, and eventually to an integrated approach combining defence, diversion, and storage. Early settlements avoided floodplains entirely, locating on hillsides. Subsequent urban expansion and the construction of defensive city walls later enabled development on the flatlands near the river. However, repeated instances of floods breaching the walls demonstrated the limitations of relying solely on a defence strategy.

From the Song Dynasty onwards, an integrated strategy emerged. First, defensive measures were progressively enhanced. The city walls, recognized for their irreplaceable role in flood control, were exempted from demolition even during peacetime. Successive flood events prompted the heightening of the walls from 3 m in the Tang Dynasty to the current 7 m, with stone cladding added for reinforcement. Barbican gates were constructed outside the main gates to shield vulnerable entry points.

Second, acknowledging the insufficiency of defence alone, diversion and storage strategies were implemented. For instance, following the 1067 flood, authorities relocated the eastern wall inward and excavated East Lake for flood storage basin. Canals were constructed along historical flood pathways, integrating flood control with irrigation and navigation. Under normal conditions, these canals diverted water from the Ling River and East Lake through wall sluices. During flood events, when river levels exceeded the height of the sluices, the canals reversed flow, channelling urban floodwaters into East Lake for temporary storage. This adaptive approach reduced damage during extreme floods while supporting dual functions for peacetime and emergencies, thereby minimizing the impact on daily life.

4.1.2. Management experience

Linhai's planning responses also manifested in disaster and construction management. In the immediate aftermath of major floods, post-disaster recovery strategies were enacted. These included central government interventions to reduce or waive local taxes to aid reconstruction, while local officials distributed grain relief. This was complemented by the rigorous management of flood control infrastructure, where strict protocols governed the surveying, construction, and inspection of defences. For instance, after the 1061 flood, officials oversaw wall reconstruction, employing techniques such as compacting rammed earth with oxen in the vulnerable southern section. Quality was verified by digging test holes in completed sections, filling them with water, and checking for leakage the following day (Jiading chicheng zhi, 1539). The administrative systems supporting these efforts were highly developed, with formalized flood control responsibilities assigned to dedicated officials and specialized agencies, such as the flood defence garrisons that existed prior to 1175 (Linhai County Chronicles, 1683).

Significantly, while ancient Chinese planning was typically top-down, Linhai officials incorporated community input, treating flood mitigation projects as public goods requiring coordinated government-community effort as early as the Song Dynasty. By raising public awareness of the link between flood defences and personal safety, authorities fostered community involvement in construction and reduced vandalism. Furthermore, local gentry proactively organized residents to establish community granaries, thereby creating a form of 'insurance' to cope with post-disaster food shortages (Linhai County Chronicles, 1934). This model of broad public participation continues today, remaining integral to Linhai's contemporary planning management. Therefore, Linhai's planning heritage is not a static relic but a dynamic crystallization of experience and wisdom, co-created by the local government and residents through repeated ‘disaster-response-adaptation’ cycles.

4.2. *Built heritage under flood risk*

Planning wisdom, strategies and management practices shaped the survival and transformation of built heritage within the urban form, gradually enhancing spatial resilience under persistent flood pressure. To unravel this adaptive process, the analysis follows a multi-scalar logic: it commences with the macro-morphological evolution to establish the city's overall physical framework; proceeds to the evolution of the street network as the critical circulatory system; and culminates in an examination of the functional layout, which reveals the wisdom of how land uses were strategically organized across this physical armature for flood adaptation.

4.2.1. *Macro-morphological evolution*

Fig. 9 illustrates the symbiotic trajectory between the city and its water systems. Initial walls built along the northern mountains in the Jin Dynasty established a ‘mountains-north, waters-south’ pattern, initiating a long adaptive process. The Tang Dynasty’s expansion and canal construction marked a shift towards comprehensive floodplain management. In the Song Dynasty (1200 s), responding to frequent flooding and the need for water transport, the vast East Lake was excavated east of the city. This was accompanied by an inward relocation of the eastern wall, placing the lake outside the city proper. Canals were added along historical flood routes. This change reflected a conceptual shift from a pure defence strategy towards coexisting with water. The Qing Dynasty (1600 s) saw further prioritization of flood control: inner walls were demolished while the outer flood-defence wall was retained, and

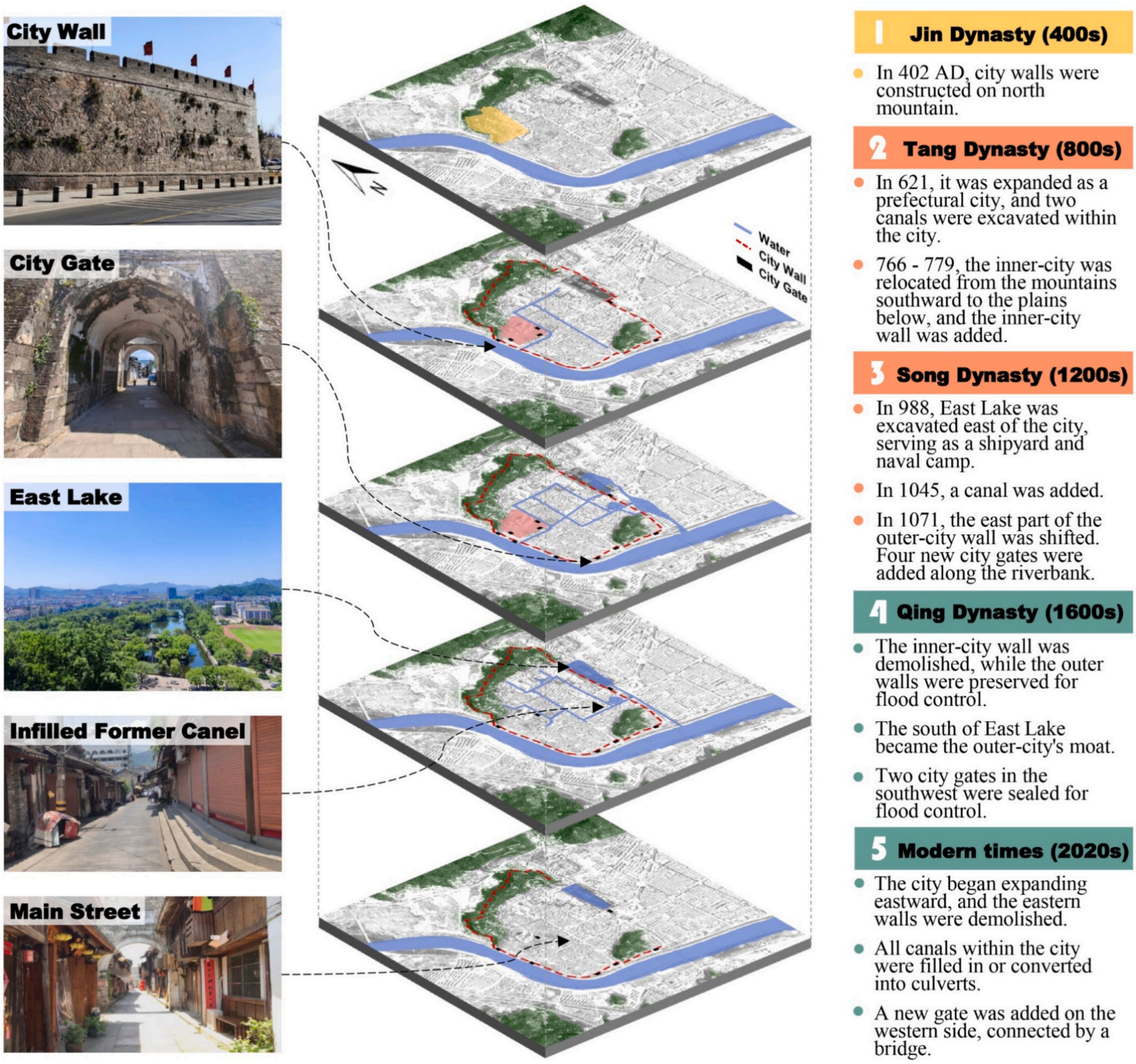

Fig. 9. Morphological evolution of the Ancient City of Linhai at the macro level.

some gates were sealed for enhanced protection. Modern eastward expansion, involving wall demolition and canal infilling, reflects the impact of modernization on traditional ‘city-water’ relationships.

4.2.2. *Evolution of street network*

The integration analysis (Fig. 10) reveals the street network's morphological evolution, characterized by a sequence of ‘centralized – dispersed – recentralized – diversified.’ The early Jin Dynasty network (400 s) was structurally simple, with high integration values concentrated on a limited set of main streets. The Tang Dynasty witnessed significant expansion, forming a grid prototype characterized by a more concentrated and distinctly cross-shaped integration core, consistent with the spatial logic of the traditional Chinese ward system (Lifang Zhi). During the Song Dynasty, the network densified, yet its integration core became more dispersed, corresponding historically with the decline of the rigid ward system and the emergence of fragmented commercial districts. The Qing Dynasty network exhibited a clear north–south fishbone structure, featuring a strong and centralized integration core that concentrated urban functions. In contrast, the modern network, while denser overall, displays a spatially dispersed and polycentric integration pattern — a development concurrent with population growth and accelerated urbanization. Throughout this evolution, the spatial locus of highest accessibility remained persistently stable along the north–south axis, underscoring its enduring role as the city's primary structural corridor. Field interviews confirm that this axis continues to connect key historic core areas and concentrate commercial, administrative, healthcare, and major traffic flows.

The choice analysis (Fig. 11) reveals a long-term, gradual decline in average network choice values. This trend indicates an increase in network redundancy and a greater number of potential route alternatives over time. The Space Syntax choice metric measures how frequently a street segment falls on the shortest paths between all origin–destination pairs within a specified search radius (R). Higher choice values signify corridors that carry more through-movement, whereas lower values indicate streets primarily serving local movement. The results show systematically higher choice values for longer-distance movements (R = 7) compared to shorter-range movements (R = 3), demonstrating that long-distance travel remains dependent on a limited set of critical corridors, even as short-range movement benefits from numerous local alternatives. This structural pattern has functional implications for flood scenarios. Historical records and resident reports indicate that during past flood events, people often shelter locally rather than undertaking long-distance evacuation. Therefore, increased neighbourhood-level route redundancy can enhance resilience by providing multiple local escape options, reducing the risk of blockages on any single path. However, high-choice corridors present a duality: they are vital lifelines for daily mobility and coordinated emergency response, yet they can also act as inadvertent rapid drainage conduits, potentially spreading floodwater into the urban form if not properly managed. Thus, a key planning challenge lies in protecting these primary corridors for evacuation access while implementing measures to prevent them from becoming uncontrolled channels for flood propagation.

Network intelligibility, measured by the R^2 of the correlation between local and global integration (Fig. 12), shows an initial decline followed by a partial recovery. Higher R^2 values indicate that the local street configuration reliably predicts the global accessibility structure, corresponding to greater spatial legibility and ease of wayfinding. The relatively high values in the Jin ($R^2 = 0.706$) and Tang ($R^2 = 0.600$) periods reflect their simpler and more legible structures. A sharp decline occurred in the Song period ($R^2 = 0.153$), coinciding with the collapse of the formal ward system and less regulated commercial growth, which obscured the relationship between local and global spatial structure. Qing-era planning interventions partially restored intelligibility ($R^2 = 0.462$) by creating more coherent urban patterns. The modern network exhibits a slightly lower intelligibility ($R^2 = 0.403$), which may contribute to wayfinding challenges during emergencies, particularly for non-residents.

4.2.3. *Functional layout*

Fig. 13 shows the relationship between key facility locations in Qing Dynasty and topography, revealing different siting strategies. First, symbols of state power such as Taizhou Prefecture and Linhai County seat, and granaries were clustered almost entirely in the northern and central-eastern higher elevation areas, which carried lower inundation risk. This distribution reflects the core logic of historical resource allocation: safeguarding governance by placing administrative centres in the safest locations to ensure continuity

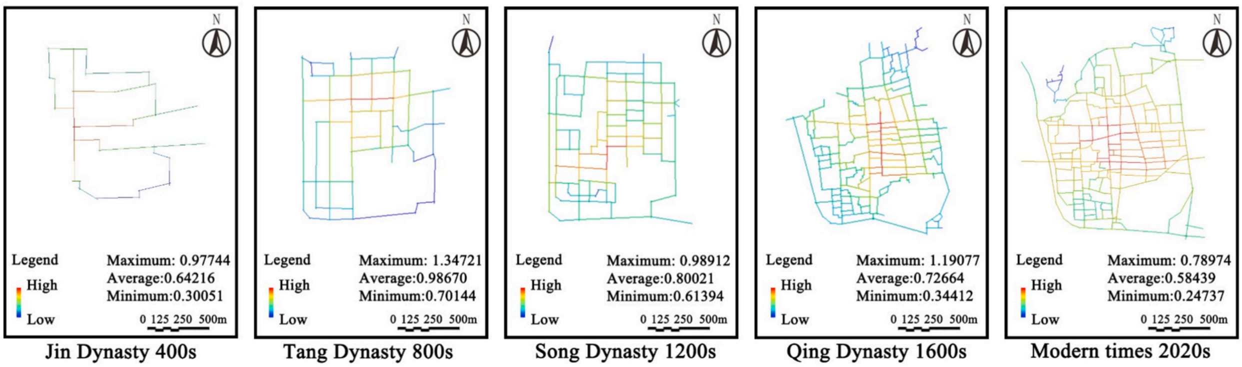

Fig. 10. Integration analysis results of road networks in different periods.

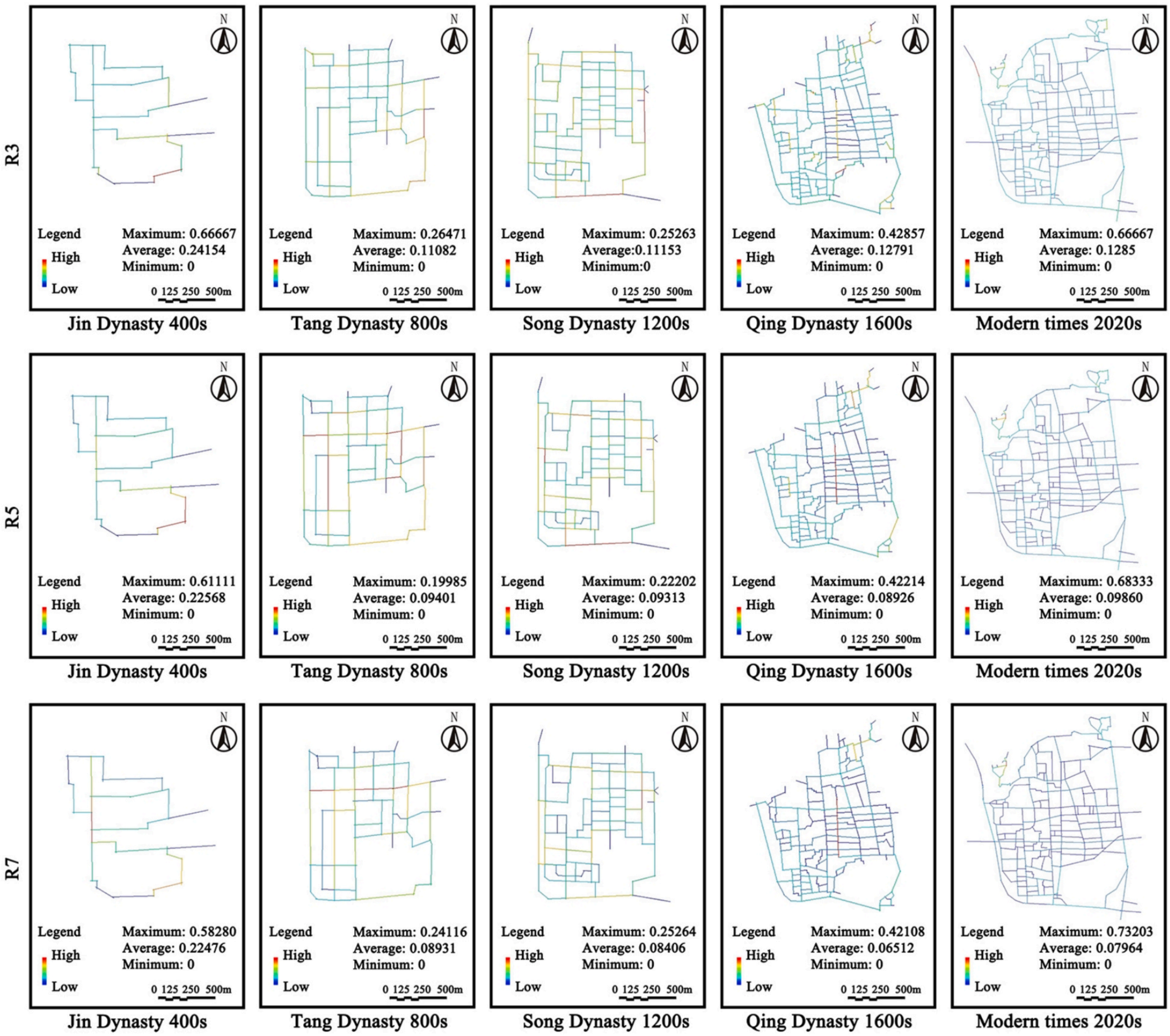

Fig. 11. Choice analysis results of road networks in different periods.

during floods, and protecting granaries as vital strategic resources to minimize post-disaster famine and social unrest.

Conversely, commercial areas followed a distinct 'water-seeking' and 'near-gate' pattern, concentrating along the Ling River in the west and south, inside the inner walls, and along main streets. These low-lying areas were flood-prone and, as noted, were often high-choice streets. This reflects early planners' risk tolerance and trade-offs. Commerce inherently relies on accessibility, necessitating proximity to gates, docks, and main streets for the flow of goods and people. Planners accepted this inherent vulnerability as a necessary cost for economic vitality. To mitigate losses, city walls and canals provided macro-scale protection. Furthermore, buildings lining high-choice streets were predominantly traditional two-story structures with heights of 7–8 m. Historical records and local reports confirm that valuable items were moved upstairs to withstand first-floor inundation during floods. Roofs were designed with detachable tiles and rafters, allowing people to climb onto the roof frame for refuge during extreme events. This represents a micro-architectural adaptation within the macro-planning framework.

4.3. Planning heritage in the contemporary context

The assessment of the contemporary functions of planning heritage is based on a cross-analysis of interviews with urban planners, residents, and heritage practitioners alongside historical documentary evidence. Testimony from multiple stakeholders indicates that these heritage elements continue to influence urban resilience at physical, cognitive, and managerial levels.

Many tangible heritage assets have been well preserved and continue to contribute to contemporary flood mitigation. The riverside wall system has been conserved and is described as the final and most important physical flood defence of the ancient city. East Lake

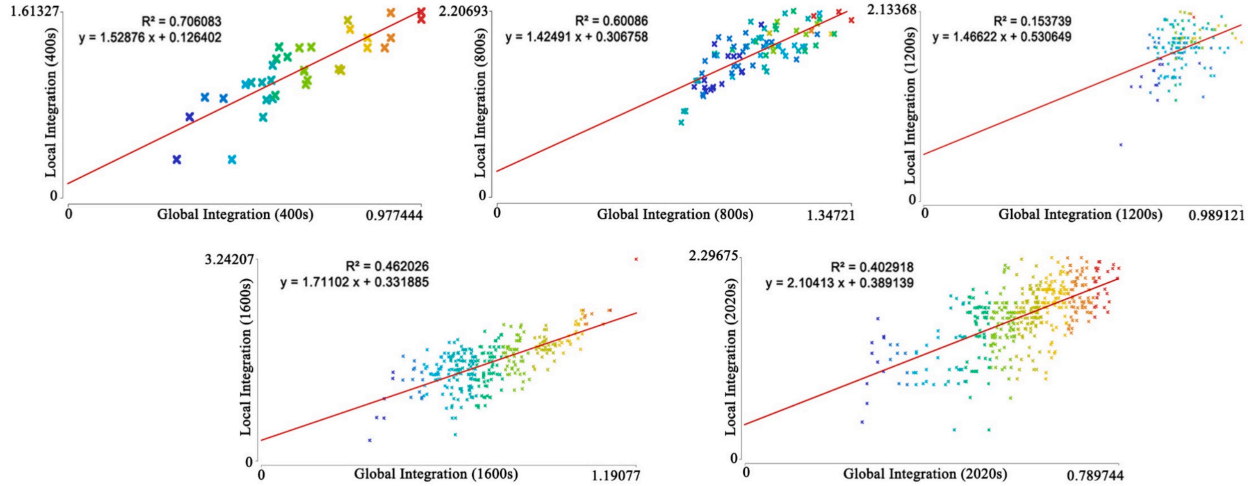

Fig. 12. Intelligibility analysis results of road networks in different periods.

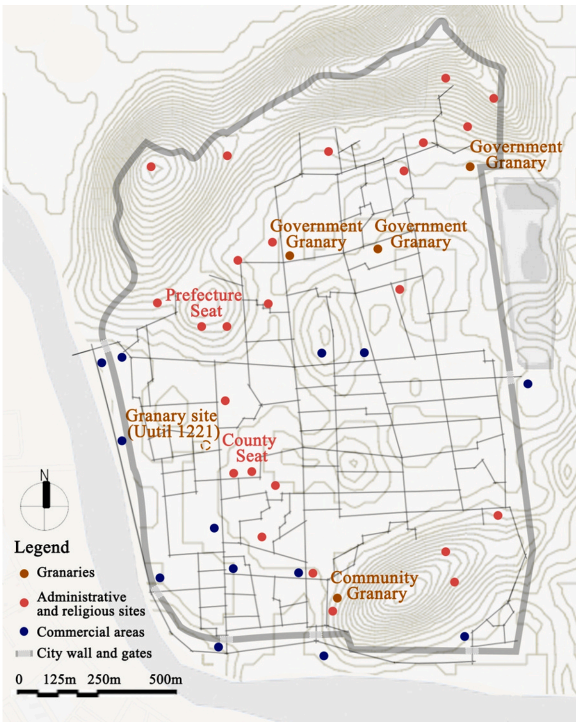

Fig. 13. Spatial distribution of granaries, administrative and religious sites, and commercial areas in the qing dynasty.

and its connected groundwater network continue to provide important flood storage and drainage. Despite urban expansion and functional changes, the main streets in the ancient city retain their role as the primary circulation routes and spaces for daily activity. This enduring spatial skeleton, imbued with historical memory, is explicitly designated in emergency plans as a primary evacuation network. These areas are prioritized in contemporary conservation and flood mitigation planning, equipped with drainage systems, hazard maps, signage, relief supplies, and other mitigation measures. Their early planning strategies profoundly influence contemporary urban planning; for example, critical facilities such as hospitals continue to be sited on higher ground, and are often designed as multi-storey structures that provide vertical refuge during floods while maintaining essential medical services.

Management wisdom also plays a crucial role in the modern era. During Typhoon Lekima in 2019, when the Ling River rose to a record height of 10 m, Linhai sustained structural damage and economic losses, yet casualties remained minimal. Residents' and officials' collective memory of recurring floods has prompted both government and citizens to heighten flood awareness seasonally. In practice, this involved reinforcing vulnerable points such as city gates with wooden boards and sandbags in advance, promptly notifying and evacuating residents in low lying areas, and keeping main streets clear to prevent debris from blocking evacuation routes. Following the typhoon, government agencies and community members collaborated to clear silt from urban areas, and disaster relief subsidies from central and local authorities accelerated reconstruction. Therefore, Linhai's planning heritage is a living tradition rather than a static relic. It represents a dynamic wisdom co-created by officials and the public, making community participation integral to the city's modern resilience.

However, an incomplete understanding of and inadequate protection for planning heritage have intensified flood risk in certain areas. At the strategic level, this is due to a misjudgement of heritage value. Former canals were not recognised as critical infrastructural assets for flood resilience but were instead been treated as available land for development. Their infilling resulted from decision-making that prioritised short-term economic gains over long-term systemic safety. From a governance perspective, this situation is caused by the limitations of fragmented decision processes. Water management, planning and land administration departments lacked coordinated mechanisms to assess long-term impacts on the regional hydrological system. Furthermore, the emergency management department typically only exercised unified management and deployment functions in emergency situations. Heritage authorities were also often unable to intervene in the transformation of historical landforms that were not formally protected. This absence of preventative governance has led to a loss of resilience capacity and to hazards that are now recurring and intensifying: former canals have become frequent internal flooding points, and residents report that flooding occurs after almost every significant rainfall event. Responding to these risks requires critical reflection on past development practices and a shift in management paradigms from reactive emergency response to proactive, systemic governance. While protecting remaining heritage elements is essential, it is even more important to establish a cross-sectoral coordination framework that can evaluate the long-term impacts of development decisions on overall flood resilience and prevent further erosion of latent resilience assets.

5. Discussion

This section interprets and synthesizes the findings from the Linhai case study to provide systematic responses to the study's core research questions. Furthermore, it explores viable pathways for integrating planning heritage as a living resource within contemporary sustainable development agendas. First, it clarifies the conceptual content of planning heritage and situates this concept within the analytical framework of this study (RQ1). Second, it demonstrates the synergistic relationship between urban morphological evolution and flood adaptation, addressing the complexity driven by multiple interacting factors (RQ2). Third, drawing on the empirical results, it analyses the opportunities and challenges that planning heritage presents for contemporary urban resilience and proposes actionable integrative strategies (RQ3). Finally, it acknowledges methodological and argumentative limitations and identifies directions for future research.

5.1. Composition and evolution of planning heritage elements

This study adopts a planning heritage perspective to systematically consolidate and deepen the understanding of long-term adaptive mechanisms in historic cities. In the case of Linhai, planning heritage can be parsed into two interrelated categories.

Tangible spatial elements: These are the physical flood mitigation systems and resilient spatial structures consolidated into the urban form through successive planning practices. They include the city wall system as the primary line of defence, which was progressively heightened and reinforced, recording a morphological shift from a sole emphasis on blocking floods to combined strategies of blocking and mitigating. They also include East Lake and the canal network, which perform storage and diversion functions, and the street topologies. The increased network redundancy, long-term stability of key integrated corridors, and shifts in spatial legibility of these streets collectively embody changes in evacuation and drainage performance. Rather than existing as isolated assets, these elements constitute a functionally complementary spatial system.

Intangible knowledge elements: These encompass the governance models and practical wisdom that have supported the formation, maintenance, and evolution of the tangible systems. This category includes shifts in planning strategy (from avoidance to preventing, and ultimately to living with water), traditional Chinese spatial arrangement methods such as the ‘Lifang’ system, accumulated engineering techniques and quality standards, resource allocation mechanisms for post-disaster recovery, and the tradition of coordinated official and community governance. Crucially, these intangible institutional and practical resources serve as the fundamental guarantee for the sustained performance of the tangible heritage.

The evolutionary trajectory of Linhai's planning heritage manifests as a cyclical process of ‘Shock-Response-Adaptation-Accumulation’ under periodic flood pressure. In each major flood event, proactive planning responses have not only guided the repair of damaged structures but have also driven engineering upgrades, urban morphological evolution, and improvements in management. In this way, new adaptive knowledge has been layered into the spatial and institutional memory (Corboz, 1983; Folke et al., 2001). This planning heritage perspective thus bridges the process-oriented concerns of historical adaptation research with the pattern-oriented descriptions of urban morphology. It moves beyond a static notion of heritage resilience, enabling a dynamic, life-cycle understanding of how heritage is created, evolves, and continues to shape subsequent response capacity (Harvey, 2001; Holtorf, 2018). In this sense, planning heritage extends and enriches the conceptualisation of resilience in historic cities under the HUL approach by explicitly foregrounding the role of long-term planning logics, institutional learning and spatial decision-making (Veldpaus, 2015; Hein, 2020).

5.2. Synergistic co-evolution of urban form and flood adaptation

Urban morphological change is the product of dynamic interactions among social, economic and environmental forces. The findings demonstrate that, under the persistent environmental pressure of flood risk, morphology shaped by multiple drivers undergoes a process of adaptive co-evolution.

Flooding functions as a selective natural pressure in this process, although it is not always the initial driver of morphological change. Historically, spatial layouts that clashed with hydrological conditions or lacked resilience suffered greater damage during disasters and were consequently prioritised for adjustment during reconstruction or renewal (Vale and Campanella, 2005; Liao, 2012). Consequently, the urban forms that have accumulated and survived to the present day can be regarded as adaptive solutions that have passed repeated real-world stress tests (Alexander, 1964; Jigyasu, 2002). For example, although the densification and increasing complexity of the street network after the Song dynasty were largely driven by vibrant commercial activity, the resulting improvements in network connectivity and path redundancy objectively increased the number of alternative evacuation routes and the potential for drainage during flood events (Sharifi, 2019). Such morphological features proved their adaptive value through systemic evolution and were therefore preserved and reinforced (Cun et al., 2019).

The mixed methods used in this research provide multidimensional evidence for this co evolutionary process. The integrative value of this approach lies in its ability to cross-validate planning intent, spatial realisation, functional performance, and social cognition (Yin, 2018). For major interventions such as the excavation of East Lake, historical records clearly document flood mitigation intent, GIS reconstruction visibly displays abrupt changes in spatial patterns, Space Syntax quantifies the reshaping of local accessibility structures, and contemporary interviews confirm the system's persistent storage function and presence in collective memory. The convergence of this multi-source evidence at specific spatio-temporal nodes strongly supports the interpretation that flooding and planning responses have acted as key shaping forces (Kostof, 1991; Gregory and Ell, 2012).

More importantly, for gradual morphological changes that lack explicit documentary records, this study develops a functional retrospective analysis of spatial performance. When the original purpose of a given morphological feature cannot be precisely traced, the alternative is to systematically evaluate the performance roles it may have played under flood stress. Space syntax becomes a crucial tool in this approach because it quantifies structural network attributes (integration, choice and intelligibility) and allows spatial correlation with known flood inundation routes, resident evacuation behaviour, and infrastructure layouts (Sharifi, 2019). This analytical framework treats urban form itself as a vessel that records long-term adaptation processes (Barthel et al., 2010). By decoding its spatial logic, we can extract embedded resilience wisdom. The method therefore provides a transferable framework for identifying and assessing the latent resilience functions of planning heritage in other historic cities that lack comprehensive historical sources.

5.3. Practical application of planning heritage

Based on the empirical study of Linhai, this research proposes an operational framework for managing planning heritage in flood-prone areas (Fig. 14). The framework establishes a systematic workflow that bridges the critical gap between static heritage conservation and dynamic disaster resilience. Identified traditional flood-response strategies should be explicitly integrated into contemporary flood planning measures through three interrelated stages: identification, assessment and implementation. As the framework shows, each stage links specific methodological pathways to concrete outputs, integrates historical spatial logic with

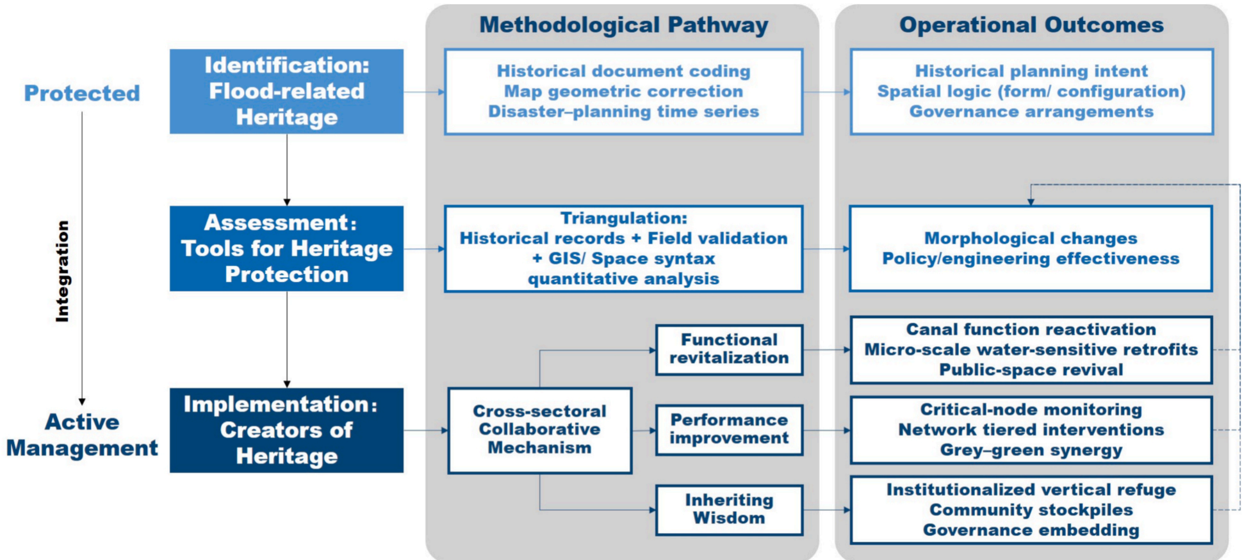

Fig. 14. An operational framework for planning heritage management in flood-prone historic cities.

modern engineering techniques, and provides concrete decision-support mechanisms (Adamson et al., 2018). As a result, the model translates the specific insights into methods adaptable by other historic cities facing similar flooding challenges.

5.3.1. Identification stage: decoding spatial logic

The primary challenge is to accurately identify the historical resilience mechanisms embedded within the modern urban fabric. As indicated in Fig. 14, this stage employs quantitative methods including historical document coding and geometric rectification of historical maps. By georeferencing historical maps to modern coordinate systems, planners can reconstruct a temporal sequence of flood-related planning responses. This process reveals original historical planning intents and underlying spatial logic, particularly the form and configuration of street networks. The main output is a clear understanding of governance arrangements related to water resources management, serving as the foundational database for subsequent resilience assessment.

5.3.2. Assessment stage: triangulation and analytical tools

To overcome the limitations of single-method studies, the framework adopts a triangulation strategy. This stage combines qualitative historical records and field verification with quantitative GIS and Space Syntax analysis. The objective is to track morphological change and evaluate the effectiveness of past policies and engineering interventions. Heritage impact assessment is recommended as a core decision-support instrument at this stage to determine whether existing heritage structures can continue to function effectively under current hydrological conditions (Cacciotti et al., 2021). The assessment provides an evidential basis for decisions regarding the protection, restoration, or functional conversion of specific heritage elements.

5.3.3. Implementation stage: governance and dynamic revival

The implementation stage addresses the root causes of strategic disconnection, fragmented management, and the separation between pre-event planning and emergency response by institutionalising a collaborative governance arrangement (Ansell and Gash, 2008). At the core of this stage is the establishment of a permanent municipal body led by city-level government, with explicit responsibilities, authority and budget for coordinating cultural heritage, water resources, emergency management, housing, natural resources, and community offices. This anticipatory action is intended to replace temporary and reactive coordination mechanisms (Tozier De La Poterie et al., 2023). Operational strategies focus on three mutually reinforcing pathways:

Functional revival: This pathway redefines heritage from a cultural backdrop into an active, infrastructure-based resilience asset. Historical data-based planning is employed to integrate micro-scale water-sensitive interventions into urban renewal, such as green spaces and permeable paving, while restoring historical hydrological functions in previously infilled areas. In addition, incremental construction within the historic core is strictly controlled to safeguard the revitalisation of public spaces such as historic streets and squares.

Performance enhancement: To modernise management and refine decision-making, the framework advocates the establishment of a monitoring, simulation and intervention loop. Real-time monitoring of key heritage nodes and urban waterlogging hotspots enables coordinated simulations across grey infrastructure (heritage structures and pipe networks), green infrastructure (ecological facilities) and blue infrastructure (historical water systems). It provides continuous monitoring and assessment of heritage and hydrological conditions across hazard phases, enabling prioritised, evidence-based interventions (Han et al., 2025). In addition, compatible structural reinforcement and hydraulic performance upgrades are implemented for surviving city walls and existing water management systems, drawing on historical techniques, so that they can fulfil contemporary flood defence and detention functions while preserving cultural authenticity.

Inheriting wisdom: Building resilience depends on social foundations. This pathway systematically transforms local knowledge into institutional resources. For example, Public Participatory GIS can be used to draw community disaster memory maps and to collect and digitise traditional coping practices (including detailed historical refuge points and community evacuation routes). These records are formally incorporated into municipal emergency plans to inform the siting of institutional vertical refuge locations, design community level stockpiling and skill training programmes, and ultimately achieve the creative translation and embedded application of traditional wisdom within modern emergency governance (Mercer et al., 2010; Brown and Kyttä, 2014).

Through these pathways, planning heritage can shift from a static and passive object of protection into a proactive engine for systemic risk governance, spatial renewal, and social co-creation. It thus becomes an indispensable component of modern flood mitigation systems, contributing to the shaping of historic cities as heritage for the future.

5.4. Research limitations and future directions

This study has several limitations that future research should address. First, despite efforts to strengthen causal attribution through methodological cross-validation, disentangling the multiple drivers of morphological change (including economic, political, and flood-related factors) remains a significant challenge in historical research. The associations identified here, therefore, constitute robust correlational evidence rather than definitive causal proof. Second, inherent limitations in the precision and completeness of historical maps and documents constrain the accuracy of spatial analysis and causal inference. Third, the assessment of the contemporary functional performance of planning heritage, although supported by quantitative Space Syntax metrics, lacks coupled hydrological and hydraulic modelling. As a result, it cannot precisely quantify actual engineering benefits in terms of peak flow reduction or runoff delay. Fourth, the analysis of fragmented governance relies mainly on policy texts and interviews. It does not include in-depth empirical observation of inter-departmental decision processes and resource bargaining, which would strengthen the practical relevance of the discussion. Finally, the Linhai case is specific due to its intact city wall system and particular geographic context. The broader generalisability of the findings therefore requires comparative studies across different types of historic cities.

6. Conclusion

This study uses a planning heritage lens to examine the long-term adaptive mechanisms of historic urban areas in flood-prone regions and their contemporary implications, using the longitudinal case of the Ancient City of Linhai. The main findings are as follows.

RQ1: Linhai's planning heritage comprises a composite of tangible spatial systems and intangible knowledge systems. It is not a static relic. Rather, it has been dynamically accumulated and evolved over nearly two thousand years through repeated cycles of disaster, planning responses, and system level adjustments.

RQ2: There is a clear synergistic co-evolution between Linhai's urban morphological change and flood adaptation. Major flood events directly triggered strategic adjustments to macro-spatial patterns, while long-term morphological changes in the street network, driven by multiple factors, encoded functional logic that improved evacuation efficiency and drainage capacity. These developments produced an adaptive urban form that integrates development and disaster mitigation.

RQ3: Planning heritage provides contemporary communities with valuable resilience assets, including physical defence systems and embedded social adaptive knowledge. However, its effective functioning faces fundamental challenges regarding systemic cognitive rupture and fragmented management. Fragmented management can weaken the holistic functioning of planning heritage and may even damage it through inappropriate renewal, thereby potentially increasing community vulnerability.

In summary, enhancing the resilience of historic cities in flood-prone areas requires moving beyond the static preservation of planning heritage toward a paradigm of system-level cognition, holistic management, and adaptive revival. This entails the development of interdisciplinary diagnostic methods to identify resilience cores, the reform of cross-sectoral governance frameworks to protect functional integrity, and implementing fine-grained design interventions that allow heritage to meet modern needs while strengthening its innate buffering capacity. Planning heritage thus transforms from a conservation object into a critical planning interface and a living resource that links historical wisdom with future sustainability.

CRediT authorship contribution statement

Qinglong An: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Chiho Ochiai:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Qinglong An reports financial support was provided by Obayashi Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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