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Spatial Morphology of Historic Built Environments in Valley Settings: A Comparative GIS and Space Syntax Analysis for Sustainable Conservation Planning

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Abstract

The sustainable development of valley-type historic towns is increasingly challenged by tourism growth, infrastructure modernization, and community change. Effective responses require a systematic understanding of how spatial morphology mediates the trade-offs between heritage conservation and socio-economic vitality. However, existing studies rarely connect configurational analysis with actionable sustainability strategies in topographically constrained settings. This study addresses this gap by developing a multi-level comparative framework that integrates GIS-based environmental assessment, space syntax configurational modelling, and building-fabric fieldwork. The framework is applied to three historic towns in the upper Yellow River Basin—Qingcheng, Hekou, and Hongcheng—which share similar valley constraints but diverged in historical functions (commercial, defensive, and mixed). Four dimensions are examined, mountain–water patterns, street networks, building fabric, and public-space systems, using indicators including elevation, slope, distance to water, axial integration, intelligibility, shop-front proportion, street aspect ratio, and public-node service radius. The results reveal two complementary layers of spatial logic. At the environmental level, all three towns exhibit shared valley-adaptive traits—near-water locations on relatively gentle terrain, low-slope terrace occupation, axial elongation, and concentrated public spaces. Flood risk was not directly assessed in this study. At the functional level, marked differentiation emerges. Hekou shows the highest network intelligibility (R^2 = 0.900) and commercial frontage (35% shop-front proportion), which may be interpreted in relation to its commercial and transportation history; however, socio-economic vitality was not directly measured. Hongcheng displays lower intelligibility (R^2 = 0.556) and thicker defensive walls (0.6–0.8 m), which may be interpreted in relation to its defensive history; however, cultural resilience and economic adaptability were not directly measured. Qingcheng presents a mixed pattern with a single high-integration axis and diverse public nodes, which may be interpreted as functional layering; this interpretation is theoretical and was not directly tested. Rather than offering a universal model, this study provides an evidence-based framework for diagnosing the sustainability implications of spatial form in valley-type historic towns. The findings translate morphological indicators into differentiated management strategies—prioritising commercial corridor continuity in Hekou, preserving defensive spatial sequences in Hongcheng, and balancing functional layering along the historic axis in Qingcheng. This framework contributes to sustainable heritage management by demonstrating how spatial analysis can inform context-sensitive planning that reconciles conservation with development in environmentally constrained settings.

Check for updates

Academic Editor: Antonio Miguel Martínez-Graña

Received: 1 September 2026
Revised: 29 September 2026
Accepted: 30 September 2026
Published: 4 October 2026

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Keywords: valley-type historic towns; spatial morphology; GIS; space syntax; comparative analysis; upper Yellow River Basin

1. Introduction

These spatial characteristics are not only environmental adaptations but also material records of long-term social, economic, military, and cultural activities. This perspective is grounded in the foundational works of Conzen [1] on urban form persistence and Lynch [2] on settlement legibility. Recent studies have likewise shown how urban form can be operationalised for heritage-led regeneration and public value creation in historic districts [3]. Lynch's framework—particularly his identification of paths, nodes, edges, districts, and landmarks—provides a theoretical grounding for analysing how street networks and public spaces shape spatial cognition and collective memory [2].

What makes valley-type towns analytically distinctive is not the mere presence of topographical constraints, but the specific nature of those constraints. In valley settings, mountains and hills create a rigid spatial envelope that sharply delimits buildable land and forces settlement to elongate along the valley axis rather than expand radially [4,5]. This axial compression produces linear street networks, strong dependence on a single primary axis, and close relationships between river proximity and terrace siting. We define valley-type historic towns as settlements whose spatial morphology is fundamentally constrained by valley topography—elongated along a single axis, bounded by slopes, and dependent on river proximity for transportation and subsistence—distinguishing them from plain, plateau, or coastal settlement types. Valley settings within the same river system offer a relatively stable environmental baseline across multiple sites, allowing researchers to examine how different historical functional orientations are associated with divergent morphological outcomes while topographical constraints remain broadly similar [6].

This research opportunity is not confined to China. Valley-type historic settlements have been examined worldwide, from the Kathmandu Valley in Nepal [7–9] to Italian hill-top and valley-bottom towns [10,11], the Tamar Valley in southwest England, and 19th-century mining towns in the Rocky Mountains [12]. Across these regions, GIS-based spatial analysis and space syntax configurational modelling have been increasingly employed to decode valley settlement morphology [13,14]. Recent work has further advanced heritage impact assessment and the integration of space syntax with heritage frameworks [15]. Yet comparative studies that systematically examine how different historical functional orientations are associated with divergent morphological outcomes within similar valley environments remain rare.

The upper Yellow River Basin in Northwest China offers a particularly suitable setting for comparative analysis due to its concentration of historic towns that share similar topographical constraints yet diverged in historical functions. Some towns served as commercial and transportation hubs along river and land routes, while others originated from military defence systems or gradually transformed from military settlements into commercial and cultural centres. Under contemporary conditions, these towns face increasing pressure from tourism development, road improvement, infrastructure construction, and residential renewal. Identifying their stable spatial characteristics and differentiated morphological patterns is therefore important for both historical interpretation and sustainability-oriented spatial management. Because these towns also differ in settlement size, preservation status, and contemporary development pressure, the present study treats historical function as one potential influence among several rather than as a deterministic cause.

Existing studies on historic settlements have developed rich theoretical and methodological approaches. Urban morphology research has emphasised the stability of street networks, plot structures, building fabrics, and town-plan units [1,5,6]. The Historic Urban Landscape (HUL) framework advocates integrated assessment of natural topography, historical layering, and cultural values [16,17]. Quantitative methods such as GIS analysis, space syntax [10], graph theory, and network analysis have increasingly been applied to traditional villages, historic districts, and old urban centres [13,18,19]. GIS-based approaches have also been integrated with HUL frameworks to analyse layered urban transformations [20,21]. Lynch's conceptual toolkit—particularly the distinction between paths, nodes, edges, districts, and landmarks—has found renewed relevance as a qualitative counterpart to quantitative configurational analysis, linking measurable spatial properties with human-centred notions of legibility, identity, and place attachment [2,22].

However, research on valley-type historic towns still requires further development. Many existing studies focus on single cases, while comparative studies among multiple towns under similar topographical constraints remain limited. Although both natural environment and historical function are recognised as important factors shaping settlement morphology, it remains insufficiently explained how similar valley environments are associated with shared spatial characteristics while different historical functional orientations are associated with differentiated morphological patterns. In addition, quantitative spatial indicators are often used for diagnosis, but their translation into sustainability-oriented spatial management measures—such as historic-axis protection, street-scale control, courtyard-fabric conservation, and public-space management—remains underdeveloped.

Qingcheng, Hekou, and Hongcheng provide suitable cases for exploring these issues. All three towns are located in the upper Yellow River Basin and its tributary valley system, sharing broad environmental conditions such as river proximity, terrace-based construction land, and strong relationships between settlement, water, and surrounding mountains. At the same time, they differ in historical functional orientation: Hekou developed as a commercial and transportation hub, Hongcheng retained a stronger military-defensive character, and Qingcheng presents a mixed pattern formed through military-to-commercial transformation and cultural layering. The three towns are not matched on settlement area, preservation status, or contemporary development pressure, so the comparison is exploratory and associational rather than a controlled test of historical function. Historical function is treated as one co-constituting influence among several, including settlement size, topographic setting, preservation history, and recent redevelopment. A fuller account of case comparability and potential confounders is provided in Section 2.2 and Table 1.

Table 1. Case comparability and potential confounders.

Town	Area (km^2)	Historical Functional Orientation	River Setting	Elevation/Slope of Core	Preservation Status	Contemporary Tourism/ Development Pressure	Main Potential Confounders
Qingcheng	0.945	Military–commercial–cultural layering	Yellow River alluvial plain	1429–1734 m; ≤2°	Mixed, dispersed historic fabric	Moderate–high tourism and renewal	Largest area; dispersed fabric; multiple heritage layers
Hekou	0.113	Commercial–transport	River-confluence terrace	1551–1881 m; ≤2°	Relatively concentrated	High commercial/tourism pressure	Smallest area; strongest modern commercial pressure

Table 1. *Cont.*

Town	Area (km^2)	Historical Functional Orientation	River Setting	Elevation/Slope of Core	Preservation Status	Contemporary Tourism/ Development Pressure	Main Potential Confounders
Hongcheng	0.239	Military-defensive	Zhuanglang River valley	1774–2042 m; 2–8°	Compact defensive fabric	Lower tourism pressure	Steeper valley; stronger defensive remains

Note: Area is based on the unified historic-core boundary. Preservation status and development pressure are qualitative assessments based on conservation planning documents and field observation. These variables are not controlled in the comparative design and are discussed as competing explanations in Section 4.6.

This study examines the spatial morphology of the three towns through four analytical dimensions: mountain–water pattern, street network, building fabric, and public space. Field surveys, GIS analysis, space syntax, and building-fabric measurements are used to compare indicators such as elevation, slope, distance to water, axial integration, intelligibility, shop-front with rear-residence proportion, street aspect ratio, public-node distribution, and service radius. The objectives of this study are threefold. First, it identifies the shared valley-adaptive spatial characteristics of Qingcheng, Hekou, and Hongcheng, including near-water location, low-slope construction land, axis-led organisation, and public-space agglomeration. Second, it explores how differentiated morphological patterns—commercial openness in Hekou, defensive enclosure in Hongcheng, and functional layering in Qingcheng—are associated with different historical functional orientations, while acknowledging that other factors may also contribute. Third, it translates quantitative findings into sustainability-oriented conservation planning implications, including the protection of high-integration historic axes, control of traditional street aspect ratios, conservation of courtyard fabric, and management of public-space service areas.

The motivation for investigating spatial morphology extends beyond morphological description. Spatial form is not a neutral physical container; it mediates the social, cultural, and economic life of a place [23,24]. Street networks condition patterns of pedestrian movement and social encounter, which in turn shape community vitality and everyday practices [25,26]. Building fabric and public spaces carry material traces of historical functions and serve as anchors for collective memory and identity [27]. When these spatial structures are eroded or fragmented, what is lost is not merely physical artefacts but the relational fabric that sustains local knowledge, social cohesion, and continuity with the past [28]. Analysing spatial morphology is therefore a necessary first step toward understanding how a town works as a living environment, not just as a historical document.

It should be noted that this study does not claim that historical function alone explains morphological variation. Rather, it asks whether, within a shared valley-environmental baseline, towns with different functional histories exhibit systematically different morphological tendencies. Because the three cases are not matched on area, preservation status, or contemporary development pressure, the findings are offered as exploratory and hypothesis-generating rather than causal. Within this framing, the specific innovation of the study lies in its multi-level comparative framework. Unlike previous GIS–space syntax studies that focus primarily on street-network configuration, this study integrates environmental assessment, configurational modelling, building-fabric measurement, and public-space mapping, and applies this integrated framework to valley-type historic towns with different historical functional orientations. Its contribution lies in linking quantitative spatial morphology analysis with sustainability-oriented spatial management practice, rather than in constructing a universal theory. Given the limited number of cases, the find-

ings should be understood as a preliminary regional comparison; their broader applicability requires further verification through larger samples and cross-regional studies.

2. Materials and Methods

2.1. Analytical Framework

This study constructs a comparative analytical framework for valley-type historic towns based on the relationship between natural constraints, historical functional orientation, spatial morphology, and conservation planning. The framework does not aim to establish a universal model but to examine how historic towns within similar valley environments share common spatial characteristics while developing differentiated morphological patterns that are associated with different historical functional orientations. The basic analytical logic proceeds in four steps. First, the valley environment provides a shared natural setting—river proximity, terrace-based land, and low-slope areas—forming the environmental basis for spatial development. Second, different historical functional orientations (commercial, military, mixed) are associated with the organisation of street networks, building fabric, and public spaces. Third, these spatial differences are identified through measurable indicators derived from GIS analysis, space syntax, field surveys, and building-fabric measurements. Fourth, the quantitative findings are translated into sustainability-oriented spatial management implications. In this study, "spatial gene" is used heuristically as an interpretive concept referring to relatively stable and inheritable spatial characteristics, translated into measurable morphological indicators for operational comparison. The overall analytical framework is illustrated in Figure 1.

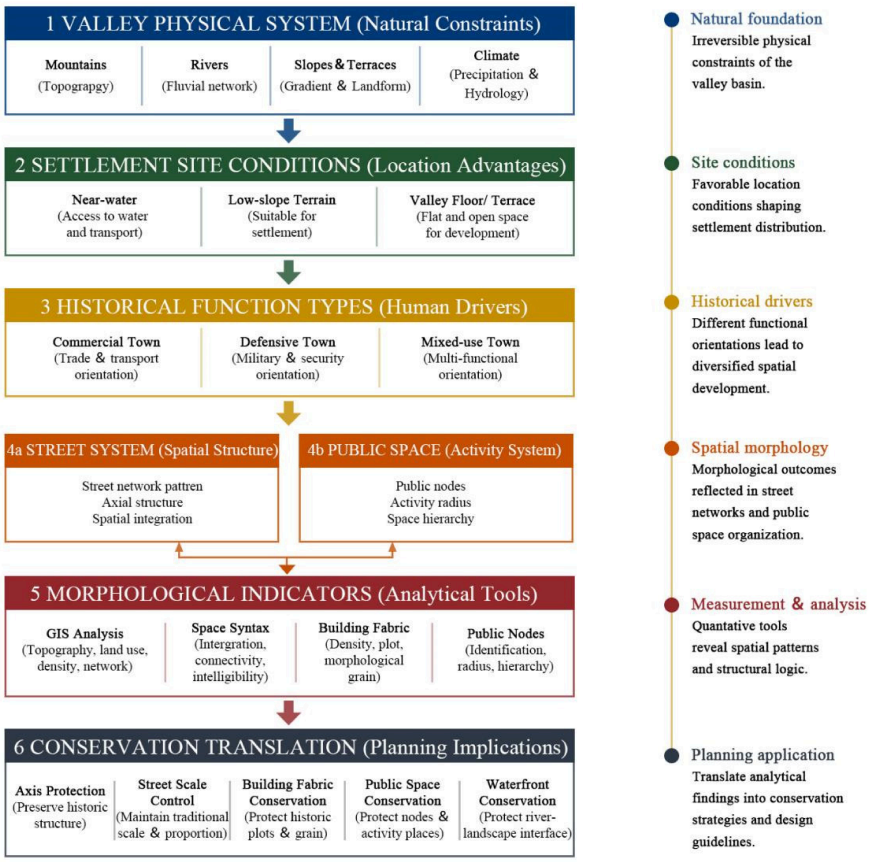


Figure 1. Analytical framework of the study. A multi-level framework linking valley physical constraints, settlement conditions, historical functions, spatial morphology, and sustainability-oriented spatial management, operationalized through GIS, space syntax, and morphological indicators.

In this study, four interpretive terms are used. "Spatial gene" is used heuristically to refer to relatively stable and inheritable spatial characteristics of traditional settlements, which are translated into measurable morphological indicators for operational comparison. "Cultural resilience" refers to the capacity of a historic town's spatial and material fabric to sustain cultural identity and continuity under change; it is interpreted here through morphological indicators such as defensive walls and enclosed layouts, but is not directly measured. "Economic adaptability" refers to the capacity of the spatial structure to accommodate changing commercial and functional uses; it is interpreted through indicators such as shop-front proportion and street connectivity, but is not directly measured. "Socio-economic vitality" refers to the intensity and diversity of economic and social activities in public space; it is interpreted here through configurational indicators such as integration and intelligibility, but is not directly measured. These terms are used consistently throughout the manuscript as interpretive concepts, not as empirically verified outcomes.

2.2. Study Area and Case Selection

The study focuses on three valley-type historic towns in the upper Yellow River Basin: Qingcheng, Hekou, and Hongcheng. Qingcheng is located in Yuzhong County, Lanzhou City, on the south bank of the Yellow River. Hekou is located in Xigu District, Lanzhou City, near the confluence of the Yellow River and the Zhuanglang River (Figure 2). Hongcheng is located in Yongdeng County, along the Zhuanglang River valley. All three towns are situated in the upper Yellow River valley system and have spatial forms strongly influenced by mountains, rivers, terraces, and limited construction land.

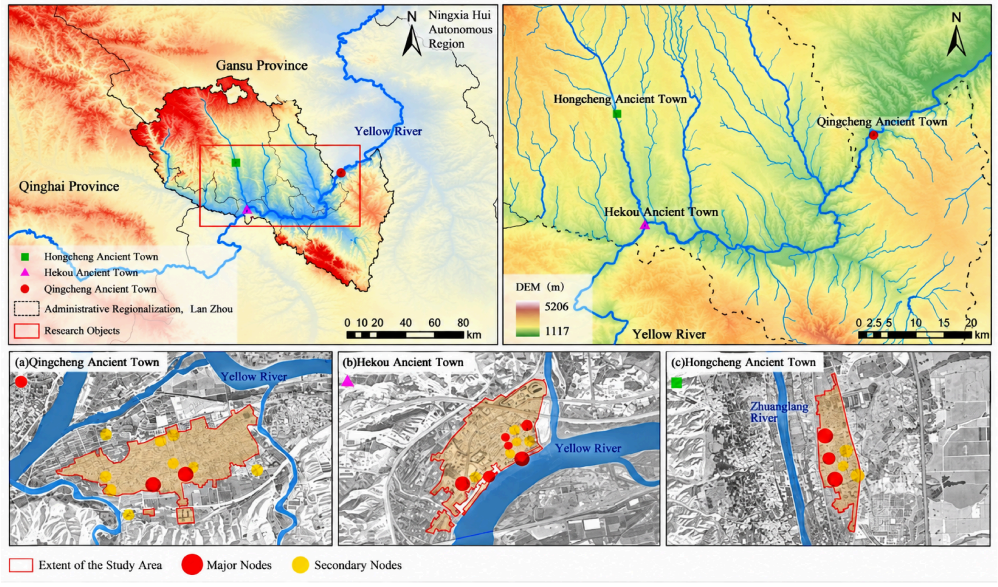


Figure 2. Location of Qingcheng, Hekou and Hongcheng in the upper Yellow River Basin and unified analytical boundaries.

The three cases were selected according to five pre-defined criteria. First, all are located within the upper Yellow River Basin or its tributary valley system, ensuring similarity in regional geographical background. Second, they were formed before or during the Ming–Qing period and preserve historical spatial patterns to varying degrees. Third, they retain identifiable historic street networks, traditional building fabric, and public nodes. Fourth, they represent different historical functional orientations: Hekou is mainly associated with commercial transportation, Hongcheng with military defence, and Qingcheng with a mixed process of military-to-commercial transformation and cultural layering. Fifth,

field-survey data, historical documents, satellite images, and spatial data are available for all three towns.

These criteria ensure broad comparability in environmental setting and historical documentation, but they do not control for differences in settlement area, preservation status, or contemporary development pressure (Table 1). These differences may influence configurational measures and the completeness of the historic fabric. The comparison is therefore exploratory and associational: historical function is treated as one co-constituting influence among several, and the observed differences are interpreted as consistent with, rather than determined by, historical functional orientation.

2.3. Boundary Definition and Comparability

A unified research boundary is essential for ensuring comparability among the three towns. If different boundary standards were applied, indicators such as building density, axial integration, and public-node service radius would become incomparable. Therefore, this study defines the research boundary according to the same principle for all three towns. The boundary refers to the historic-core area where historical streets, traditional buildings, and public nodes are continuously preserved. Modern peripheral expansion areas, agricultural land, mountains, water bodies, large-scale new tourist facilities, and non-historic construction areas are excluded. The boundary is determined through a combination of conservation planning documents, historical maps, high-resolution satellite images, field investigation, and the continuity of historic street-and-building fabric. Within this unified boundary, all publicly accessible historic streets and lanes are included in the street-network analysis. Traditional residential courtyards, commercial frontages, temples, ancestral halls, academies, wharfs, gates, towers, squares, and other public nodes are included in the building-fabric and public-space analyses when located within the defined historic core. The boundary area of Qingcheng is larger than the other two cases (0.945 km^2, compared with 0.113 km^2 for Hekou and 0.239 km^2 for Hongcheng), reflecting a relatively dispersed distribution of its historic built fabric. This variation is documented as a basic spatial descriptor; subsequent morphological indicators—such as axial integration and intelligibility—are topological measures not directly dependent on absolute area, preserving the validity of cross-town comparison.

2.4. Data Sources

This study employs a three-tier data framework distinguishing between source data, processing environments, and analytical outputs.

Source data comprise four categories. First, environmental data—ASTER GDEM v3 (30 m resolution) and river system vector layers from the National Geographic Census database—were used for terrain and distance-to-water analysis. Second, remote-sensing and cartographic data—high-resolution satellite images (Tianditu, 0.5 m resolution) and digitised historical maps from local conservation archives—were used to delineate street networks, building footprints, and public-space boundaries. Third, historical and archival data—local chronicles, town history records, cultural heritage registration documents, and conservation planning reports obtained from the Cultural and Tourism Bureaus of Lanzhou City, Yuzhong County, and Yongdeng County—were used to reconstruct historical development trajectories and functional orientations. Fourth, field-survey data were collected during campaigns conducted in July–August 2023, spanning approximately three weeks in total (one week per town). The survey covered all publicly accessible historic streets and lanes within the unified core boundary, totalling 6.2 km of street frontage across the three cases. Building measurements were recorded for 47 representative traditional buildings (16 in Qingcheng, 15 in Hekou, and 16 in Hongcheng). A stratified purposive sampling

strategy was used. The sample covered all major historical thoroughfares, all identifiable building types (shop-front with rear-residence, courtyard dwelling, temple, ancestral hall, gate/tower, and defensive wall), and different preservation conditions. Severely altered buildings that could not be measured reliably (e.g., those with structurally altered walls or lost original materials) were excluded. This exclusion may bias the detailed sample toward better-preserved buildings and potentially underestimate the extent of modern commercial renovation. To mitigate this, wall thickness and shop-front proportions were calculated from larger samples that include all accessible traditional buildings along the main historic streets. These 47 buildings constitute the detailed building-fabric sample, and measured variables included street width, building height, wall thickness, and building use. Some indicators, however, were additionally calculated from larger or differently defined samples because they can be recorded consistently beyond this detailed sample. Wall thickness was measured for all accessible traditional buildings along the main historic streets, yielding larger samples (Qingcheng n = 47; Hekou n = 39; Hongcheng n = 41). The shop-front with rear-residence proportion was calculated at the level of street-front building units rather than individual detailed sample buildings; its denominator is the total number of identifiable street-front building units along historic streets within the unified core boundary (Qingcheng 142; Hekou 117; Hongcheng 131). These larger samples are therefore not limited to the 47-building detailed fabric sample, but are used to improve the representativeness of the relevant indicators. Wall thickness was measured at three points per building at 1.0–1.5 m above the plinth, avoiding door and window openings; the mean of the three measurements was used. Measurement uncertainty for wall thickness is $\pm$1 cm. Street aspect ratio was calculated as mean building height divided by mean street width along representative continuous street sections of at least 30 m, excluding intersections. All measurements were recorded on standardised field sheets and cross-checked with photographs. Semi-structured observations documented commercial frontage continuity and public-space activity patterns, recorded through standardised field sheets and supplemented by over 800 geotagged photographs. Informal interviews with local residents, shopkeepers, and village elders were conducted to cross-verify functional interpretations derived from historical documents; these interviews served as a qualitative validation tool for morphological interpretation rather than a systematic social survey. Participation was voluntary, and verbal informed consent was obtained before each interview. Participants were informed of the purpose of the study, the voluntary nature of participation, their right to withdraw at any time, and the anonymised use of their responses for research purposes. The interviews did not collect personal identifiers or sensitive personal information. All responses were anonymised, stored securely, and used solely for research purposes. In accordance with the institutional guidelines of Lanzhou University of Technology for non-invasive social research, this study was exempt from formal ethics review.

These source data were processed in three analytical environments. GIS-based analyses—elevation, slope, aspect, distance-to-water, and building-density calculations—were conducted in ArcGIS Pro 3.1. Space syntax modelling—axial map construction and configurational analysis (global integration, local integration, intelligibility)—was performed in Depthmap X 0.8.0. Statistical and spatial calculations—including buffer analyses of public-node service radii and descriptive statistics—were performed in Microsoft Excel and ArcGIS Pro.

Analytical outputs derived from these environments include topographic maps (elevation, slope, aspect, distance-to-water); configurational indicators (axial integration, intelligibility); building-fabric metrics (building density, courtyard proportion, shop-front with rear-residence proportion, street aspect ratio); and public-space indicators (node count, functional typology, service radius). These outputs form the basis for the comparative anal-

ysis in Section 3 and are discussed in relation to sustainability-oriented spatial management in Section 4. A summary of the data framework is provided in Table 2.

Table 2. Data framework: source data, processing environments, and analytical outputs.

Source Data	Processing Environment	Analytical Outputs	Purpose
Environmental data: ASTER GDEM v3 (30 m)	ArcGIS Pro 3.1	Elevation, slope, aspect maps	Identify terrain setting and construction land suitability
Environmental data: River system vector layers (National Geographic Census)	ArcGIS Pro 3.1	Distance-to-water calculation	Assess river–settlement proximity
Remote-sensing data: Satellite images (Tianditu, 0.5 m)	ArcGIS Pro 3.1	Building footprint extraction, street-network digitisation	Delineate building fabric and street layout
Historical data: Local chronicles, conservation planning archives	Document review	Historical functional typology	Reconstruct historical development and functional orientation
Field-survey data: On-site measurements, photographic records	Documentation and cross-verification	Street width, building height, wall thickness, courtyard proportion, shop-front proportion	Quantify building-fabric characteristics
Digitised street network	Depthmap X 0.8.0	Axial maps; global/local integration; intelligibility	Evaluate street-network configuration
Digitised public nodes	ArcGIS Pro 3.1 (buffer analysis)	Public-node count, functional typology, service radius (50 m intervals, 50% coverage threshold)	Analyse public-space organisation and coverage

The GIS analysis follows standard procedures for terrain and distance-to-water calculation [29,30], using DEM data to generate elevation, slope, and aspect maps. Building density is calculated by dividing total building footprint area by total boundary area. Courtyard proportion is identified through satellite image interpretation and field verification.

ASTER GDEM v3 (30 m resolution) was used primarily for regional terrain setting and for comparing slope and elevation ranges across the three towns, rather than for parcel-level analysis within the historic cores. Fine-scale verification was based on high-resolution satellite images (0.5 m) and field surveys. We acknowledge that 30 m resolution may smoothe local topographic variation within relatively small historic cores. However, because the study focuses on comparative valley-scale setting rather than micro-topographic modelling, the data are adequate for the purposes of this analysis. Future research could use LiDAR or UAV-derived DEMs for finer slope and elevation analysis within historic cores.

For space syntax analysis, the fundamental unit is the axial line—the longest straight line of sight and movement through a street segment before a direction change is required [11]. Space syntax has been widely validated in historic urban studies, including recent comparative analyses of Chinese historic towns from a heritage tourism perspective and studies of pedestrian accessibility in world heritage cities [18,19]. The axial map, consisting of the least set of such lines passing through each convex space of the settlement, is treated as a topological graph with lines as nodes and intersections as edges. Axial maps were drawn according to the "longest and fewest lines" principle and verified using satellite images and field records. Three indicators were calculated: global integration (HH), local integration (R = 3), and intelligibility (R^2).

Integration values were first calculated within the unified historic-core boundary of each town. Because global integration is sensitive to system size and boundary definition, we additionally report local integration at R = 3 and R = 5 and conducted boundary sensitivity tests using three conditions: (1) historic core only; (2) core plus a 400 m contextual buffer; and (3) core plus an 800 m contextual buffer.

For the two expanded conditions, all publicly accessible roads and lanes that were historically connected to the internal street system of the historic core were included. Modern peripheral highways, temporary construction roads, private access roads, and roads that were not historically connected to the core street system were excluded. Axial lines were redrawn for the expanded networks following the same "longest and fewest lines" principle used for the core network.

Integration values were calculated within each expanded network. To avoid the direct influence of network size on the summary statistics, the reported mean integration values for the expanded networks are based only on the axial lines that correspond to the original historic-core streets and lanes, rather than on all axial lines within the expanded network. The total number of axial lines in each expanded network is also reported to document the change in network size. This procedure ensures that the comparison focuses on how the configurational position of the historic core changes when embedded in a larger urban context, rather than on the average integration of the entire expanded network.

Absolute integration values are interpreted only in relative terms; the comparative conclusions rely on the relative ranking and the convergence of local integration, intelligibility, and buffer sensitivity results. The implications of this methodological choice are further addressed in Section 4.6. The resulting core axial maps contain 76 lines for Hekou, 112 for Hongcheng, and 189 for Qingcheng. Modelling rules are summarised in Table 3, and expanded-network values are reported in Table S3.

Table 3. Space syntax modelling rules.

Modelling Item	Rule Used in This Study
Research boundary	Unified historic-core boundary
Included roads	Publicly accessible historic streets and lanes
Excluded roads	Private courtyard passages, agricultural paths, modern peripheral roads, temporary tourist routes
Dead-end lanes	Retained
Riverbank roads	Included only when historically connected to the internal street system
Axial-line drawing rule	Longest and fewest lines principle
Software	Depthmap X 0.8.0
Global indicator	Global integration
Local indicator	Local integration, R = 3, R = 5
Legibility indicator	Intelligibility, measured by R^2
Model verification	Satellite images and field-survey records

For building-fabric analysis, shop-front with rear-residence proportion was calculated among street-front buildings. Wall thickness was measured through field surveys. Street aspect ratio (*H/W*) was calculated as mean building height divided by mean street width along representative continuous street sections of at least 30 m, excluding intersections. A lower *H/W* value indicates a wider and more open street, whereas a higher *H/W* value indicates a narrower and more enclosed street. Public-space analysis focused on core

public nodes—temples, ancestral halls, academies, wharfs, towers, gates, squares, and historically significant spaces—defined as public or semi-public spaces with historical, social, or symbolic significance remaining identifiable in the current spatial structure.

2.5. Public-Space Analysis

Public-space analysis focuses on core public nodes, including temples, ancestral halls, academies, wharfs, towers, gates, squares, and historically important activity spaces. A core public node is defined as a public or semi-public space that has historical, social, religious, commercial, educational, or symbolic significance and remains identifiable in the current spatial structure.

Nodes were classified using a six-criteria scoring system (Table 4). Each criterion was scored from 0 to 2, giving a total score of 0–12. Nodes scoring ≥8 were classified as primary nodes; nodes scoring 5–7 were classified as secondary nodes; nodes scoring below 5 were not included in the core public-node analysis. In this study, the term "core public nodes" refers to all nodes scoring ≥5, i.e., the combined set of primary and secondary nodes. The classification was cross-checked by two researchers, and disagreements were resolved through field verification.

Table 4. Classification criteria for primary and secondary public nodes.

Dimension	Definition	Score 0	Score 1	Score 2	Data Source
Historical importance	Documented role in town history	Not documented	Mentioned in local records	Explicitly documented in chronicles or conservation plans	Local chronicles, conservation reports
Heritage designation	Official protection level	None	County-level	Provincial-level or above	Heritage registration documents
Spatial scale	Area of node or associated open space	<100 m^2	100–500 m^2	>500 m^2	Satellite images, field survey
Service range	Approximate catchment within the historic core	<150 m	150–300 m	>300 m	GIS buffer analysis, field observation
Relationship with main axis	Proximity to the primary historic axis	Not connected	Near main axis	Directly on main axis	Axial map overlay
Functional diversity	Number of historical or social functions	One function	Two functions	Three or more functions	Historical records, field observation

Service radius was calculated using GIS multi-ring buffer analysis at 50 m intervals. All core public nodes (score ≥ 5) were digitised as point features representing the centre of the associated public space; for square-like open spaces, the point was placed at the geometric centre of the open area. Buffers were generated from these point features. For each town, buffers were generated around all core public nodes. The union of all buffers was used to calculate the proportion of the historic-core area covered. The system-level effective service radius was defined as the first 50 m increment at which the union of all core-node buffers covered ≥50% of the historic-core area. Overlapping buffers were counted only once in the union calculation. Individual node service radii were also recorded at 50 m, 100 m, 150 m,

200 m, and 250 m for comparison. The node-level scores and inclusion list are provided in Table S1, and cumulative coverage at each 50 m increment is reported in Table S2.

The 50% coverage threshold was adopted as a pragmatic criterion to identify the distance at which a majority of the historic-core area is served by the public-node system. Because the three historic cores differ in size, the absolute radius values are interpreted comparatively rather than as universal standards. This threshold is consistent with pedestrian catchment approaches used in comparable historic urban studies [31], but we acknowledge that it is a heuristic choice. Alternative thresholds (e.g., 40% or 60%) would shift the absolute radius values, although the relative ranking of the three towns is likely to remain stable. The reported effective radius is the first 50 m increment at which cumulative coverage reaches 50%; cumulative coverage values are provided in Table S2.

2.6. Comparative Analysis and Translation to Sustainability-Oriented Management

After the above indicators are calculated, the three towns are compared across four analytical dimensions. The comparison first identifies shared spatial characteristics related to valley constraints—river proximity, low-slope construction land, axis-led organisation, public-space agglomeration—and then examines differentiated morphological patterns associated with historical functional orientations. The final step translated into sustainability-oriented spatial management implications: high-integration axes as priority corridors for historic street protection; street aspect ratios for building-height and street-interface control; courtyard proportion and building density for fabric conservation; public-node service radius for public-space management units; and distance-to-water and mountain–water relationships for waterfront landscape and flood-risk-sensitive conservation.

This four-step workflow—from environmental baseline through functional interpretation to morphological measurement and conservation translation—constitutes the study's core methodological contribution. Unlike single-case morphological descriptions or purely configurational analyses that stop at spatial diagnosis [18,19], our framework explicitly links spatial indicators to planning actions, offering a replicable protocol for conservation-oriented morphological analysis of valley-type historic towns in other regions. Through this workflow, the study links spatial morphology analysis with practical conservation planning.

3. Results

3.1. Shared Valley-Adaptive Setting: Near-Water and Low-Slope Location

The GIS analysis shows that Qingcheng, Hekou, and Hongcheng share a common valley-adaptive spatial environment. Although the three towns are located in different river reaches and have distinct historical functions, their historic-core areas are all closely associated with river systems, terrace landforms, and low-slope construction land. This indicates that valley topography provides an important natural foundation for their spatial development (Figure 3a–Figure 3c, for Qingcheng, Hekou, and Hongcheng respectively), which is consistent with all three towns being situated within valley- or terrace-based geomorphological settings.

In terms of elevation, the three towns are distributed on river terraces or valley plains within the upper Yellow River Basin and its tributary system. Qingcheng is located on the alluvial plain of the Yellow River, with an elevation range of approximately 1429–1734 m (Figure 4a). Hekou is situated at the confluence area of the Yellow River, the Zhuanglang River, and related tributaries, with an elevation range of approximately 1551–1881 m (Figure 4b). Hongcheng is located along the Zhuanglang River valley, with an elevation range of approximately 1774–2042 m (Figure 4c). Although their absolute elevations differ, all three towns are located on relatively gentle terrain within valley environments rather

than on steep mountain slopes. However, this study does not analyse flood levels, historical inundation, channel change, or floodplain extent, and therefore cannot conclude that these locations are flood-safe or were intentionally selected above flood-risk areas.

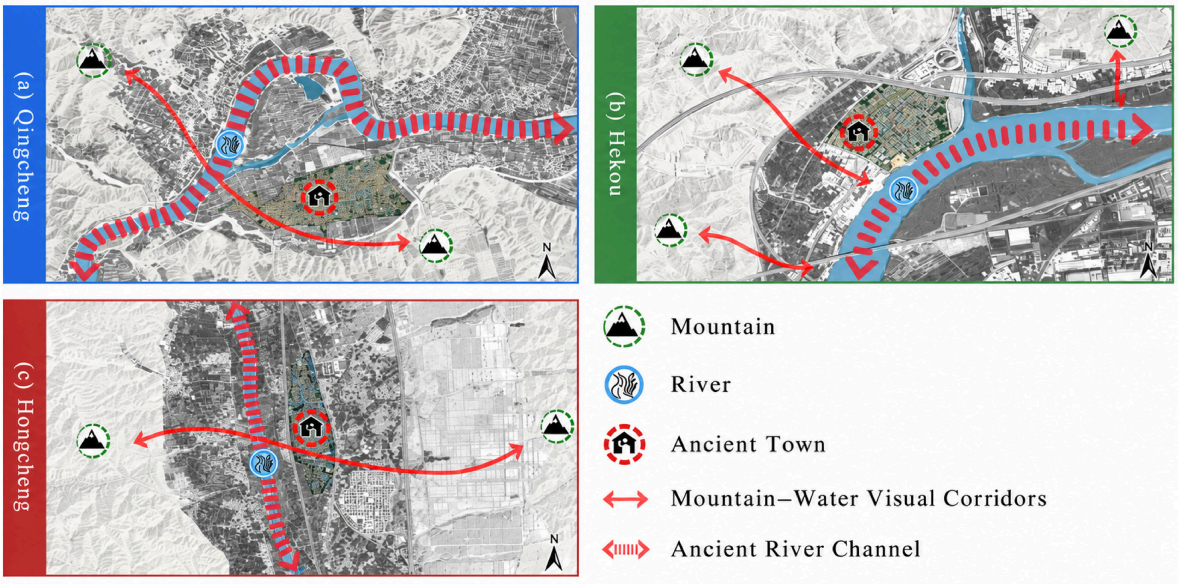
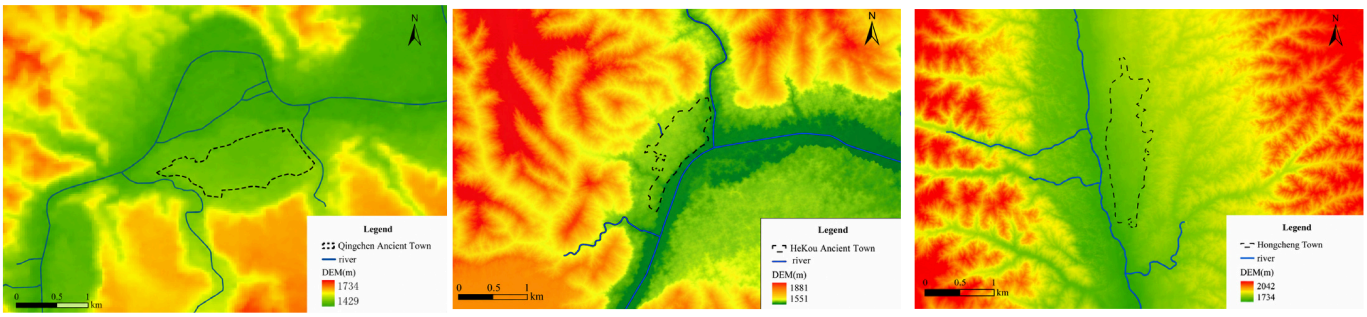


Figure 3. Mountain–water-based site selection of three historic towns.

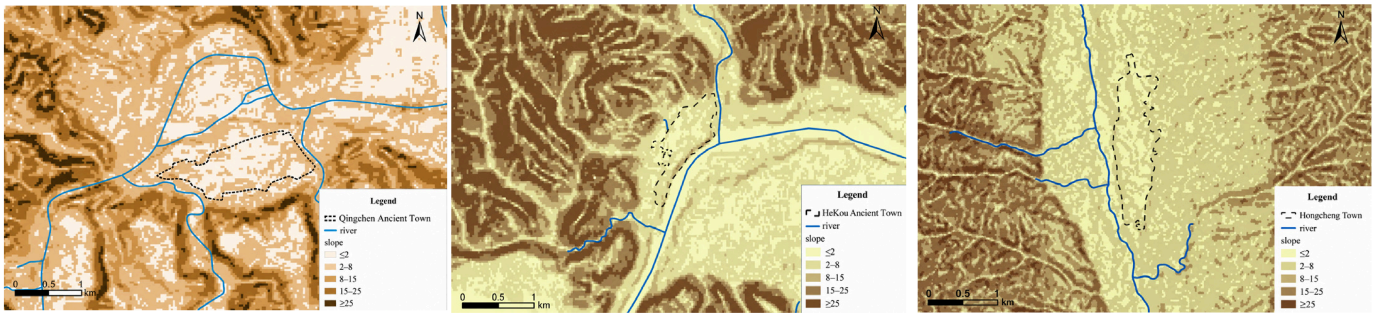


(**a**) (**b**) (**c**)

Figure 4. Elevation ranges and topographic settings of the three historic towns: (**a**) Qingcheng on the alluvial plain of the Yellow River; (**b**) Hekou at the confluence of three rivers; (**c**) Hongcheng along the Zhuanglang River valley.

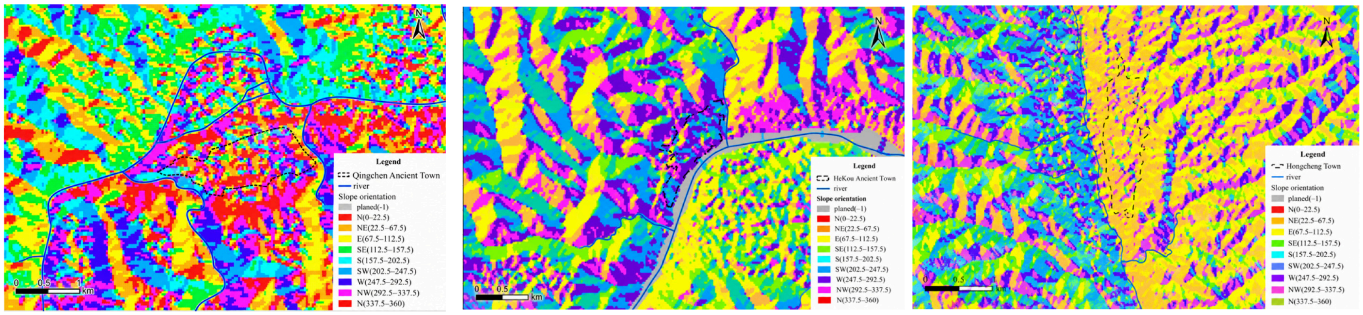
Slope analysis further confirms this commonality. Qingcheng's historic core is mainly located on flat alluvial land with slopes generally below 2° (Figure 5a). Hekou is also dominated by gentle terrace land within its core area, while the surrounding mountains form a natural spatial boundary (Figure 5b). Hongcheng is distributed along a slightly steeper valley basin, with most of its historic construction land located on gentle slopes of approximately 2–8° (Figure 5c). These results show that all three towns selected relatively flat or gently sloping land for construction, reflecting a shared preference for stable and buildable valley terraces.

The aspect analysis shows some differences among the three towns, but these differences are mainly related to local valley orientation. Qingcheng has a relatively diverse aspect distribution because of its broad alluvial plain (Figure 6a). Hekou is more strongly associated with southeast- and south-facing slopes (Figure 6b), while Hongcheng is mainly related to southwest- and west-facing valley slopes. Despite these differences (Figure 6c), the three towns generally avoid unfavourable steep terrain and make use of relatively suitable orientations for settlement development.



(**a**) (**b**) (**c**)

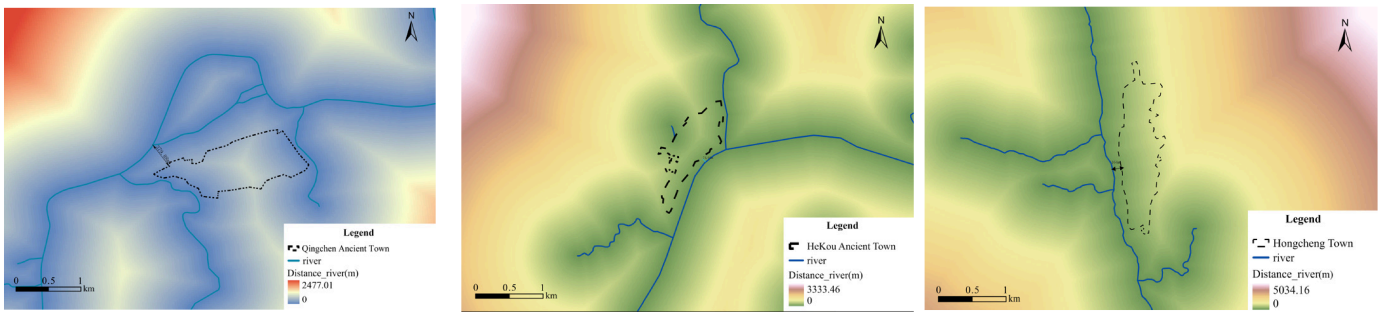
Figure 5. Slope characteristics of the three historic towns: (**a**) Qingcheng (mostly ≤2°); (**b**) Hekou (≤2° on terraces, 15–25° on surrounding hills); (**c**) Hongcheng (2–8° on core area, 15–25° on both sides as defensive barriers).



(**a**) (**b**) (**c**)

Figure 6. Aspect distributions of the three historic towns: (**a**) Qingcheng (diverse aspects, dominated by flat land and sunny slopes); (**b**) Hekou (southeast- and south-facing slopes); (**c**) Hongcheng (southwest- and west-facing slopes).

Distance-to-water analysis shows that all three towns maintain a close relationship with nearby water systems. Qingcheng is approximately 379.89 m from the nearest water body (Figure 7a), Hekou is approximately 71.93 m from the nearest water body (Figure 7b), and Hongcheng is approximately 164.10 m from the Zhuanglang River (Figure 7c). Hekou has the shortest distance to water, which is consistent with its historical role as a river-port and commercial transportation hub. Qingcheng and Hongcheng are also located within accessible distance to water systems, but their settlement positions are consistent with a balance between water access and other locational factors, but flood avoidance cannot be confirmed without hydrological and historical flood data.



(**a**) (**b**) (**c**)

Figure 7. Distance to the nearest water body in the three historic towns: (**a**) Qingcheng (379.89 m); (**b**) Hekou (71.93 m); (**c**) Hongcheng (164.1 m).

Overall, the three towns share common valley-adaptive characteristics, including near-water location, low-slope construction land, and spatial extension along river valleys or terrace landforms (Table 5). These shared features provide the natural basis for later differences in street networks, building fabric, and public-space organisation.

Table 5. Comparison of mountain–water pattern indicators of the three towns.

Indicator	Qingcheng	Hekou	Hongcheng
Elevation range/m	1429–1734	1551–1881	1774–2042
Dominant slope of historic core	≤2°	≤2°	2–8°
Dominant aspect	Flat land and sunny slopes	Southeast- and south-facing slopes	Southwest- and west-facing slopes
Length–width ratio of historic core (main axis length/core width)	approx. 3.2:1	approx. 1.8:1	approx. 4.5:1
Distance to nearest water body/m	379.89	71.93	164.10
Landform setting	Yellow River alluvial plain	River-confluence terrace	Zhuanglang River valley basin
Spatial extension tendency	Along the Yellow River terrace	Around the river-confluence core	Along the Zhuanglang River valley

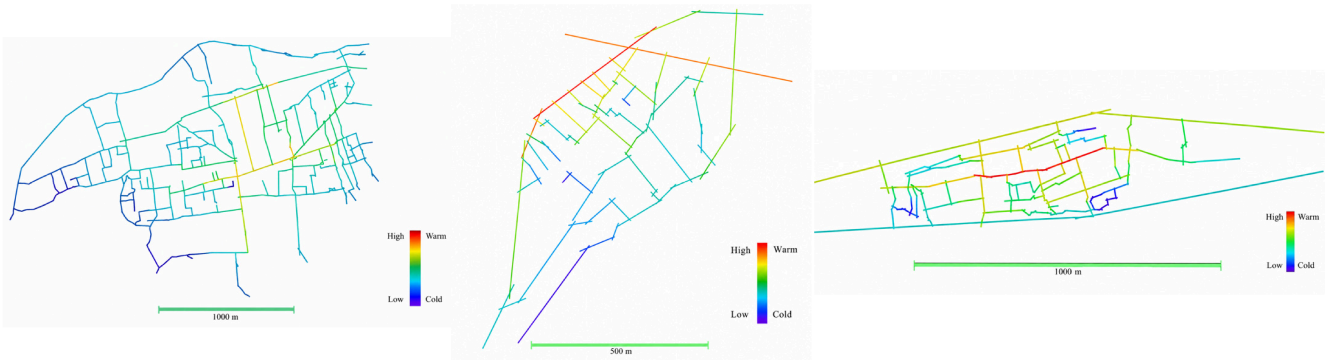
Note: Length–width ratio is calculated as the length of the main historical axis divided by the maximum width of the historic core perpendicular to that axis, based on the unified research boundary. This ratio serves as a supplementary indicator of valley-induced elongation.

3.2. Differentiated Street-Network Morphology Under Historical Functions

Space syntax analysis reveals clear differences in the street-network morphology of the three towns. Although all three towns show axis-led organisation to some extent, their levels of integration, intelligibility, and street-network openness differ markedly.

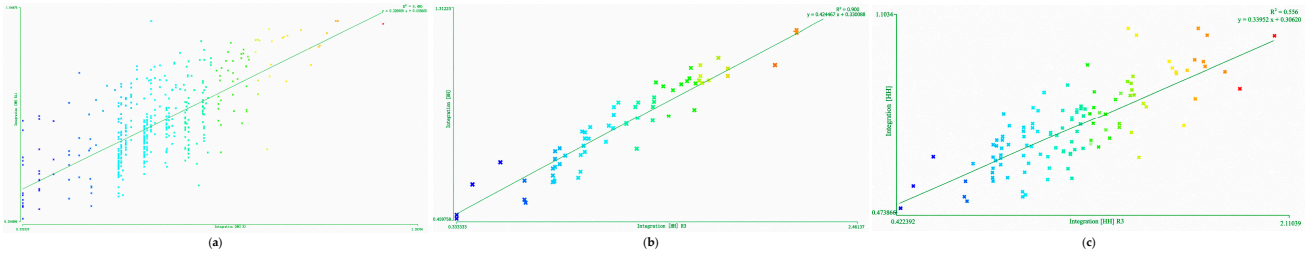
Qingcheng presents a single-axis structure centred on Tiaocheng Street. The mean global integration value is 0.425, which is the lowest among the three towns. The highest integration is concentrated along the main street, while many secondary lanes are connected in a relatively subordinate manner (Figure 8a). This indicates that Qingcheng's spatial structure is strongly organised by one dominant historical axis rather than by a multi-centred grid. Its intelligibility value is 0.490 (Figure 9a), suggesting that the relationship between local spatial experience and the overall street-network structure is moderate to weak. This pattern is consistent with Qingcheng's historical transformation from a military settlement to a commercial and cultural town: the original axial skeleton remained important, while later commercial and residential functions accumulated along and around it.

Hekou shows the most open and legible street-network structure among the three towns (Figure 8b). Its mean global integration value reaches 0.847, and its intelligibility value is 0.900 (Figure 9b). High-integration axial lines are concentrated around the central street intersection and extend along the main commercial streets. This indicates that Hekou's street network has strong accessibility and a clear spatial structure. The high integration and high intelligibility are consistent with its historical role as a commercial and transportation hub, where circulation efficiency, public accessibility, and central gathering spaces were important.



(**a**) (**b**) (**c**)

Figure 8. Global integration (Integration [HH]) maps of the three towns: (**a**) Qingcheng, (**b**) Hekou, (**c**) Hongcheng. Red lines indicate high integration, blue lines low integration. Qingcheng shows a single high-integration axis (Tiaocheng St); Hekou exhibits four high-integration axes intersecting at the centre; Hongcheng displays a chessboard pattern with moderate integration.



(**a**) (**b**) (**c**)

Figure 9. Intelligibility scatterplots of the three towns: (**a**) Qingcheng (R^2 = 0.490), (**b**) Hekou (R^2 = 0.900), (**c**) Hongcheng (R^2 = 0.556). Each dot represents an axial line. The fitted regression line and coefficient of determination (R^2) indicate how well local integration (R = 3) predicts global integration.

Hongcheng presents a relatively regular but more defensive street-network structure (Figure 8c). Its mean global integration value is 0.747, higher than Qingcheng but lower than Hekou. Its intelligibility value is 0.556 (Figure 9c), suggesting that although the town has a relatively regular street framework, the global structure is not as easily inferred from local spatial experience as in Hekou. The street network is associated with a chessboard-like defensive layout and a clear main axis, while narrower streets, controlled access, and defensive remains reinforce its inward-oriented character.

The comparison shows that Hekou has the strongest network openness and legibility, Hongcheng retains a more defensive and inward-oriented structure, and Qingcheng presents a single-axis composite structure formed through historical functional layering. These differences indicate that, under broadly similar valley constraints, street-network morphology is associated with different historical functional orientations (Table 6). To assess the robustness of this association, boundary sensitivity tests were conducted. Hekou consistently ranks first in network integration under core, 400 m, and 800 m boundary conditions. Under core and 400 m conditions, the ranking is Hekou > Hongcheng > Qingcheng; under the 800 m buffer, it becomes Hekou > Qingcheng > Hongcheng. However, because absolute integration values are sensitive to network size and boundary definition, this ranking consistency should not be interpreted as proof of robustness. The relative positions of Qingcheng and Hongcheng change under the 800 m buffer, indicating that their comparative openness is boundary-sensitive. Cross-town comparison therefore relies primarily on the convergence of global integration, local integration, intelligibility, and boundary sensitivity results, rather than on a single ranking. Overall, the results support an association

between street-network morphology and historical functional orientation, but the internal ranking of the three towns should be treated as exploratory rather than definitive.

Table 6. Boundary sensitivity of space syntax indicators in the three towns.

Boundary Condition	Indicator	Qingcheng	Hekou	Hongcheng
Core boundary	Total number of axial lines	189	76	112
Core boundary	Mean global integration	0.425	0.847	0.747
Core boundary	Mean local integration, R = 3	1.038	1.217	1.216
Core boundary	Intelligibility, R^2	0.490	0.900	0.556
Core boundary	Rank	3	1	2
400 m buffer	Total axial lines in expanded network	264	114	163
400 m buffer	Core axial lines used for summary	189	76	112
400 m buffer	Mean global integration (core lines)	0.371	0.774	0.662
400 m buffer	Mean local integration, R = 3 (core lines)	1.014	1.193	1.188
400 m buffer	Intelligibility, R^2 (core lines)	0.441	0.872	0.514
400 m buffer	Rank	3	1	2
800 m buffer	Total axial lines in expanded network	347	157	208
800 m buffer	Core axial lines used for summary	189	76	112
800 m buffer	Mean global integration (core lines)	0.578	0.721	0.336
800 m buffer	Mean local integration, R = 3 (core lines)	0.987	1.166	1.142
800 m buffer	Intelligibility, R^2 (core lines)	0.507	0.844	0.463

Note: In the 400 m and 800 m buffer conditions, axial lines were redrawn for the expanded network. Integration values were calculated within the expanded network, but summary statistics are based only on the axial lines corresponding to the original historic-core streets and lanes. The total number of axial lines in the expanded network is reported to document the change in network size. Rank 1 = highest integration/openness, Rank 3 = lowest. Absolute integration values are not directly compared across towns.

3.3. Building Fabric: Commercial Openness, Defensive Enclosure and Courtyard Continuity

Building-fabric indicators further reveal differences among the three towns. The comparison focuses on building density, courtyard proportion, shop-front with rear-residence proportion, wall thickness, and street aspect ratio. Among these indicators, shop-front with rear-residence proportion, wall thickness, and street aspect ratio are especially useful for distinguishing commercial, defensive, and mixed morphological characteristics (Figure 10).

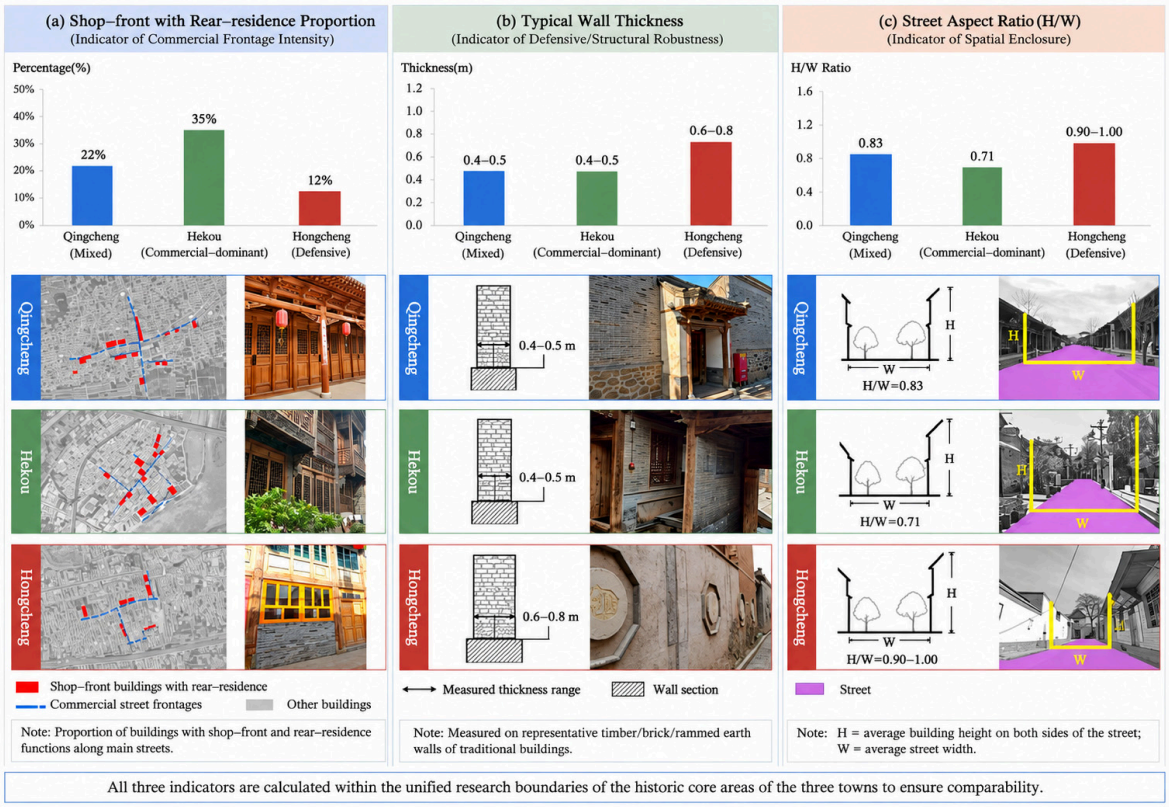


Figure 10. Comparative analysis of building-fabric indicators in Qingcheng, Hekou, and Hongcheng: (**a**) shop-front with rear-residence proportion; (**b**) typical wall thickness; and (**c**) street aspect ratio.

The proportion of shop-front with rear-residence buildings differs among the three towns. These proportions are calculated as the number of shop-front with rear-residence buildings divided by the total number of street-front building units along historic streets within the unified core boundary. The results are: Qingcheng 31/142 (approximately 22%), Hekou 41/117 (approximately 35%), and Hongcheng 16/131 (approximately 12%). Hekou has the highest proportion, indicating a strong commercial frontage along its main streets. Qingcheng has a moderate proportion, mainly distributed along Tiaocheng Street. Hongcheng has the lowest proportion, suggesting that commercial activity was more limited and did not dominate its building frontage.

Wall thickness also differs among the three towns. Hongcheng's traditional buildings generally have thicker rammed-earth walls (n = 41, mean = 0.71 m, SD = 0.057, range = 0.6–0.8 m), while Qingcheng (n = 47, mean = 0.45 m, SD = 0.041, range = 0.4–0.5 m) and Hekou (n = 39, mean = 0.44 m, SD = 0.038, range = 0.4–0.5 m) show lighter and more commercially adaptable building interfaces. The thicker walls in Hongcheng are consistent with its defensive background and more enclosed building character. Wall thickness was measured at three points per building at 1.0–1.5 m above the plinth, avoiding door and window openings; the mean of the three measurements was used. Measurement uncertainty is ±1 cm.

Street aspect ratio (H/W) further reflects differences in street enclosure and functional character. It was calculated as mean building height divided by mean street width along representative continuous street sections of at least 30 m, excluding intersections. A lower H/W indicates a wider and more open street, while a higher H/W indicates a narrower and more enclosed street. Hekou has the lowest mean H/W (n = 22, mean = 0.71, SD = 0.10, range = 0.60–0.82), indicating relatively wider streets and a more open commercial environment. Qingcheng has a medium value (n = 29, mean = 0.83, SD = 0.11, range = 0.70–0.96), re-

flecting a more compact but still commercially active main street environment. Hongcheng has the highest value (n = 24, mean = 0.95, SD = 0.03, range = 0.90–1.00), indicating narrower and more enclosed streets, which correspond to its defensive and inward-oriented spatial character.

To assess the statistical uncertainty of the reported building-fabric indicators, we calculated 95% confidence intervals for street aspect ratio (*H*/*W*). The intervals are 0.79–0.87 for Qingcheng, 0.67–0.75 for Hekou, and 0.94–0.96 for Hongcheng. These intervals indicate that the observed differences among the three towns are descriptively clear. Because the building-fabric indicators are based on purposive samples rather than random sampling, these intervals provide an indication of precision rather than formal statistical significance. The shop-front with rear-residence proportions are reported with explicit denominators (142, 117, and 131 street-front building units), and wall thickness is reported with sample sizes (47, 39, and 41) and standard deviations. Together, these measures provide a transparent basis for comparing the three towns.

The results suggest that Hekou's building fabric is more commercially open, Hongcheng's fabric is more defensive and enclosed, and Qingcheng presents a mixed condition in which commercial frontage, courtyard fabric, and historical layering coexist. These differences provide material evidence for the differentiated spatial morphology of the three towns (Table 7).

Table 7. Comparison of building-fabric indicators of the three towns.

Indicator	Qingcheng	Hekou	Hongcheng
Shop-front with rear-residence proportion/%	22(31/142)	35(41/117)	12(16/131)
Typical wall thickness/m	0.45 (n = 47, SD = 0.041, range = 0.4–0.5)	0.44 (n = 39, SD = 0.038, range = 0.4–0.5)	0.71 (n = 41, SD = 0.057, range = 0.6–0.8)
Street aspect ratio (*H*/*W*)	0.83 (n = 29, SD = 0.11, range = 0.70–0.96; 95% CI: 0.79–0.87)	0.71 (n = 22, SD = 0.10, range = 0.60–0.82; 95% CI: 0.67–0.75)	0.95 (n = 24, SD = 0.03, range = 0.90–1.00; 95% CI: 0.94–0.96)

Note: Shop-front with rear-residence proportion is calculated as the number of such buildings divided by the total number of street-front building units along historic streets within the unified core boundary. Wall thickness was measured at three points per building at 1.0–1.5 m above the plinth; uncertainty is ±1 cm. *H*/*W* = mean building height/mean street width; lower values indicate wider and more open streets, higher values indicate narrower and more enclosed streets. Samples correspond to continuous street sections of at least 30 m. The 95% confidence intervals are reported for street aspect ratio (*H*/*W*). Because samples are purposive rather than random, these intervals indicate precision rather than formal statistical significance.

3.4. Public Space: Node Aggregation and Functional Layering

Public-space organisation also differs among the three towns. Public nodes such as temples, academies, ancestral halls, wharfs, towers, gates, squares, and commercial gathering spaces are important carriers of collective activities and historical functions. Their number, functional type, spatial distribution, and relationship with main streets help reveal how public life was organised in each town (Figure 11).

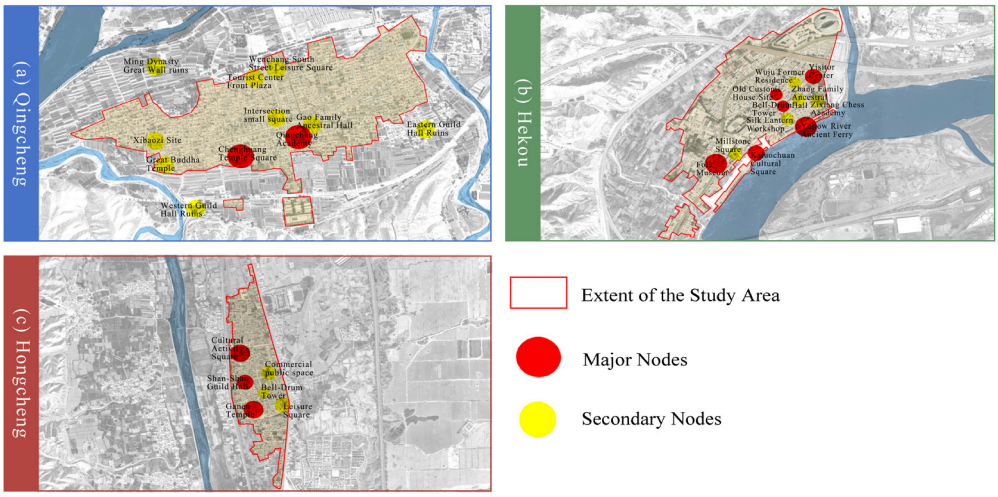


Figure 11. Spatial distribution of core public nodes in the three towns: (**a**) Qingcheng, (**b**) Hekou, (**c**) Hongcheng. Red nodes indicate primary public nodes (e.g., central squares, major temples, ancestral halls, key commercial streets), and yellow nodes indicate secondary public nodes (e.g., smaller squares, neighbourhood shrines, minor commercial nodes).

Qingcheng has two primary public nodes and six secondary public nodes, giving a total of eight core public nodes (score ≥ 5) included in the buffer analysis. These nodes cover functions such as military memory, commerce, kinship, education, folk belief, and local public activities. These nodes are mainly connected by Tiaocheng Street, forming a linear series of public spaces along the main historical axis. The system-level effective service radius—defined as the first 50 m increment at which the union of all core-node buffers covered $\geq$50% of the historic-core area—is 150 m, with a buffer union coverage of 58.2%. This indicates that Qingcheng's public-space organisation is closely related to its historical transformation and functional layering.

Hekou has six primary public nodes and five secondary public nodes, giving a total of eleven core public nodes (score ≥ 5) included in the buffer analysis. Its public space is more strongly associated with commercial gathering and transportation. Its central public node is organised around the Bell and Drum Tower area and related commercial streets. Public activities are concentrated near the core intersection, where circulation, trade, and gathering functions overlap. The system-level effective service radius—defined as the first 50 m increment at which the union of all core-node buffers covered $\geq$50% of the historic-core area—is 100 m, with a buffer union coverage of 52.8%. Compared with Qingcheng, Hekou's public-space system is more commercially oriented and more strongly centred on the main street intersection.

Hongcheng has three primary public nodes and three secondary public nodes, giving a total of six core public nodes (score ≥ 5) included in the buffer analysis. Its public space is more closely related to military-defensive and ritual functions. Nodes such as the ancient city wall area, defensive-related spaces, temples, and small squares form a more inward-oriented public-space system. The system-level effective service radius—defined as the first 50 m increment at which the union of all core-node buffers covered $\geq$50% of the historic-core area—is 150 m, with a buffer union coverage of 51.5%. This reflects a relatively compact and enclosed pattern of public activities.

The comparison shows that Qingcheng has a more diverse and layered public-space system, Hekou has a more commercially centralised public-space structure, and Hongcheng has a more defensive and inward-oriented public-space organisation. These differences correspond to the historical functional orientations of the three towns and further support the need for differentiated conservation strategies (Table 8). The node-level scores and

inclusion list are provided in Table S1, and cumulative coverage at each 50 m increment is reported in Table S2.

Table 8. Comparative public-space indicators of the three towns.

Indicator	Qingcheng	Hekou	Hongcheng
Number of primary nodes (score $\geq$ 8)	2	6	3
Number of secondary nodes (score 5–7)	6	5	3
Number of core public nodes (score $\geq$ 5; primary + secondary)	8	11	6
Effective service radius (first $\geq$ 50% coverage)/m	150	100	150
Buffer union coverage at effective radius/%	58.2	52.8	51.5

Note: Core public nodes are defined as all nodes scoring $\geq$ 5 in the six-criteria system, i.e., primary nodes (score $\geq$ 8) plus secondary nodes (score 5–7). Buffers were generated from point features representing the centre of each core public node. The effective service radius is the first 50 m increment at which the union of all core-node buffers covers $\geq$ 50% of the historic-core area. Cumulative coverage at each 50 m increment is provided in Table S2.

3.5. Integrated Comparison of Spatial Morphology

Taken together, the results in Sections 3.1–3.4 show that Qingcheng, Hekou, and Hongcheng share a common valley-adaptive baseline but differ in street-network configuration, building fabric, and public-space organisation. Their shared characteristics include near-water locations on relatively gentle terrain, low-slope terrace occupation, and axis-led spatial organisation. Their differences are reflected in the degree of street-network openness, commercial frontage, defensive enclosure, and public-space functional diversity. These similarities and differences are summarised in Table 9. Rather than restating the detailed characteristics of each town here, the following discussion (Section 4) interprets these measured differences in relation to historical functional orientations and considers their implications for conservation planning.

Table 9. Integrated comparison of spatial morphology of the three towns.

Town	Shared Valley Condition	Historical Functional Orientation	Street-Network Morphology	Building-Fabric Character	Public-Space Organisation
Qingcheng	River terrace, near-water location, low-slope land	Military–commercial mixed and cultural layering	Single-axis structure with secondary lanes	Mixed commercial-residential fabric and courtyard continuity	Linear series of diverse public nodes
Hekou	River-confluence terrace, near-water location, low-slope land	Commercial transportation	Open and legible street network with central aggregation	High commercial frontage and open street interface	Commercial gathering around central node
Hongcheng	Tributary valley basin, near-water location, gentle-slope land	Military defence	Defensive chessboard-like structure with inward tendency	Thick walls, higher enclosure, narrower streets	Defensive and ritual nodes with compact service radius

In summary, the three towns demonstrate both commonality and differentiation. Their commonality lies in valley-adaptive site selection and axis-led spatial organisation under similar natural constraints. Their differentiation lies in how historical functional orientations are reflected in street-network accessibility, building-fabric openness or enclosure, and public-space organisation. These findings provide the empirical basis for the following discussion on spatial formation mechanisms and conservation planning implications (Table 9).

4. Discussion

4.1. Common Spatial Characteristics Under Valley Constraints

The results suggest that Qingcheng, Hekou, and Hongcheng share a common valley-adaptive spatial logic. All three towns are sited near water and on relatively gentle terrain. The available evidence supports near-water and low-slope location, but not the stronger conclusion of flood safety. Flood levels, historical inundation, and channel change were not analysed. Hekou has the closest river proximity (71.93 m), consistent with its historical role as a commercial port, while Qingcheng and Hongcheng maintain slightly greater distances (379.89 m and 164.10 m, respectively), consistent with a balance between water access and other locational factors, but flood avoidance cannot be confirmed without hydrological and historical flood data. This pattern aligns with broader findings on traditional settlement distribution in the Yellow River Basin, where elevation, slope, and river proximity consistently emerge as dominant determinants of settlement location [32–36]. Similar topographic determinism has also been observed in other contexts—in computational space syntax studies of Chinese historic towns more broadly, and in comparative analyses of historic city centres in other topographically constrained settings [13,18]. The preference for low-slope construction land—Qingcheng and Hekou on near-level terraces ($\leq 2°$), Hongcheng on gentle slopes (2–8°)—is consistent with valley-type towns selecting relatively stable, buildable land and avoiding steep slopes. However, flood risk was not directly assessed. This shared environmental baseline is consistent with the basic logic of valley settlement: construction land tends to be close to water and transport routes, and on relatively stable terrain. However, flood safety cannot be inferred from elevation, slope, and distance-to-water alone. The characterisation of valley-type settlements as a distinct morphological category is consistent with broader typologies of human settlements that distinguish valley, plain, hilly, and arid regions based on their adaptive spatial logics [27].

4.2. Historical Functional Orientation and Morphological Differentiation

As summarised in Table 9, the three towns share a common valley-adaptive baseline but differ markedly in street-network configuration, building fabric, and public-space organisation. These measured differences are associated with their respective historical functional orientations. In this section, we interpret these associations through space syntax theory and urban morphological frameworks, rather than restating the measured results already reported in Section 3.

Hekou's higher network integration and intelligibility are consistent with a commercial logic that prioritises circulation efficiency and public accessibility. According to natural movement theory, such configurational properties are expected to support pedestrian flow and commercial activity [10,11], although these behavioural and economic outcomes were not directly measured in this study. Hongcheng's lower intelligibility and stronger enclosure are consistent with a defensive logic that prioritises controlled access and inward orientation. Qingcheng's single-axis structure with diverse public nodes is consistent with a layered functional history, in which military, commercial, kinship, educational, and cultural functions accumulated over time. These interpretations are theoretically grounded

but should be treated as interpretive rather than causal, given the synchronic design of the study.

The configurational contrasts observed here extend recent comparative space syntax work by suggesting that intelligibility may vary systematically with historical functional orientation [18]. They also resonate with Conzen's observation that town-plan units often persist through functional changes while adapting their internal configurations [1], and with Kropf's framework for interpreting urban form as the material expression of socio-economic processes [5]. At the same time, quantitative indicators should not be interpreted mechanically: higher integration does not automatically mean greater historical value, and lower intelligibility does not necessarily indicate a problematic spatial structure. In Hongcheng, lower intelligibility reflects a defensive spatial logic; in Qingcheng, lower mean integration reflects the persistence of a single-axis historical skeleton [37,38].

These theoretical interpretations provide the basis for the planning implications discussed in Section 4.3. They are offered as hypotheses to be tested through future behavioural, social, and diachronic research, rather than as demonstrated outcomes of the present study.

4.3. From Morphological Indicators to Sustainability-Oriented Spatial Management

The morphological indicators used in this study are proxies for spatial conditions, not direct measures of environmental, social, or economic sustainability outcomes. To clarify how they could translate into measurable outcomes, Table 10 maps each indicator to potential sustainability dimensions, measurable variables, and required data. For example, high-integration axes may support pedestrian movement and commercial activity, measurable through pedestrian counts, retail turnover, or vacancy rates. Street aspect ratio and building fabric may influence thermal comfort, energy performance, and sense of place, assessable through microclimate simulations, energy audits, or resident surveys. Public-node service radius may relate to social interaction and accessibility, measurable through visitor surveys, activity mapping, or service usage data. However, these outcomes were not directly measured in this study.

Table 10. Linking morphological indicators to measurable sustainability outcomes.

Morphological Indicator	Sustainability Dimension	Potential Measurable Outcome	Required Data/Method
High global integration axes	Economic; Social	Pedestrian flow, retail vitality, social encounter	Pedestrian counts, retail turnover, vacancy rates, activity mapping
Local integration and intelligibility	Social	Wayfinding, visitor experience, accessibility	Visitor surveys, GPS tracking, wayfinding tests
Street aspect ratio (*H*/*W*)	Environmental; Social	Thermal comfort, energy performance, perceived enclosure	Microclimate simulation, energy audits, resident surveys
Shop-front with rear-residence proportion	Economic; Social	Commercial diversity, mixed-use vitality, affordable retail space	Land-use surveys, rent data, business mix analysis

Table 10. *Cont.*

Morphological Indicator	Sustainability Dimension	Potential Measurable Outcome	Required Data/Method
Wall thickness and defensive remains	Environmental; Cultural	Thermal inertia, heritage authenticity, cultural identity	Building performance modelling, heritage condition assessment, resident interviews
Public-node number and function	Social	Social interaction, community cohesion, cultural participation	Activity mapping, visitor surveys, event frequency
Distance to water and river-town relationship	Environmental; Social	Flood exposure, waterfront accessibility, ecological quality	Hydrological modelling, flood-risk mapping, ecological assessment

Note: this table is illustrative. The present study does not directly measure these outcomes; the links are theory-based planning hypotheses requiring future empirical validation.

The measured morphological differences reported in Section 3 and interpreted in Section 4.2 therefore provide the basis for the planning implications discussed here. These implications are offered as theory-based planning hypotheses rather than demonstrated sustainability outcomes. Their validation would require future behavioural, social, and economic assessment.

According to space syntax theory, high-integration axes may be expected to support pedestrian movement and social encounter [10,11]. However, this study did not directly measure pedestrian movement, commercial activity, or social encounter. On this theoretical basis, high-integration axes are identified as priority corridors for conservation planning, subject to future behavioural and social assessment. In Qingcheng, Tiaocheng Street is the main spatial skeleton connecting diverse public nodes; in Hekou, the highly integrated streets around the central intersection form the core of the town's historic commercial fabric; in Hongcheng, the main defensive axis and associated historical remains form a military-spatial sequence. These interpretations are based on morphological and configurational evidence and historical documents, not on direct observation of current use.

Street aspect ratio, as a proxy for perceived enclosure and human-scale experience, provides a basis for street-scale control. Differences in aspect ratio across the three towns suggest that spatial management should avoid applying a single standard. Building-fabric indicators, including wall thickness and the proportion of shop-front with rear-residence buildings, reflect the material conditions within which residents conduct their daily lives and businesses. These indicators help identify historic commercial corridors and areas where traditional fabric remains intact, and they support conservation by guiding frontage management and controlling large-scale demolition or inappropriate façade reconstruction. Public-node distribution and service radius inform public-space management: linear public-space systems require pedestrian continuity, central commercial gathering areas require focused attention, and compact defensive and ritual nodes should be managed as integrated public-space units. Mountain–water relationships inform waterfront landscape and flood-risk-sensitive conservation, helping to maintain historical visual corridors and avoid hard engineering that disconnects the town from its water environment. However, flood risk

was not directly assessed in this study, and flood-risk control zones require separate hydrological assessment.

Through this translation, the analysis moves from spatial diagnosis to planning application [15,39]. The results can help identify which streets, buildings, courtyards, nodes, and waterfront areas should receive priority protection. They also show that different towns require different conservation strategies, each derived from the specific morphological logic summarised in Table 9, rather than following a one-size-fits-all template. These strategies are evidence-based planning priorities derived from morphological analysis; their sustainability outcomes require further validation through behavioural, social, and economic assessment (Table 11).

Table 11. Translation from morphological indicators to sustainability-oriented spatial management measures.

Morphological Indicator	Identified Conservation Challenge	Recommended Intervention
High global integration axes	Loss of historic circulation corridors	Prioritise safeguarding main historic streets, traditional frontage, and pedestrian continuity
Local integration and intelligibility	Poor wayfinding and heritage interpretation	Improve wayfinding and visitor circulation without disrupting traditional street networks
Street aspect ratio	Inappropriate building height and façade renovation	Control building height, façade renovation, roofline, and street-interface proportion
Shop-front with rear-residence proportion	Excessive tourism-oriented replacement	Safeguard traditional commercial-residential patterns
Wall thickness and defensive remains	Loss of defensive construction character	Safeguard representative defensive buildings, walls, gates, and details
Public-node number and function	Loss of collective activity spaces	Classify public nodes by function and formulate differentiated management strategies
Distance to water and river-town relationship	Disconnection from waterfront	Safeguard river-related heritage and visual corridors; flood-risk control zones require separate hydrological assessment

4.4. Methodological Implications

The specific innovation of the proposed framework lies in its multi-level integration and its translation of morphological indicators into conservation planning priorities, rather than in the application of GIS or space syntax alone. This study demonstrates the applicability of combining multiple forms of spatial evidence within a unified comparative framework. While previous comparative space syntax studies have typically focused on street-network configuration alone [18,19], our integration of building-fabric indicators (wall thickness, shop-front proportion, aspect ratio) adds a material layer that bridges configurational analysis and functional interpretation. GIS analysis reveals the environ-

mental basis of settlement location; space syntax measures street-network configuration; building-fabric indicators show material and functional differences; and public-space analysis identifies collective activity structures. This integration moves beyond purely descriptive comparison and provides transparent spatial evidence for conservation planning. However, quantitative indicators should not be interpreted mechanically. Higher global integration does not automatically mean greater historical value, nor does lower intelligibility necessarily indicate a problematic spatial structure—in Hongcheng, it reflects defensive spatial logic; in Qingcheng, lower mean integration reflects the persistence of a single-axis historical skeleton. Quantitative spatial analysis should therefore be used as a tool for interpretation and planning support, combined with field surveys, historical documents, and sustainability objectives. This integrated approach is particularly important for historic towns, where spatial value is embedded in long-term continuity, everyday use, and cultural memory. The growing integration of GIS with HUL frameworks for layered urban analysis [20,21] and the application of space syntax to heritage contexts both point toward a more evidence-based, configurational approach to historic urban sustainability—an approach that the present study contributes to by adding building-fabric indicators as a third analytical layer. Importantly, the specific numerical values reported here—integration, intelligibility, aspect ratio, and service radius—are context-dependent. What is transferable is the analytical framework: the integration of GIS-based environmental assessment, space syntax configurational analysis, building-fabric measurement, and public-space mapping within a comparative case-study design. This study demonstrates the applicability of the framework, not its validated effectiveness. Independent evaluation through community engagement, planning implementation, and post-occupancy assessment is needed to validate its practical effectiveness in conservation planning.

4.5. Synthesis: A Comparative Picture of Valley-Type Morphology

Taken together, the analysis reveals a clear and consistent picture. Across the three towns, a shared valley-adaptive logic is at work: all are sited near water and on relatively gentle terrain. Flood risk was not directly assessed. This common baseline is consistent with environmental constraint—mountains, rivers, and buildable land—rather than cultural diffusion or historical contingency. Against this shared backdrop, the three towns exhibit differentiated morphological patterns, as summarised in Table 9 and interpreted in Section 4.2. These differences are associated with their respective historical functional orientations. The two-level logic—environmental baseline plus functional differentiation—suggests a refinement of Conzen's [1] and Oliveira's models of morphological persistence: functional differentiation appears to operate within—and be constrained by—topographical parameters. This two-level logic provides both a framework for interpreting other valley-type historic towns and a basis for tailoring sustainability strategies to each town's specific morphological character. It invites cross-regional testing in other valley-settled contexts.

4.6. Limitations and Future Research

This study has several limitations that should be acknowledged.

First, the sample size is limited to three towns in the upper Yellow River Basin. The three cases were selected to hold broad valley-environmental conditions relatively constant while allowing historical functional orientation to vary. However, they differ substantially in area, preservation status, and contemporary development pressure. Qingcheng (0.945 km^2) is roughly eight times larger than Hekou (0.113 km^2), and its historic fabric is more dispersed. Hekou has experienced stronger commercial and tourism pressure, while Hongcheng retains more defensive remains and has lower redevelopment pressure. These differences may influence configurational measures independently of historical function.

Consequently, the observed morphological patterns should be interpreted as associations consistent with functional differentiation, not as proof of functional determinism. The specific numerical values—integration thresholds, aspect ratios, and service radii—are context-dependent and should not be applied as universal standards without local calibration. What is transferable is the analytical framework: the integration of GIS-based environmental assessment, space syntax configurational analysis, and building-fabric measurement within a comparative case-study design.

Second, the study relies primarily on the current spatial pattern and field-survey data. Present-day spatial patterns are used to interpret historical functional orientations, and those orientations are then used to explain morphological differences. This creates a risk of circular reasoning. Although historical documents are used to interpret functional orientation, we do not fully reconstruct the long-term morphological evolution of the three towns through multi-temporal maps, historical aerial photographs, or remote-sensing data from different periods. The study can demonstrate associations, but it cannot establish that historical functions caused the observed morphological differences. Future research should incorporate historical maps, diachronic morphological reconstruction, and archival evidence of spatial change over time to test the proposed associations more rigorously. Multi-temporal GIS analysis would be particularly valuable for examining how street networks, building fabric, public spaces, and waterfront relationships have changed across different historical periods.

Third, the study does not analyse flood levels, historical inundation, channel change, floodplain extent, or elevation relative to the river surface. The results therefore support the conclusion that the three towns are located near water bodies and predominantly occupy relatively gentle terrain. They do not support the stronger conclusion that these settlements are relatively elevated terrace locations or were intentionally located above flood-risk areas. Future research should incorporate hydrological and historical flood data to assess flood risk more directly.

Fourth, several indicators required further refinement, and we have addressed this. Building-fabric measurements are based on a stratified purposive sample of 47 representative traditional buildings for detailed fabric analysis, supplemented by larger samples for wall thickness (47 in Qingcheng, 39 in Hekou, and 41 in Hongcheng) and street aspect ratio (29, 22, and 24 street sections, respectively). Shop-front with rear-residence proportions are reported with explicit denominators (142, 117, and 131 street-front building units, respectively). Wall thickness has a measurement uncertainty of ± 1 cm. Street aspect ratio (H/W) is based on continuous street sections of at least 30 m and may not fully represent the entire street network. Public nodes were classified using a six-criteria scoring system (Table 4); while this improves transparency, the scoring inevitably involves qualitative judgments, although classifications were cross-checked by two researchers and verified in the field. Future research could expand the sample, apply more detailed building-use surveys, and incorporate systematic social activity observations to improve the reliability of functional interpretation. A further limitation concerns data availability and verification. Original fine-scale GIS vector files (public-node point features and historic-core boundary polygons) are held in internal project archives and are not publicly available due to conservation and data-sharing restrictions. The area and coverage values reported in Table S2 were calculated from these files in ArcGIS Pro 3.1. Precise geographic coordinates and the full shapefile cannot be made publicly available, but the core area, intersected area, and coverage percentage are provided for each town and each 50 m increment, which is sufficient to verify the reported effective service radii.

Fifth, a further methodological limitation concerns the sensitivity of space syntax measures to system size and boundary definition. As noted in Section 2.4, integration

values were first calculated within the unified historic-core boundaries of each town. To address the potential boundary effect, we additionally conducted sensitivity tests using a 400 m and an 800 m contextual buffer, and we report local integration at R = 3 and R = 5. As reported in Section 3.2, Hekou remains the most integrated network across all boundary conditions, whereas the relative positions of Qingcheng and Hongcheng change under the 800 m buffer. This boundary sensitivity is acknowledged, and conclusions regarding the relative openness of these two towns are presented as tentative. Absolute integration values should also be interpreted with caution, since they are known to be sensitive to system size [31,40]. Future research could adopt a normalised integration measure that is less dependent on system size, or apply a uniform contextual buffer across a larger set of cases, to further improve cross-town comparability.

Sixth, the social perception and behavioural dimensions are not directly measured. The study interprets integration and intelligibility in terms of movement and legibility based on space syntax theory, and interprets enclosure and wall thickness as potential indicators of cultural resilience. However, it does not directly examine commercial activity, resident behaviour, visitor movement, social perception, or place attachment. The sustainability implications discussed in Section 4.3 should therefore be understood as theory-based planning hypotheses rather than demonstrated outcomes. Future research could incorporate interviews, behavioural mapping, participatory mapping, GPS trajectory analysis, or questionnaire surveys to examine how residents and visitors perceive and use historic streets, courtyards, public nodes, and waterfront spaces. While we have drawn on space syntax theory to interpret the behavioural implications of integration and intelligibility (see Section 4.2), systematic empirical data on actual movement patterns and user perceptions would strengthen future work. Similarly, environmental and economic sustainability outcomes were not directly measured; future research should incorporate microclimate simulation, energy audits, retail surveys, and hydrological modelling to validate the proposed links.

Finally, the findings are derived from a synchronic analysis of only three cases, which limits statistical extrapolation and prevents direct application as a universal model. Nevertheless, this limitation does not undermine the validity of the framework; rather, it constitutes a testable working hypothesis. Future research should incorporate additional cases from other sections of the Yellow River Basin, as well as from other river systems such as the Yangtze, Mekong, or Danube, to test whether the proposed two-level framework—environmental baseline plus functional differentiation—possesses trans-basin theoretical generalisability or remains specific to the arid and semi-arid valley settings of northwest China.

5. Conclusions

This study examined the spatial morphology of three valley-type historic towns in the upper Yellow River Basin—Qingcheng, Hekou, and Hongcheng—through four analytical dimensions: mountain–water pattern, street network, building fabric, and public space. By integrating GIS analysis, space syntax, field surveys, and building-fabric measurements, the study compared how towns located within similar valley environments share common spatial characteristics while developing differentiated morphological patterns under different historical functional orientations.

The findings suggest two complementary layers of spatial logic. It is important to emphasise that the sustainability implications discussed in Section 4.3 are theoretical and have not been empirically verified in this study. The conclusions presented here focus on the demonstrated morphological findings. At the environmental level, all three towns share a valley-adaptive logic, including near-water locations on relatively gentle terrain

and low-slope terrace construction. Flood risk, however, was not directly assessed. At the functional level, the measured morphological differences reported in Section 3 and interpreted in Section 4.2 are associated with different historical functional orientations. These differences are summarised in Table 9 and are not repeated here.

These patterns suggest that valley-type morphology is not a single uniform category but a family of related forms. Their shared features are consistent with environmental adaptation, while their differences are associated with different historical functional orientations. Because the three cases are not matched on area, preservation status, or contemporary development pressure, and because the analysis is synchronic, these findings are offered as a testable working hypothesis rather than a causal conclusion. Future research with larger samples and matched controls is needed to distinguish functional effects from other factors.

The study's contributions are threefold. Methodologically, it demonstrates the applicability of integrating GIS-based environmental analysis, space syntax configurational modelling, and building-fabric fieldwork within a unified comparative framework—an approach replicable in other valley-settled regions. However, the practical effectiveness of the framework for conservation planning has not been independently validated; future research should evaluate its implementation through community engagement, planning application, and post-occupancy assessment. Empirically, it provides detailed morphological evidence that can serve as reference benchmarks for comparative studies, while recognising that these values are context-dependent. The transferable contribution is the analytical framework itself. Practically, it translates morphological indicators into differentiated planning priorities. These priorities are offered as evidence-based hypotheses for conservation planning; their sustainability outcomes have not been empirically verified in this study and require future behavioural, social, and economic assessment. These priorities are summarised in Section 4.3 and are not repeated here.

While the spatial patterns observed are context-dependent, the analytical framework and comparative logic are transferable to valley-type historic towns in other river basins—from the Kathmandu Valley to the Rhine, Danube, or Mekong—where topography imposes similar constraints and functional histories shape divergent outcomes. While the framework is transferable, the specific sustainability benefits of the proposed strategies remain to be tested in practice. The findings thus speak to both regional conservation practice and the broader international discourse on sustainable heritage management in topographically constrained settings.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su181910137/s1. Due to the presence of commercially sensitive and unpublished primary data, the supplementary files for this study are not publicly available. They may be provided by the corresponding author upon reasonable request.

Author Contributions: Resources, supervision, project administration, X.Z.; conceptualisation, methodology, software, data curation, writing—original draft preparation, writing—review and editing, J.Z.; data curation, validation, visualisation, investigation, S.W.; data curation, validation, Z.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study by the Institution Committee due to the Measures for Ethical Review of Science and Technology (Trial), issued on 7 September 2023, and effective from 1 December 2023, https://www.most.gov.cn/xxgk/xinxifenlei/fdzdgknr/fgzc/gfxwj/gfxwj2023/202310/t20231008_188309.html (accessed on 1 August 2026). All interview data were anonymized, and no personally identifiable or sensitive information was collected during the investigation.

Informed Consent Statement: Verbal informed consent was obtained from all interview participants. Participants were informed of the purpose of the study, the voluntary nature of participation, their right to withdraw at any time, and the anonymised use of their responses for research purposes.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to the nature of field investigation records and unpublished local archival materials. Interview data were anonymised, and no personal identifiers were recorded; these data are not publicly available to protect participant privacy. Original fine-scale GIS vector files (public-node point features and historic-core boundary polygons) are held in internal project archives and are not publicly available due to conservation and data-sharing restrictions. The area and coverage values reported in Table S2 were calculated from these files in ArcGIS Pro 3.1, and are provided in the Supplementary Materials.

Acknowledgments: The authors would like to thank the students and library staff at Lanzhou University, Lanzhou Jiaotong University, and Northwest Normal University, as well as the local Cultural and Tourism Bureaus in Lanzhou City, Yuzhong County, and Yongdeng County for their assistance and provision of archival materials.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GIS	Geographic Information System
HUL	Historic Urban Landscape

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