buildings

MDPI

Article

Planning for Cultural Connectivity: Modeling and Strategic Use of Architectural Heritage Corridors in Heilongjiang Province, China

Lyuhang Feng [1,*], Jiawei Sun [1,*], Tongtong Zhai [1], Mingrui Miao [2] and Guanchao Yu [1,3,4]

[1] School of Art, Heilongjiang University, Harbin 150080, China; zhaitongtong123@gmail.com (T.Z.); 2020004@hlju.edu.cn (G.Y.)
[2] Gold Mantis School of Architecture, Soochow University, Suzhou 215006, China; 20244041002@stu.suda.edu.cn
[3] Social Science Division, Heilongjiang University, Harbin 150080, China
[4] Fine Art College, Harbin Normal University, Harbin 150025, China
* Correspondence: 2016068@hlju.edu.cn (L.F.); sunjiawei.121@gmail.com (J.S.)

Abstract: This study focuses on the systematic conservation of historical architectural heritage in Heilongjiang Province, particularly addressing the challenges of point-based protection and spatial fragmentation. It explores the construction of a connected and conductive heritage corridor network, using historical building clusters across the province as empirical cases. A comprehensive analytical framework is established by integrating the nearest neighbor index, kernel density estimation, minimum cumulative resistance (MCR) model, entropy weighting, circuit theory, and network structure metrics. Kernel density analysis reveals a distinct spatial aggregation pattern, characterized by "one core, multiple zones." Seven resistance factors—including elevation, slope, land use, road networks, and service accessibility—are constructed, with weights assigned through an entropy-based method to generate an integrated resistance surface and suitability map. Circuit theory is employed to simulate cultural "current" flows, identifying 401 potential corridors at the provincial, municipal, and district levels. A hierarchical station system is further developed based on current density, forming a coordinated structure of primary trunks, secondary branches, and complementary nodes. The corridor network's connectivity is evaluated using graph-theoretic indices (α, β, and γ), which indicate high levels of closure, structural complexity, and accessibility. The results yield the following key findings: (1) Historical architectural resources in Heilongjiang demonstrate significant coupling with the Chinese Eastern Railway and multi-ethnic cultural corridors, forming a "one horizontal, three vertical" spatial configuration. The horizontal axis (Qiqihar–Harbin–Mudanjiang) aligns with the core cultural route of the railway, while the three vertical axes (Qiqihar–Heihe, Harbin–Heihe, and Mudanjiang–Luobei) correspond to ethnic cultural pathways. This forms a framework of "railway as backbone, ethnicity as wings." (2) Comparative analysis of corridor paths, railways, and highways reveals structural mismatches in certain regions, including absent high-speed connections along northern trunk lines, insufficient feeder lines in secondary corridors, sparse terminal links, and missing ecological stations near regional boundaries. To address these gaps, a three-tier transportation coordination strategy is recommended: it comprises provincial corridors linked to high-speed rail, municipal corridors aligned with conventional rail, and district corridors connected via highway systems. Key enhancement zones include Yichun–Heihe, Youyi–Hulin, and Hegang–Wuying, where targeted infrastructure upgrades and integrated station hubs are proposed. Based on these findings, this study proposes a comprehensive governance paradigm for heritage corridors that balances multi-level coordination (provincial–municipal–district) with ecological planning. A closed-loop strategy of "identification–analysis–optimization"

check for updates

Academic Editor: Elena Lucchi

Received: 3 May 2025
Revised: 3 June 2025
Accepted: 5 June 2025
Published: 6 June 2025

Citation: Feng, L.; Sun, J.; Zhai, T.; Miao, M.; Yu, G. Planning for Cultural Connectivity: Modeling and Strategic Use of Architectural Heritage Corridors in Heilongjiang Province, China. *Buildings* **2025**, *15*, 1970. https://doi.org/10.3390/buildings15121970

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

is developed, featuring tiered collaboration, cultural–ecological synergy, and multi-agent dynamic evaluation. The framework provides a replicable methodology for integrated protection and spatial sustainability of historical architecture in Heilongjiang and other cold-region contexts.

Keywords: Heilongjiang province; historical architecture; heritage corridor; circuit theory; spatial connectivity

1. Introduction

Historical architectural heritage, as a direct material and spiritual embodiment of various social strata in specific historical periods, carries profound cultural significance and serves as one of the most important physical carriers of human civilization [1]. However, heritage sites around the world are facing escalating threats [2]. The continuous expansion of urban areas has encroached upon the spatial environments in which these heritage sites are embedded, leading to the fragmentation and isolation of historical buildings and threatening the continuity of cultural memory [3]. As such, there is an urgent need to explore effective and systematic conservation strategies to achieve the sustainable development of historical architectural heritage.

With the accelerating pace of globalization and urbanization, traditional conservation methods have proven inadequate in coping with increasingly complex urban environments and evolving societal demands. Conventional models typically emphasize singular physical interventions, such as structural restoration, façade rehabilitation, or construction restrictions. These approaches primarily address physical decay and aging but fall short in terms of resolving the spatial-level fragmentation, functional degradation, and cultural value erosion of historical architectural heritage. To address these issues, a series of quantitative methods have been proposed for the planning and analysis of heritage corridors. For example, space syntax and network centrality analysis have been applied to identify potential connections among cultural nodes, revealing the integration level of heritage systems and key access routes [4–6]. In terms of path simulation, resistance surfaces have been constructed based on factors such as topography and land use, and the minimum-cost-path model has been used to simulate optimal connections between heritage sites, thereby improving spatial organization at the regional level [7,8]. For spatial distribution analysis, the standard deviation ellipse method has been adopted to quantify the clustering trends, principal orientation, and the spatial extent of heritage resources, providing intuitive guidance for corridor alignment [9]. Techniques such as GIS-based spatial analysis, the nearest neighbor index, and kernel density estimation have been used to identify the spatial distribution, connectivity, and functional relationships among heritage sites, strengthening their overall spatial integration [10].

Heilongjiang Province, as a historically and culturally significant region in China, is home to a wide array of architectural heritage sites that reflect its rich regional culture and historical identity. However, despite ongoing conservation efforts, outcomes remain limited. Many brick-and-wood structures suffer from delayed restoration, resulting in serious aging and physical deterioration, with some facing irreversible damage [11]. Moreover, the region's "simplistic and crude" commercial redevelopment strategies—such as displacing original residents, enforcing uniform façades, and introducing repetitive commercial formats—have further undermined the cultural significance and functional vitality of heritage buildings, leading to a break in urban cultural continuity [12]. Consequently, many historical structures have been abandoned and neglected.

At the root of these issues lies the absence of a systematic conservation mechanism and an integrated macro-level planning approach. For example, although Harbin's Central Avenue and the Baroque Historic District are only a few kilometers apart, they demonstrate stark differences in vitality due to a lack of coordination or joint development strategies [13]. Similarly, Qiqihar's Labor Lake area and its surrounding Russian-style buildings once retained relatively intact urban fabric. However, recent road expansions and real estate development have led to the demolition or encapsulation of many valuable buildings within new high-rise developments, resulting in spatial fragmentation and the isolation of heritage resources. These cases reflect the broader deficiency of holistic and sustainable planning approaches in Heilongjiang's heritage conservation, which has led to fragmented, passive, and reactive practices.

To address these challenges, this study focuses on the architectural heritage of Heilongjiang Province and seeks to transcend the limitations of traditional conservation through the construction of a heritage corridor system. This system is based on GIS spatial analysis, nearest neighbor index, kernel density estimation, the MCR model, entropy weighting, circuit theory, and the network structure analysis method. This integrated approach enables the precise identification and classification of historical buildings, quantifies the spatial relationships among heritage sites, and reveals optimized pathways for the construction of heritage corridors.

From the perspective of research focus, this study is the first to concentrate on the conservation of historical architectural heritage in Northeast China. As a border region characterized by a cold climate and multi-ethnic integration, Northeast China exhibits distinct historical and cultural features that differ significantly from those of China's central and southern regions. Due to its peripheral location, the region has long functioned as a "terminal node" in the national transportation network, with limited traffic density and accessibility compared to more developed areas such as the Central Plains and the Yangtze River Delta. This spatial marginality underscores the urgent need for macro-scale corridor modeling to systematically identify and repair connectivity gaps and fragmentation zones.

From a methodological perspective, this study introduces two key innovations. First, it integrates the minimum cumulative resistance (MCR) model with circuit theory, combining a conventional "static" simulation method with a "dynamic" multipath analysis approach. This integration effectively overcomes the MCR model's limitation of only identifying a single optimal path while neglecting potential multipath connections. Second, the study breaks from the traditional practice of assigning corridor hierarchies after global corridor generation, which often involves subjective judgment. Instead, it proposes a novel pre-hierarchical approach that classifies "source" nodes in advance using kernel density threshold adjustment and local peak extraction. This classification informs the subsequent generation of a tiered corridor network. In this way, the method significantly enhances the objectivity and reliability of corridor modeling and avoids the bias introduced by post hoc manual classification.

Specifically, this study aims to address the following key questions:

1. What are the spatial distribution characteristics of historical architectural heritage in Heilongjiang Province?
2. How can a systematic heritage corridor network be constructed for historical architecture in Heilongjiang using more objective and quantitative research methods?
3. What strategic insights can this study offer for the planning and conservation practices of historical architectural heritage corridors in Heilongjiang?

Ultimately, this study seeks to provide theoretical foundations and strategic recommendations for the scientific construction of heritage corridors in Heilongjiang Province and

beyond, promoting the coordinated and sustainable development of historical architectural conservation and urban growth.

2. Literature Review

2.1. Quantitative Research on Historical Architectural Heritage Corridors

The concept of heritage corridors originated from the greenway approach, emphasizing comprehensive regional conservation and development in a way that integrates cultural preservation with economic revitalization and environmental protection [14]. In the 1980s, American historians and cultural conservationists developed this into a systematic theory, aiming to integrate cultural and natural resources within linear geographic areas to produce regional conservation and development strategies [15]. Heritage corridor theory emphasizes linear or planar geographic spaces as carriers, with conservation targets including natural valleys, canals, historical roads, and railway networks. Its goal is to connect heritage sites, villages, and landmarks of cultural, historical, or ecological value, forming historically significant linear corridors [6]. The core of this methodology lies in transcending administrative boundaries through spatial connectivity, analyzing social and cultural linkages to identify optimal corridors, integrating scattered heritage sites, and thereby ensuring the integrity and continuity of regional cultural narratives [16].

Following the introduction of heritage corridor theory, scholars have continuously deepened and expanded its application, proposing strategies tailored to local contexts. For example, the UK established a "conservation–development–community participation" trinity model through the Canal Act, while France's Midi Canal Heritage Management Manual leveraged canal cultural festivals to promote tourism and economic activities along the route. Belgium's Industrial Heritage Protection Law legally solidified authenticity standards for industrial heritage corridors. Additionally, American landscape architect Grant Jones and his firm Jones & Jones, commissioned in the early 1970s to develop a conservation plan for the Nooksack River in northwestern Washington, utilized GIS technology to map the river's catchment area and viewshed, analyzing the integrity, health, uniqueness, and resilience of various regions. They proposed recommendations to "protect high aesthetic value landscape features" and delineated areas suitable for recreational use. This approach, applicable to river conservation planning, has also been extended to utility corridors and road design, demonstrating the universal applicability of GIS in route planning [17,18]. Subsequently, scholars like Wang Zhifang introduced heritage corridor theory to China, proposing an integrated planning methodology oriented toward regional economic revitalization and tourism industry upgrading [19]. By integrating international methodologies with local case studies, they laid the foundation for the localization of heritage corridor theory in the context of China's urban and rural development [20].

To date, heritage corridor research has been categorized into three types: experience-driven, technology-driven, and interdisciplinary. Experience-driven research relies on field surveys and expert assessments, constructing heritage value evaluation systems through historical literature analysis, field mapping, and expert experience. Technology-driven research employs ArcGIS as a spatial analysis platform, utilizing the minimum cumulative resistance (MCR) model to quantify and simulate heritage connectivity and also identifying minimum-cost paths by constructing cultural and ecological resistance surfaces. Specifically, it focuses on linear heritage distribution areas, integrating spatial tools such as kernel density analysis into a GIS framework to analyze historical heritage aggregation characteristics. It uses methods like the Analytic Hierarchy Process (AHP) or the entropy weight method to quantify and evaluate resistance factors, constructs comprehensive resistance surfaces, and identifies potential corridors while optimizing path selection [21]. Interdisciplinary research builds on GIS and MCR technologies, incorporating multidimensional resistance

factors (e.g., cultural weights, community participation) from sociology and ecology, and achieves multi-objective balance in heritage corridors through spatial overlay analysis and model optimization [22] (Table 1).

Table 1. Corridor quantitative research status analysis.

Category	Quantitative Method	Technical Features and Empirical Evaluation	Related Studies
Experience-Driven	Analytic Hierarchy Process (AHP)	**Technical Features:** Determines heritage value weights through expert scoring, combined with GIS kernel density analysis to identify heritage clusters. **Empirical Evaluation:** Highly subjective but simple to operate, suitable for early-stage planning with limited data.	(Wang, 2009): Constructing cultural heritage corridors using AHP [23]. (Chen, 2014): Hierarchical structure model for corridor landscape system construction [24].
	Kernel Density Analysis	**Technical Features:** Defines a core protection range based on experience, overlaying administrative boundaries and natural elements. **Empirical Evaluation:** Relies on planner experience; requires integration with other quantitative tools for dynamic optimization.	(Liu, 2013): Holistic protection and utilization of linear industrial heritage [25].
Technology-Driven	Nearest Neighbor Index	**Technical Features:** Measures the distribution pattern of spatial points by calculating the distance between a point and its nearest neighbor. **Empirical Evaluation:** Assesses the randomness of point distribution and performs statistical significance tests.	(Zhou et al., 2023): Measuring spatial clustering of intangible cultural heritage to reveal distribution characteristics [26].
	GIS + MCR Model (Minimum Cumulative Resistance)	**Technical Features:** Integrates land use, elevation, and other factors in ArcGIS to construct a resistance surface. Experts assign resistance values, and the MCR model calculates optimal paths between heritage nodes, identifying connectivity bottlenecks. **Empirical Evaluation:** Highly quantitative, enabling visualization of corridor suitability, but resistance parameters rely on subjective assignment.	(Yu et al., 2005): Simulating corridor suitability areas using resistance coefficients [27] (Ye et al., 2020): Identifying ecological-cultural composite corridors using the MCR model [21]. (Xu et al., 2023): Extracting ecological corridors using GIS and MCR [28].
	Space Syntax Analysis	**Technical Features:** Quantifies accessibility and integration using space syntax to identify transportation advantages and evaluates spatial structure rationality with an axial model. **Empirical Evaluation:** Suitable for functional optimization of urban-scale heritage corridors but less sensitive to natural terrain.	(Zhang et al., 2017): Proposing revitalization strategies using space syntax [29]. (Lin et al., 2022): Building a suitability model for heritage corridors using space syntax and axial integration [30]. (Li et al., 2023): Evaluating accessibility and constructing a 3D coupling model for heritage corridors [31].
	Kernel Density Analysis + Standard Deviation Ellipse Analysis	**Technical Features:** Kernel density analysis identifies heritage hotspots, while standard deviation ellipses reveal spatial distribution directions. **Empirical Evaluation:** Visually reveals distribution directions and morphological features but requires integration with path simulation models for deeper spatial structure analysis.	(Wang, 2022): Quantifying spatiotemporal clustering and distribution evolution of heritage points [32]. (Zhang et al., 2023): Constructing ecological tourism corridors using kernel density analysis, standard deviation ellipses, and the MCR model [33].

Table 1. *Cont.*

Category	Quantitative Method	Technical Features and Empirical Evaluation	Related Studies
Interdisciplinary Integration	Circuit Theory	**Technical Features:** Analogizes current conduction, treating heritage nodes as "source–sink." GIS assigns conduction coefficients to calculate effective conduction values, identifying high-resistance areas and integrating cultural (entropy weight method), ecological, and social resistance surfaces to generate comprehensive conduction maps. **Empirical Evaluation:** Dynamically simulates heritage element flows, overcoming limitations of static models.	(Ognyanova et al., 2024): Combining circuit theory and SNA to analyze heritage node connectivity and conduction, establishing a corridor system [34]. (Wu et al., 2025): Optimizing heritage corridor closure and connectivity using current conduction simulation [16].
	Geodesign Theory	**Technical Features:** Integrates GIS spatial analysis with planning and design, overlays natural, cultural, and administrative boundaries, and simulates tourist behavior and community interactions using ABM models. **Empirical Evaluation:** Achieves integrated planning and analysis but requires multi-departmental collaboration due to model complexity.	(Chen et al., 2014): Integrating GIS spatial analysis with planning and design to delineate heritage corridors [35].
	Network Structure Analysis	**Technical Features:** Evaluates network structure based on graph theory, quantifying node connectivity and path redundancy. **Empirical Evaluation:** Efficiently quantifies network structure rationality, suitable for multi-scale analysis.	(Wu et al., 2025): Introducing network structure analysis to evaluate corridor structure rationality, optimize path closure, and enhance connectivity analysis adaptability and practicality [16].

However, in the practical context of heritage conservation in Heilongjiang Province, architectural resources are managed by various administrative systems, lacking a unified coordination mechanism. Moreover, current policies tend to emphasize structural restoration while neglecting cultural connectivity, resulting in severe spatial fragmentation and thee isolation of heritage sites. The heritage corridor system proposed in this study directly responds to these challenges by establishing intrinsic linkages among diverse historical buildings through both spatial and cultural dimensions. This approach aims to shift conservation efforts from isolated interventions toward an integrated framework, thereby providing a foundation for the formulation of more systematic and strategic protection policies.

Overall, heritage corridor research is evolving from experience-driven methods to technology-driven and interdisciplinary approaches, gradually achieving spatial analysis, data quantification, and multidimensional optimization. To further advance the systematic and scientific study of heritage corridors, there is an urgent need to introduce more objective, efficient, and adaptable quantitative methodologies. While traditional expert-assigned path models are operational in preliminary identification, they often suffer from subjectivity, static parameters, and slow responsiveness when handling complex multivariate relationships, making them inadequate for multi-source heterogeneous data fusion and dynamic path optimization. Therefore, selecting integrated models with both spatial simulation and connectivity analysis capabilities has become a critical research direction. For instance, circuit theory demonstrates flexibility in identifying multipath conduction characteristics, while the entropy weight method effectively reduces human intervention, enhancing the objectivity of factor weight assignment. By integrating the strengths of different technical methods, these approaches not only address the limitations of traditional models, such as

single-path and static evaluations, but also provide a more robust quantitative foundation for network construction and the optimization of heritage corridor systems.

2.2. Review Conclusions and Research Proposal

The findings from Section 2.1 reveal that the precise quantification of the spatial characteristics and connectivity of historical architectural heritage involves several key steps: the identification of the spatial distribution of heritage nodes, the optimal construction of connectivity paths, the assessment of spatial resistance surfaces, and the visualization of corridor networks. The nearest neighbor index, the minimum cumulative resistance model (GIS + MCR), kernel density analysis, and circuit theory have been widely demonstrated as highly accurate and adaptable technical approaches for addressing these steps in their respective dimensions [36]. Additionally, network structure analysis methods, commonly used in ecological corridor planning, effectively evaluate and verify the connectivity performance of multi-level ecological corridors.

Among these, the nearest neighbor index, as a crucial tool for identifying spatial point patterns, effectively assesses the clustering degree and distribution characteristics of historical buildings, providing data support for subsequent kernel density analysis and resistance surface construction. Its significance analysis results reveal the clustering trends of historical buildings, offering a scientific basis for identifying potential heritage corridors [37]. Kernel density analysis, with its intuitive advantages in clustering analysis and hotspot identification, visualizes the core distribution areas of historical buildings, supporting the identification of potential nodes in heritage corridors [38]. The MCR model, which constructs multi-factor resistance surfaces and calculates the minimum cost of connecting paths between historical buildings, provides an efficient and quantifiable path optimization solution for the preliminary selection of heritage corridors [39]. Although the MCR model relies on parameter settings, its integration with GIS platforms is mature, making it suitable for large-scale heritage area analysis. Combination with the entropy weight method used for objective weighting further enhances the scientific rigor and adaptability of the MCR model [40]. Circuit theory, as a dynamic simulation model, effectively complements the static limitations of MCR in path construction, which focuses solely on identifying single paths while neglecting multipath potential [41]. By deriving connectivity based on current distribution, it identifies potential "bottleneck areas" and "high-traffic nodes," offering advantages in multipath identification and dynamic adjustment. Unlike MCR, which emphasizes minimum-cost paths, circuit theory focuses on the multipath structure and redundancy of the entire network, making it more suitable for assessing system resilience and providing more adaptable quantitative support for practical planning. Network structure analysis plays a critical role in the later stages of heritage corridor evaluation, quantifying the overall connection efficiency between nodes under different corridor layouts, and is suitable for optimizing corridor structures [42].

This study aims to address the prominent issues of "fragmentation, isolation, and lack of systematic connectivity mechanisms" in the conservation of historical architectural heritage in Heilongjiang Province, constructing a spatial connectivity system oriented toward "holistic protection" and "sustainable transmission." In terms of methodological selection, considering the efficiency and visualization advantages of the GIS + MCR model in path construction, as well as the multipath identification and dynamic response capabilities of circuit theory in simulating spatial transmission paths [43], this study integrates the two to overcome the limitations of traditional minimum-cost-path models in single-path dependency and node degradation. Furthermore, to address the over-reliance on subjective judgment in factor weighting in traditional research, the entropy weight method is adopted to ensure the objectivity and data-driven nature of weight assignment. The nearest neighbor

index and kernel density analysis are used to identify spatial clustering characteristics, providing precise data for "source" selection and node classification. Finally, network structure analysis is introduced for connectivity verification, constructing a closed-loop model of "node identification–path generation–system evaluation," filling the gap in the systematic assessment of heritage networks in existing research.

In summary, this study uses the nearest neighbor index, kernel density analysis, the entropy weight method, the GIS + MCR model, circuit theory, and network structure analysis to produce the overall research framework. These methods form an organic connection across spatial identification, path optimization, and system evaluation, constituting a logically complete and replicable methodological system for heritage corridor generation. Specifically, spatial identification is carried out through average nearest neighbor analysis and kernel density estimation to determine the spatial distribution characteristics and clustering patterns of historical buildings. Based on these results, cultural source nodes are classified into three levels: provincial, municipal, and district. In the path optimization stage, seven resistance factors—including elevation, slope, land use, and road networks—are weighted and overlaid using a combination of entropy weighting and expert scoring to construct a comprehensive cost surface. The minimum cumulative resistance (MCR) model is then integrated with circuit theory to simulate multipath accessibility, enabling the identification of optimal connections while overcoming the limitations of traditional single-path models. This enhances the diversity of cultural flows and improves the adaptability of the corridor system. The system evaluation phase incorporates network structure analysis and employs graph-theoretic indices—such as the α index (network closure), β index (path complexity), and γ index (connectivity efficiency)—to quantitatively assess the accessibility, redundancy, and structural robustness of the corridor network. This integrated methodological framework covers the full process, from node identification and path construction to system validation. It is logically coherent, technically rigorous, and highly adaptable for practical application, being particularly suitable for heritage protection and corridor planning in regions characterized by severe spatial fragmentation and weak cultural connectivity.

3. Research Area and Methodology

3.1. Research Area

This study focuses on the historical architectural heritage of Heilongjiang Province. Located on the northeastern border of China, Heilongjiang is bounded by the Heilongjiang and Wusuli Rivers to the north and east, respectively, bordering Russia, while its southwest adjoins the Inner Mongolia Autonomous Region and its south neighbors Jilin Province (Ministry of Civil Affairs of the People's Republic of China, 2023). According to data from the official website of the Central People's Government of China (https://www.gov.cn/ (accessed on 3 April 2025)), the province comprises 12 prefecture-level cities, 1 administrative region, and 67 county-level administrative units. Covering a total area of 473,000 square kilometers, it forms a multi-level administrative spatial system (Figure 1).

Since the 18th century, Heilongjiang, as a strategic border area in Northeast China, a key trade port with Russia, and a frontier of modern industrialization, has developed a diverse and cross-temporal architectural heritage system. The region's heritage includes administrative, military, and religious buildings from the 18th to 19th centuries; public facilities and residential structures blending Chinese and Western styles from the early 20th century; and industrial plants and office buildings from the mid-to-late 20th century. These structures reflect the architectural practices and spatial patterns, shaped by varying political, economic, and cultural contexts over time. Currently, the historical architectural heritage in Heilongjiang is widely distributed, exhibiting distinct temporal continuity and regional

characteristics. For example, the Central Avenue architectural complex and St. Sophia Church in Harbin, the Dacheng Temple in Qiqihar, and the Hengdaohezi architectural complex in Mudanjiang serve as material witnesses to the region's multicultural history, showcasing the fusion of Chinese and Western cultures and the coexistence of ethnic groups, as well as reflecting the historical trajectory of industrial civilization (Figure 2).

However, due to the vast territory, scattered resource distribution, and the lack of forward-looking and systematic conservation planning, the historical architectural heritage in Heilongjiang exhibits a certain degree of spatial fragmentation and isolation. Effective spatial linkages and cultural transmission mechanisms between heritage sites have not been established, resulting in insufficient overall connectivity and integration capacity. This hinders the realization of the cluster advantages and holistic value of regional cultural heritage. Therefore, this study aims to overcome the path dependency and fragmentation issues in traditional heritage conservation by systematically identifying the spatial resistance and cultural potential of historical buildings, constructing a spatial accessibility network among heritage sites, and facilitating the transition from "point-based conservation" to a "network-based transmission" model. This transition defines heritage sites as interconnected nodes within a broader cultural and spatial system, not as isolated points. By applying kernel density analysis, resistance surface modeling, and circuit theory, the study constructs a spatial accessibility network that reflects both cultural diffusion and visitor mobility. This integrated approach supports coordinated revitalization across multiple sites, enabling a shift from static, site-specific interventions to dynamic, corridor-based planning and fostering a more resilient and synergistic model for heritage conservation.

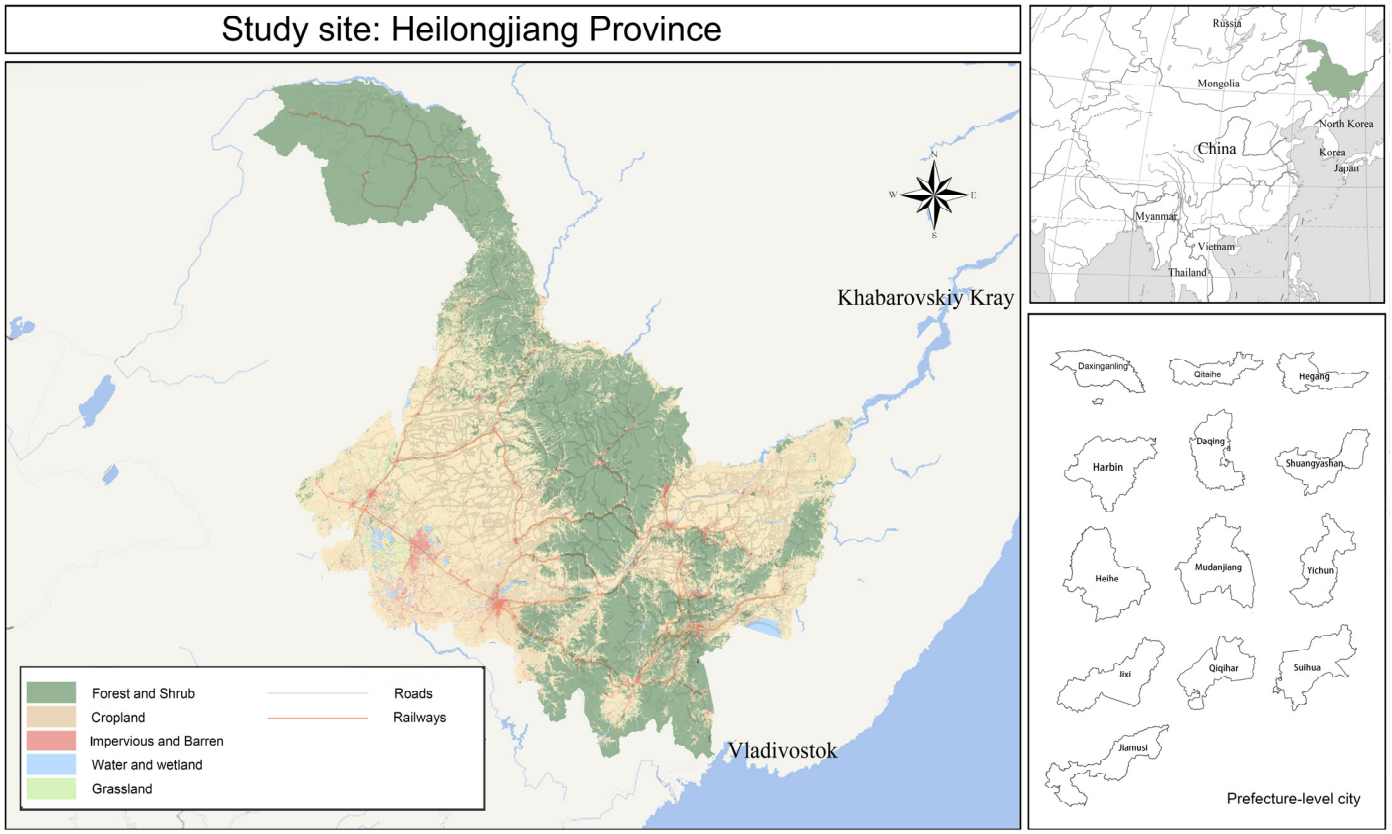


Figure 1. Overview of study area.



Figure 2. The current status of historical buildings in Heilongjiang Province.

3.2. Research Workflow

This study aims to construct a heritage corridor system for historical architectural heritage in Heilongjiang Province. The overall workflow revolves around data processing, resistance factor analysis, corridor construction, and validation (Figure 3). The specific steps are as follows:

Step 1: Data Processing and Preparation

In the initial stage, data from national, provincial, and municipal cultural heritage protection units were integrated to obtain the POI data of historical buildings in Heilongjiang Province. Additionally, multi-source spatial data, including land use, DEM elevation, roads, and water networks, were acquired from platforms such as the National Earth System Science Data Sharing Platform, the Standard Map Service System of the Ministry of Natural Resources, and Mapbox. These data provide the foundation for subsequent analyses.

Step 2: Spatial Feature Identification of Architectural Heritage

Using ArcGIS 10.8, spatial data processing and modeling were conducted. The nearest neighbor index was employed to identify the clustering characteristics of historical buildings and determine their spatial distribution patterns (clustered, dispersed, or random). Subsequently, kernel density analysis (KDE) was applied to visualize the density distribution of architectural heritage, revealing core clustering areas and edge dispersion zones and thereby constructing a spatial distribution model of historical heritage. The results of this stage provide quantitative support for identifying "core nodes" and "heritage sources."

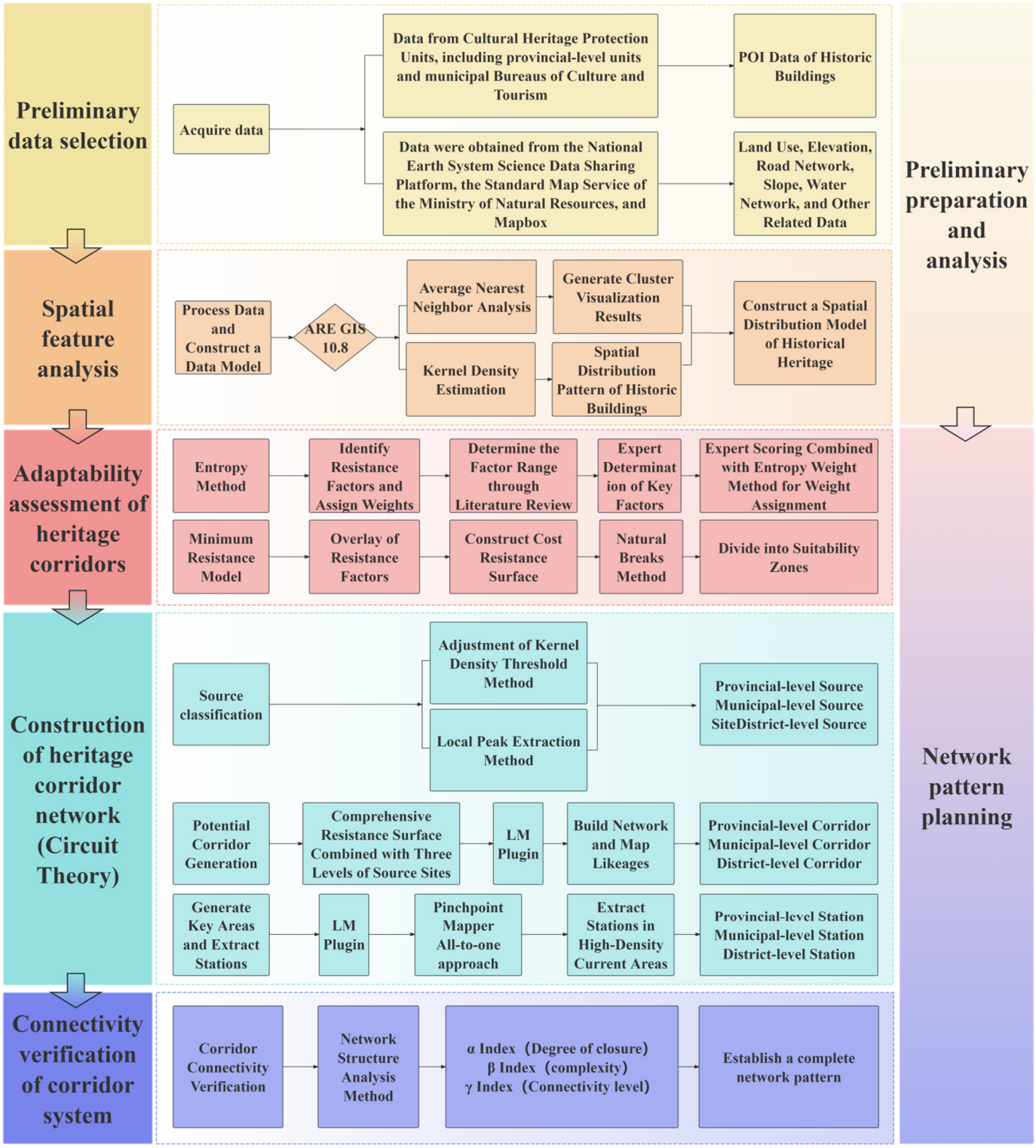


Figure 3. Research framework.

Step 3: Suitability Assessment of Heritage Corridors

After clarifying the spatial pattern of heritage, this study proceeded to establish a resistance model based on influencing factors. Seven resistance factors, including natural geography, socioeconomics, and public services, were considered. A combination of expert scoring and the entropy weight method was used to assign weights, ensuring objectivity in the distribution of factor weights. GIS spatial overlay analysis was then employed to generate a cost resistance surface, which was classified into five suitability levels (high

to low) using the natural breaks method. This step aims to provide a spatial accessibility "base map" for path construction and serves as the foundation for subsequent MCR and circuit model modeling.

Step 4: Construction of Heritage Corridor Networks

To address the limitations of traditional minimum path models, such as single-path dependency and system fragility, this study proposed and applied two source extraction methods. First, the kernel density threshold adjustment method and local high-point extraction method were used to scientifically identify provincial, municipal, and district-level "sources," which served as starting points for connectivity corridors. After constructing a complete resistance map and source system, the circuit theory model was applied using the LM plugin to simulate current flow, generate "potential corridors" and "current density paths," and identify key circulation paths and node locations. Finally, a three-tier hierarchical structure of "sources," corridors, and nodes was established. This stage integrates MCR for path cost optimization and circuit theory for multipath identification and system resilience, forming a spatial network.

Step 5: Connectivity Validation of the Corridor System

To verify the connectivity and stability of the constructed corridor network, network structure analysis was introduced for system evaluation. This method quantitatively analyzes the connection efficiency, redundancy structure, and accessibility of nodes in the network, enabling the horizontal comparison of connectivity performance across different hierarchical networks.

3.3. Research Methodology

3.3.1. Data Sources

Data were collected from national key cultural heritage protection units, provincial cultural heritage protection units, and municipal culture and tourism bureaus in Heilongjiang Province. Geographic coordinates were obtained using the Gaode Map Coordinate Picker System (https://lbs.amap.com/console/show/picker (accessed on 3 April 2025)) and imported into ArcGIS 10.8. Land use classification and administrative boundary data were acquired from the National Earth System Science Data Sharing Platform (https://www.geodata.cn/data/ (accessed on 3 April 2025)). Road and water system data were obtained from Mapbox (https://www.mapbox.com/ (accessed on 3 April 2025)). DEM digital elevation data were sourced from the Standard Map Service Website of the Ministry of Natural Resources (https://bzdt.ch.mnr.gov.cn/ (accessed on 3 April 2025)). These datasets were integrated into the ArcGIS 10.8 platform, where spatial analysis and overlay operations were conducted to uncover potential correlations and construct a spatial distribution model of historical heritage in Heilongjiang Province. This process identified core and secondary nodes, providing data support for the generation of heritage corridors.

3.3.2. Spatial Feature Analysis Methods

(1) Nearest Neighbor Index (NNI)

The nearest neighbor index (NNI) is a metric used to analyze spatial point patterns, measuring the relative clustering or dispersion of point features in space. It calculates the average distance between each point and its nearest neighbor, comparing it to the expected average distance under random distribution to determine whether the points are clustered, random, or uniformly distributed. It is commonly used to assess the proximity of data points within a space.

The primary purpose of this step is to provide a qualitative assessment of the overall distribution pattern of historical buildings before conducting kernel density analysis, offering guidance for spatial distribution and kernel function selection in subsequent re-

search. Specifically, if the NNI results indicate a high degree of clustering among historical buildings, a kernel function with a smaller bandwidth is more suitable in kernel density analysis for highlighting local high-density areas. Conversely, if the distribution is relatively uniform, a larger bandwidth is needed to capture the overall trend effectively. Additionally, NNI results can provide cross-validation for kernel density analysis, enhancing the reliability of the findings.

In this study, the nearest neighbor index was employed to investigate the spatial distribution of POI (Point of Interest) data for historical buildings in Heilongjiang Province, aiming to clarify their spatial clustering characteristics.

The formula is as follows [44]:

$$NNI = \frac{d_{obs}}{d_{\exp}} \tag{1}$$

In the formula, d_{obs} represents the observed average nearest neighbor distance. It is calculated by determining the distance from each point to its nearest neighbor within the study area and then averaging these distances. For example, when studying the distribution of historical buildings in a region, the distance from each historical building to its nearest neighboring historical building is measured, and the average of these distances is computed. $d_{\exp}$ is the expected average nearest neighbor distance under the assumption of random distribution. Its calculation is related to the area of the study region A and the number of points n. Assuming points are randomly and uniformly distributed within the region, the formula derived from geometric and probabilistic principles is as follows: $d_{\exp} = \frac{1}{2\sqrt{n/A}}$. This implies that the denser the point distribution, the larger $\frac{n}{A}$ becomes, resulting in a smaller expected average nearest neighbor distance.

Based on these calculations, the results can be interpreted in three scenarios:

1. When ($NNI = 1$), the spatial distribution of points is random, indicating no significant clustering or uniform trend.

2. When ($NNI < 1$), the observed average nearest neighbor distance is smaller than the expected distance under a random distribution, suggesting a clustered distribution. The smaller the value, the higher the degree of clustering.

3. When ($NNI > 1$), the observed average nearest neighbor distance is larger than the expected distance under a random distribution, indicating a uniform or dispersed distribution. The larger the value, the higher the degree of dispersion.

(2) Kernel Density Estimation (KDE)

Kernel density estimation (KDE) is a non-parametric method used to estimate the probability density function of a random variable. Its core function lies in clearly illustrating the spatial clustering of geographic features. In practical applications, KDE employs a kernel function for each geographic point, conducting detailed calculations within a specific surrounding area to determine the density of points in that region.

The primary objectives of KDE are as follows:

It can be used to accurately delineate high-density and low-density areas of cultural heritage resources, providing a robust basis for prioritizing conservation planning.

It can be used to identify core and secondary nodes of historical heritage, which serve as anchor points in the generation of heritage corridors, connecting heritage clusters and enhancing the value of these corridors.

It can be used to analyze the spatial accessibility of resource allocation across different regions, helping to assess the rationality of resource distribution and avoid improper corridor planning.

It can be used to supporting the dynamic evaluation of the sustainable development of heritage corridors, aiding subsequent zoning management and spatial optimization.

In this study, KDE was used to analyze the clustering degree and geographic distribution pattern of historical buildings in Heilongjiang Province. By combining the generated average nearest neighbor distance (quantitative) with KDE maps (visualization), the spatial distribution characteristics of historical buildings in Heilongjiang Province were clearly depicted.

The formula for KDE is as follows [45,46]:

$$fn(x) = \frac{1}{(nh)} \sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \tag{2}$$

In this formula, $fn(x)$ represents the kernel density estimation; h is the bandwidth, or search radius, determining the spatial range of the kernel function; n is the number of point elements; $k\left(\frac{x-x_i}{h}\right)$ is the kernel function; and $(x - x_i)$ is the Euclidean distance from the estimation point x to the sampling point x_i.

3.3.3. Corridor Suitability Analysis Methods

(1) Minimum Cumulative Resistance (MCR) Model

The minimum cumulative resistance (MCR) model is a spatial analysis method primarily used to identify optimal connectivity paths for species migration, ecological corridors, and cultural heritage corridors. The core concept is that, within a given region, individuals (e.g., animals, energy flows, cultural transmission) tend to choose the path with the least cumulative resistance during movement. This path is influenced by the "resistance values" assigned to different land cover types, where higher resistance values indicate greater traversal costs and lower values signify smoother passage. Yu Kongjian et al. introduced this model into the heritage corridor domain to simulate the dynamic process of visitors experiencing and perceiving cultural heritage in spatial contexts [27].

In this study, three physical characteristics were selected: the natural environment, socioeconomic factors, and public services. After identifying the heritage "sources" of the study objects and accumulating the resistance coefficients of these three factors, GIS spatial analysis was applied to evaluate the comprehensive resistance for heritage restoration and transit activities.

The formula for the MCR model is as follows [47]:

$$MCR = f_{\min}\left(\sum_{j=n}^{i=1} D_{ij} \times R_j\right) \tag{3}$$

In this formula, f represents the positive correlation between cumulative resistance and the movement process and D_{ij} denotes the distance- or cost-related metric from the "source" j to the destination, traversing the i-th environmental factor (e.g., forests, farmlands, urban areas, etc.). In the context of heritage corridors, it can be interpreted as the spatial distance or experiential cost incurred by visitors moving from the heritage "source" to the destination while passing through the i-th environmental element. R_i represents the resistance coefficient of the i-th environmental element. In the above steps, the resistance values (resistance surface) generated directly by GIS and R_i are typically related to the physical characteristics of the region.

(2) Entropy Method

The entropy method is a multi-attribute decision analysis approach primarily used for weight determination, ranking, and evaluation. It is widely applied in risk assessment, resource allocation, environmental management, and other fields. Its core concept is based on information entropy, which measures the contribution of each attribute to decision-

making in order to determine their weights. This method effectively avoids human bias, ensuring scientific rigor and accuracy.

The basic steps of the entropy method are as follows:

Step 1: Data Selection. Based on the research objectives, it is necessary to determine the influencing factors from multiple dimensions such as the natural environment, socioeconomic conditions, and public services. Then, construct an original data matrix with m evaluation indicators and n samples, where x_{ij} represents the value of the i-th sample on the j-th indicator, with $i = 1, 2, 3 \ldots, n$ and $j = 1, 2, 3 \ldots, m$.

Step 2: Data Standardization. It is necessary to standardize the data to address inconsistencies in measurement units and directions. To avoid meaningless logarithmic values during entropy calculation, add a small real number (e.g., 0.01) to each zero value. The calculation formula is as follows [48]:

$$X' = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})} \tag{4}$$

Step 3: Calculate the Proportion of Samples for Each Indicator. It is necessary to determine the relative importance of each sample within each indicator by calculating its proportion. The formula is as follows [48]:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \tag{5}$$

where x_{ij} represents the standardized value, and n is the total number of samples. This step transforms the influence of samples under each indicator into proportional values, providing foundational data for entropy calculation and weight allocation.

Step 4: Calculate the Information Entropy for the *j*-th Indicator. It is necessary to measure the dispersion and effective information content of the j-th indicator across all samples using the following formula [48]:

$$e_j = -K * \sum_{i=1}^{n} (P_{ij} * \ln(P_{ij})) \tag{6}$$

where $K = \frac{1}{\ln(n)}$, n is the total number of samples, and P_{ij} is the proportion of the i-th sample for the j-th indicator. To ensure that e_j lies within the interval [0,1], K is introduced. If $P_{ij} = 0$, $P_{ij} \ln(P_{ij}) = 0$ is set to 0 to avoid undefined values.

Step 5: Calculate the Variation Coefficient. The information utility value d_j for the j-th indicator is determined by the difference between its entropy e_j and 1. A higher utility value indicates greater weight. The formula is as follows [48]:

$$d_j = 1 - e_j \tag{7}$$

Step 6: Determine the Weight of Each Indicator. The weight w_j for the j-th indicator is calculated using its variation coefficient d_j. A higher d_j signifies greater importance in the evaluation. The formula is as follows [48]:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{8}$$

where m is the total number of indicators.

Step 7: Calculate the Comprehensive Score for Each Sample. After determining the weights, the standardized values of each indicator are weighted and summed to obtain the comprehensive evaluation score z_i for each sample. The formula is as follows [48]:

$$z_i = \sum_{j=1}^{m} w_j x_{ij} \quad (9)$$

where z_i represents the comprehensive score of the i-th sample, w_j denotes the weight of the j-th indicator, x_{ij} is the standardized value of the indicator, and m is the total number of indicators. This score reflects the overall performance of the sample across all evaluation dimensions, with a higher score indicating a more pronounced comprehensive advantage across key indicators.

In this study, the entropy method was employed to determine the weights of resistance factors influencing heritage corridor generation, including elevation, land use classification, water bodies, roads, slope, and accommodation. The calculated information entropy, information utility value, and weight coefficients are presented in Table 2.

Table 2. Information entropy value e, information utility value d, weight coefficient.

Item	Information Entropy Value e	Information Utility Value d	Weight Coefficient w
Elevation Classification	0.9905	0.0095	16.90%
Land Classification	0.9896	0.0104	18.53%
Slope	0.9856	0.0144	25.69%
Accommodation Core Classification	0.9987	0.0013	2.26%
Catering Core Classification	0.9989	0.0011	1.89%
Water Resistance	0.9948	0.0052	9.27%
Road Resistance	0.9857	0.0143	25.47%

Where the information entropy e measures the uncertainty of information; the information utility value d reflects the usefulness of the information; and the weight coefficient w represents the relative importance of each factor in comprehensive evaluation scenarios.

3.3.4. Circuit Theory (Corridor Network Construction)

Circuit theory, applied in spatial ecology, cultural heritage conservation, and urban planning, analogizes the principles of electric current flow to analyze connectivity between different points in geographic space. It compares species dispersal in landscape ecology to electron movement in physics (species as current, spatial environment as circuits) to simulate optimal corridor paths. Environments conducive to flow have lower resistance values, indicating higher current density, while unsuitable environments exhibit higher resistance and lower density. Notably, in this study on cultural heritage corridors, the selection of "suitable" and "unsuitable" elements differs from ecological corridors. For instance, artificial roads, typically barriers in ecological corridors, are considered favorable in cultural heritage corridors.

This study employs circuit theory to simulate heritage corridor generation and support subsequent corridor and posthouse grading. Specifically, the Pinch Point Mapper tool in the LM plugin is used to visualize corridor morphology and identify high-current-density areas, providing critical insights for planning posthouse levels and cost allocation based on the likelihood of visitor transit and rest events.

3.3.5. Network Structure Analysis for Corridor Connectivity Validation

Network structure analysis, a spatial analysis technique based on graph theory, quantitatively measures the relationships between nodes (e.g., heritage sites) and edges (e.g., corridor paths) to evaluate the structural complexity, connectivity, and operational stability of a system. In this study, three core metrics were employed to scientifically validate the connectivity and structural rationality of the historical architectural heritage corridor system in Heilongjiang Province. The α index (cyclomatic number) measures the ratio of actual loops to the maximum possible loops in the network, reflecting its closure. A value closer to 1 indicates richer internal loops, greater path flexibility, and enhanced system redundancy. The β index (edge-to-node ratio) represents the ratio of edges to nodes, assessing structural complexity. A value > 1 suggests the existence of multiple connecting paths and a more hierarchical system. The γ index (Connectivity Degree)** measures the ratio of actual connections to the theoretical maximum, evaluating network accessibility. A value closer to 1 indicates more comprehensive coverage and uniform node connections (Table 3).

Table 3. Network structure feature index table.

Index Name	Meaning	Mathematical Expression	Evaluation Focus
α Index	Degree of Closure	$\alpha = \frac{e-v+1}{2v-5}$	Measures the number of closed loops in the network; higher values indicate greater stability.
β Index	Degree of Complexity	$\beta = \frac{e}{v}$	Assesses the average number of paths connected to each node in the network.
γ Index	Degree of Connectivity	$\gamma = \frac{e}{3(v-2)}$	Ratio of actual connections to maximum possible connections, reflecting network accessibility.

The analysis was conducted using Cone for 2.6 (Cone for Sensinode) software via the following steps:

1. Network Graph Construction: Organize all heritage "source" sites into standard node and edge files (node file and connection file), formatted for Cone for software.

2. Node File Preparation: Include each node's unique ID, spatial location (optional), and weight. Uniform weights are assigned to focus on overall network structure.

3. Connection File Preparation: List all path connections, including start ID, end ID, and path weight (e.g., current density, minimum resistance length). Equal weights are used to emphasize connectivity structure.

4. Data Import and Analysis: Import node and connection files into Cone for, select the "Network topology" module, check "Basic connectivity indices," and run the program to output α, β, and γ indices.

Through the comprehensive analysis of these indices, the connectivity structure of the heritage corridor network can be quantitatively assessed for stability, complexity, and spatial adaptability, thereby providing a scientific basis for subsequent network optimization and hierarchical utilization.

4. Experimental Results

4.1. Spatial Distribution Pattern of Historical Buildings in Heilongjiang Province

This study analyzed the spatial distribution characteristics of historical buildings in Heilongjiang Province using 954 POI points. The average nearest neighbor (ANN) analysis revealed an expected nearest neighbor distance of 11,133.36 m and an actual nearest

neighbor distance of 3475.72 m, indicating a significant difference. The nearest neighbor index (NNI) was 0.31219 (<1), suggesting a pronounced clustered spatial distribution. Statistical tests yielded a z-value of −40.64 and a *p*-value of 0.000000, confirming that the non-random nature of this clustering was a statistically significant spatial pattern (Figure 4).

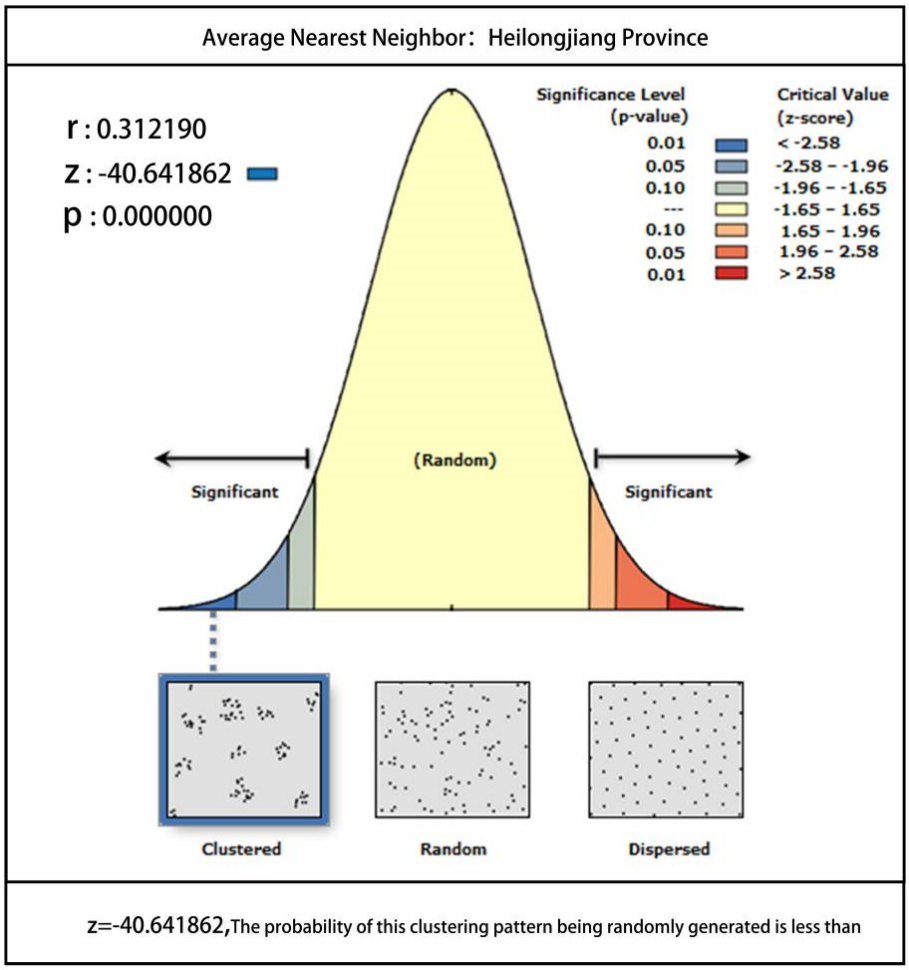


Figure 4. Nearest neighbor index results in Heilongjiang Province.

In statistical terms, the null hypothesis of ANN analysis typically assumes that there is a random spatial distribution of point features. The *p*-value represents the probability of observing the current sample data (or more extreme data) under this hypothesis. In this study, a *p*-value approaching 0 indicates that the observed clustered pattern would be highly unlikely if the historical buildings were randomly distributed. Thus, the null hypothesis is rejected, confirming the clustered spatial distribution of historical buildings in Heilongjiang Province.

To further elucidate the spatial pattern, kernel density estimation (KDE) was employed to visualize the clustering intensity and distribution (Figure 5). The results revealed a "one core, eight zones, multiple scattered points" spatial structure. Harbin City emerged as the primary clustering core with the highest density, representing the most concentrated area of historical buildings. Secondary clustering zones were identified in northern Daqing, Qiqihar, western Heihe, Mudanjiang, southern Hegang, and southwestern Jiamusi, forming the "eight zones." Additionally, scattered distributions were observed in certain regions.

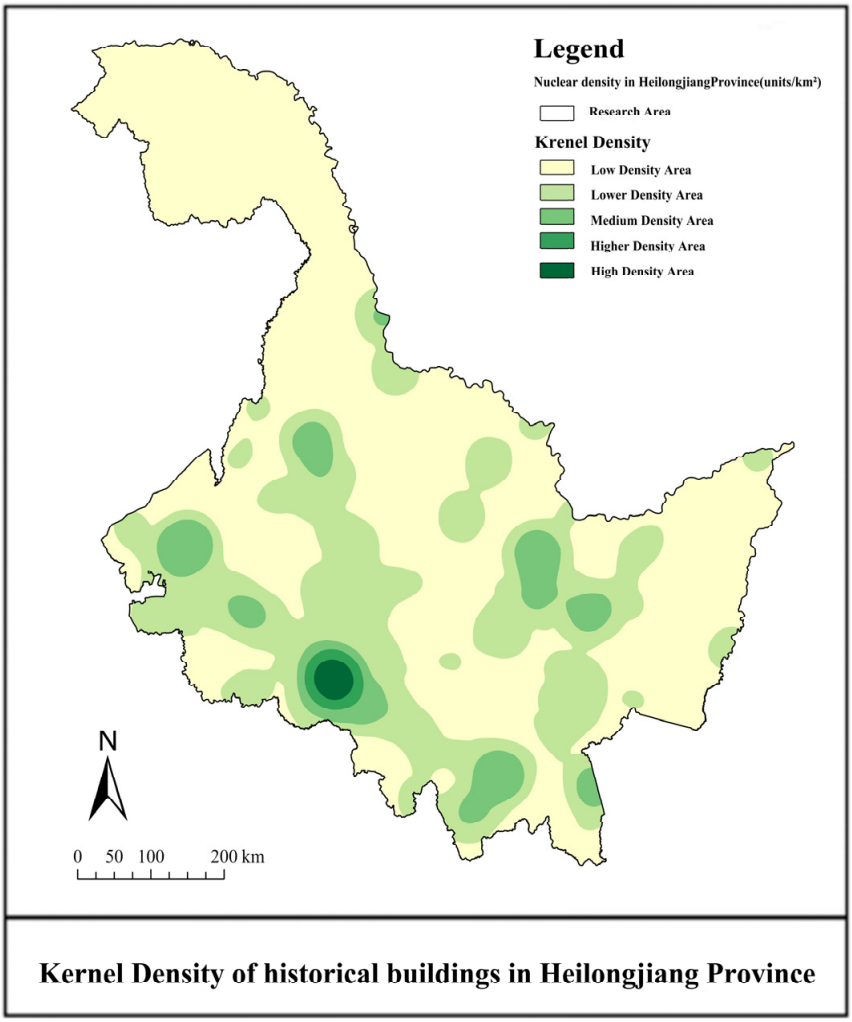


Figure 5. Results of kernel density analysis of historical buildings in Heilongjiang Province.

To quantify the density of historical buildings across prefecture-level cities, the number of historical buildings per unit area was calculated. The density ranking from high to low was as follows: Harbin > Mudanjiang > Hegang = Qiqihar > Daqing > Qitaihe = Suihua > Shuangyashan = Jiamusi > Yichun > Jixi = Heihe (Table 4).

Table 4. The average floor area of historical buildings in each city.

Prefecture-Level City	Total Area km^2	Buildings (No.)	Historical Buildings per km^2 (Average)
Harbin	53,100	298	0.0056
Daqing City	21,204.88	46	0.0022
Hegang	14,684	40	0.0027
Jixi	22,500	28	0.0012
Mudanjiang	40,600	119	0.0029
Qitaihe	6221	13	0.0021
Qiqihar	42,469	116	0.0027
Shuangyashan	22,050	39	0.0018
Suihua	35,000	75	0.0021
Yichun	32,800	43	0.0013
Jiamusi	32,460	57	0.0018
Heihe	68,726	80	0.0012

In summary, historical buildings in Heilongjiang Province exhibit a highly clustered spatial pattern, forming a multi-level clustering system centered on Harbin. This distribution is influenced by natural geography, transportation accessibility, economic development, and historical–cultural factors. Clustering zones are typically characterized by flat terrain, abundant water resources, convenient transportation, and rich historical–cultural heritage.

4.2. Comprehensive Resistance Cost Surface and Suitability Zoning

4.2.1. Analysis of the Comprehensive Resistance Surface

From the perspective of cultural ecology, this study emphasizes the need for historical building heritage to achieve coordinated interactions and symbiotic development between cultural preservation and the natural environment, thereby promoting the continuous inheritance of regional culture and the optimization of spatial systems [49]. In constructing the heritage corridor of historical buildings, spatial factors influencing accessibility were comprehensively considered. Key resistance factors were selected from three dimensions—natural environment, socioeconomic conditions, and public services—including elevation, land use types (construction land, unused land, cultivated land, grassland, shrubland, water bodies, wetlands, and forest land), slope, distance to rivers, road accessibility (distance to railways, national highways, provincial highways, and county roads), and the density of dining and accommodation services [50].

To ensure the scientific and regionally adaptive construction of the resistance surface, 27 experts from architecture, urban planning, landscape architecture, and human geography were invited to systematically score the resistance levels of these factors based on Heilongjiang Province's geographical characteristics and infrastructure status. The entropy method was used for weighting (Table 5). The weighting results indicate that natural factors such as elevation, slope, forest land, and water bodies generally exhibit higher resistance, while infrastructure factors like road accessibility, accommodation, and dining services show relatively lower resistance.

Table 5. Resistance classification and resistance value of each basic resistance surface.

Typology	Resistance Factor	Weight	Resistance Value				
			1	2	3	4	5
Environment	Elevation (m)	12.9	0–100	100–200	200–300	300–500	>500
	Land use	12.7	Construction land and unused land	Cultivated land	Grassland and shrubs	Water bodies and wetland	Woodland
	Slope (°)	24.3	0–3	3–5	5–10	10–20	>20
Economy	Distance from river (km^2)	7.05	>20	10–20	5–10	1–5	0–1
	Railway distance (km^2)	8.54	0–10	10–20	20–40	40–60	>60
	National highway distance (km^2)	7.21	0–5	5–10	10–20	20–40	>40
	Provincial highway distance (km^2)	10.2	0–5	5–10	10–20	20–40	>40
	County road distance (km^2)	6.51	0–5	5–10	10–20	20–40	>40
Public service	Food and beverages (n/km^2)	5.97	>2	0.5–2	0.05–0.5	0.01–0.05	0–0.001
	Accommodation service (n/km^2)	4.6	>0.5	0.1–0.5	0.05–0.1	0.01–0.05	0–0.001

Specifically, from the natural environment perspective, regions with higher elevation, steeper slopes, and greater terrain undulation exhibit poorer accessibility and higher resistance. Areas with lower ecological sensitivity (e.g., low-coverage regions) are more suitable for setting heritage nodes and transit service points. The resistance values of land use types are determined based on the convenience of potential users' rest and transit activities, with higher convenience corresponding to lower resistance. Areas closer to water sources exhibit higher resistance due to increased ecological protection sensitivity.

In the socioeconomic dimension, the completeness of the road transportation system directly determines the accessibility of historical buildings and the continuity of the corridor network. Regions closer to roads exhibit stronger accessibility and lower resistance. Considering the differences in traffic capacity among road grades, the resistance settings were refined for national highways, provincial highways, and county roads.

In the public service dimension, the spatial distribution of dining and accommodation facilities significantly influences the stopping and transit behaviors of cultural visitors. This study collected POI data from related services within the study area and identified regions with strong service capabilities based on their spatial kernel density distribution, assigning them lower resistance values [51] (Figure 6).

Subsequent interviews with scoring experts revealed that these results reflect the uniqueness of Heilongjiang Province's geographical and developmental patterns. Although kernel density analysis indicates the pronounced clustering of historical buildings, their clustering morphology does not rely on natural resources such as cultivated land and water systems, differing significantly from traditional villages in southern China. Traditional villages in southern China are often established based on cultivated land and water systems, where natural factors exhibit relatively lower resistance to accessibility. In contrast, the distribution of historical buildings in Heilongjiang Province is more influenced by urbanization, foreign trade, and military layouts during specific historical periods rather than natural environments or basic survival needs. Conversely, due to the vast territory of Heilongjiang Province, particularly in its northern and border regions, complex natural landscapes, extensive forest land and water bodies, and significant slope undulation, coupled with relatively insufficient road infrastructure, constrain spatial accessibility and path selection between heritage sites. Thus, natural factors exert more significant resistance on heritage corridor paths, while areas with dense transportation and service facilities exhibit lower resistance levels due to their stronger connectivity and support capabilities.

Based on the above findings, this study constructed the comprehensive resistance surface by assigning high resistance levels to natural factors such as forest land, water bodies, elevation, and slope, accurately reflecting their constraints on actual accessibility and cost control. Conversely, artificial surfaces, construction land, and areas with good road accessibility were assigned low resistance levels, highlighting their relatively superior construction feasibility and resource integration advantages. This allocation strategy effectively leverages existing infrastructure resources while prioritizing ecological protection, thereby minimizing environmental damage from corridor construction.

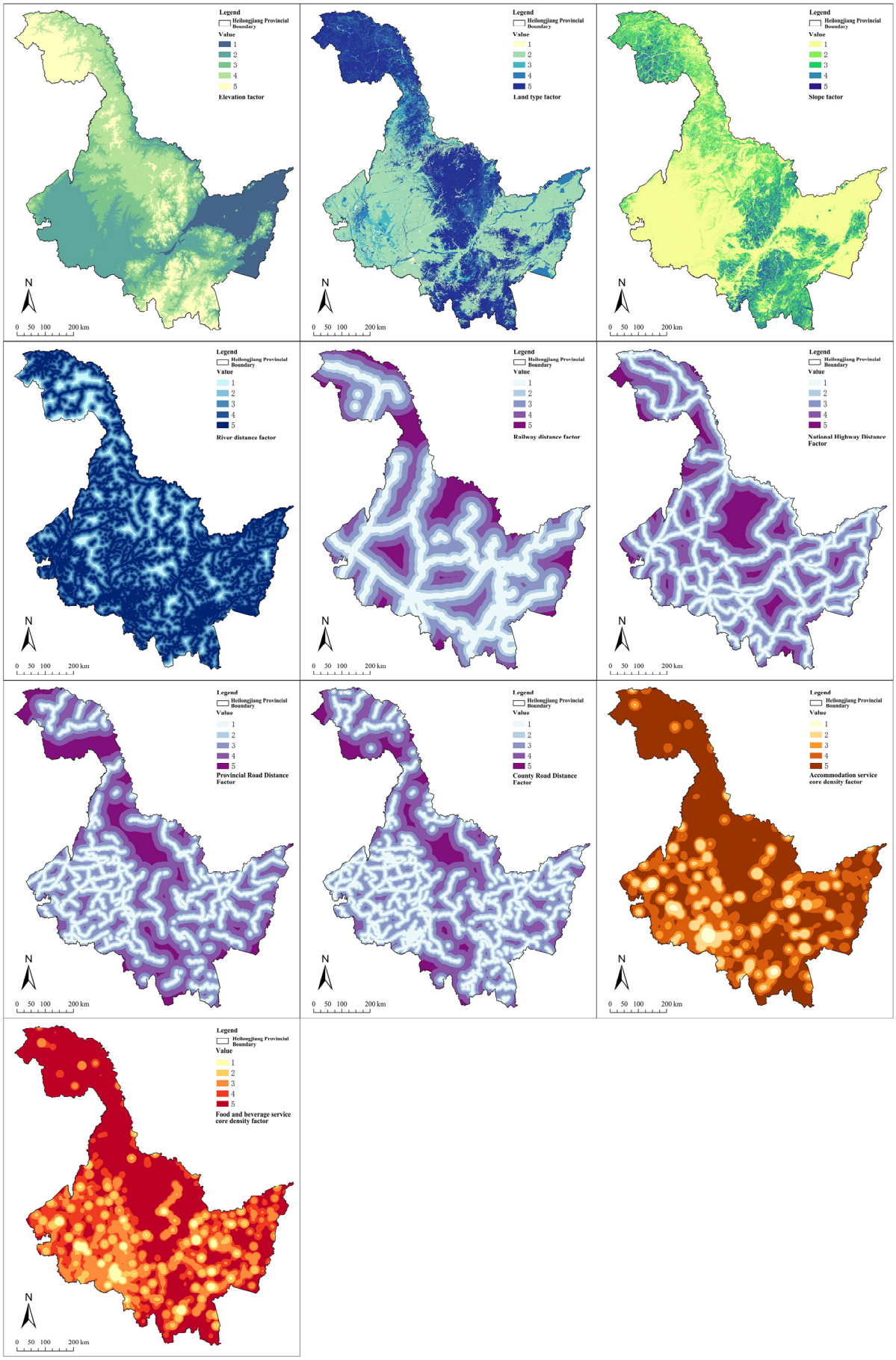


Figure 6. The surface of each resistor.

Finally, the resistance factors were overlaid to generate the comprehensive resistance surface for historical building heritage in Heilongjiang Province (Figure 7). Overall, the northern, central, and southern regions of Heilongjiang Province exhibit higher resistance values, while the western and eastern regions show lower resistance values.

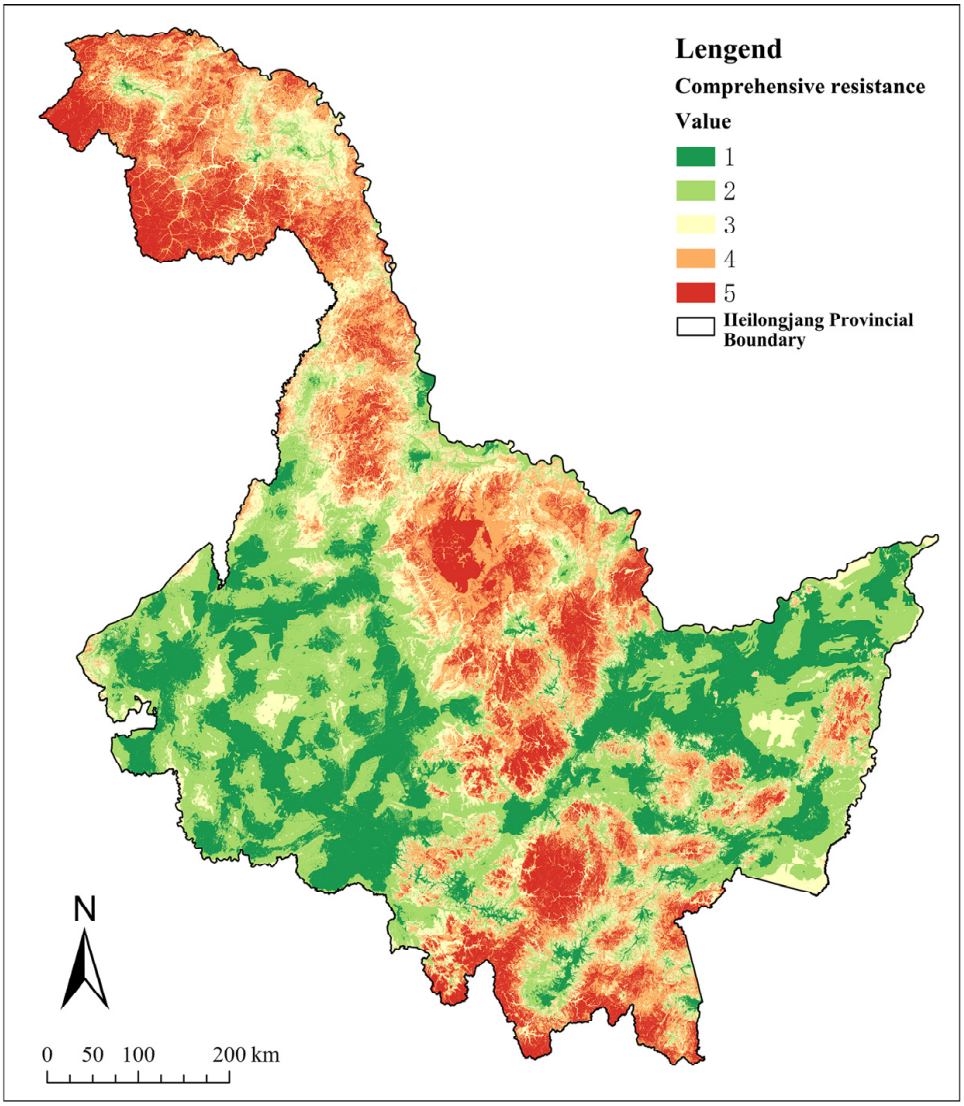


Figure 7. Comprehensive resistance surface.

4.2.2. Suitability Zoning Results

Based on the constructed comprehensive resistance surface, the resistance data were imported into GIS, and the Jenks natural breaks classification method was applied to spatially classify the suitability of historical building heritage in Heilongjiang Province. Five suitability zones were delineated: "High Suitability, Moderately High Suitability, Medium Suitability, Moderately Low Suitability, and Low Suitability." These zones are represented by dark green, light green, yellow, light red, and red, respectively, forming a suitability distribution map across the province (Figure 8).

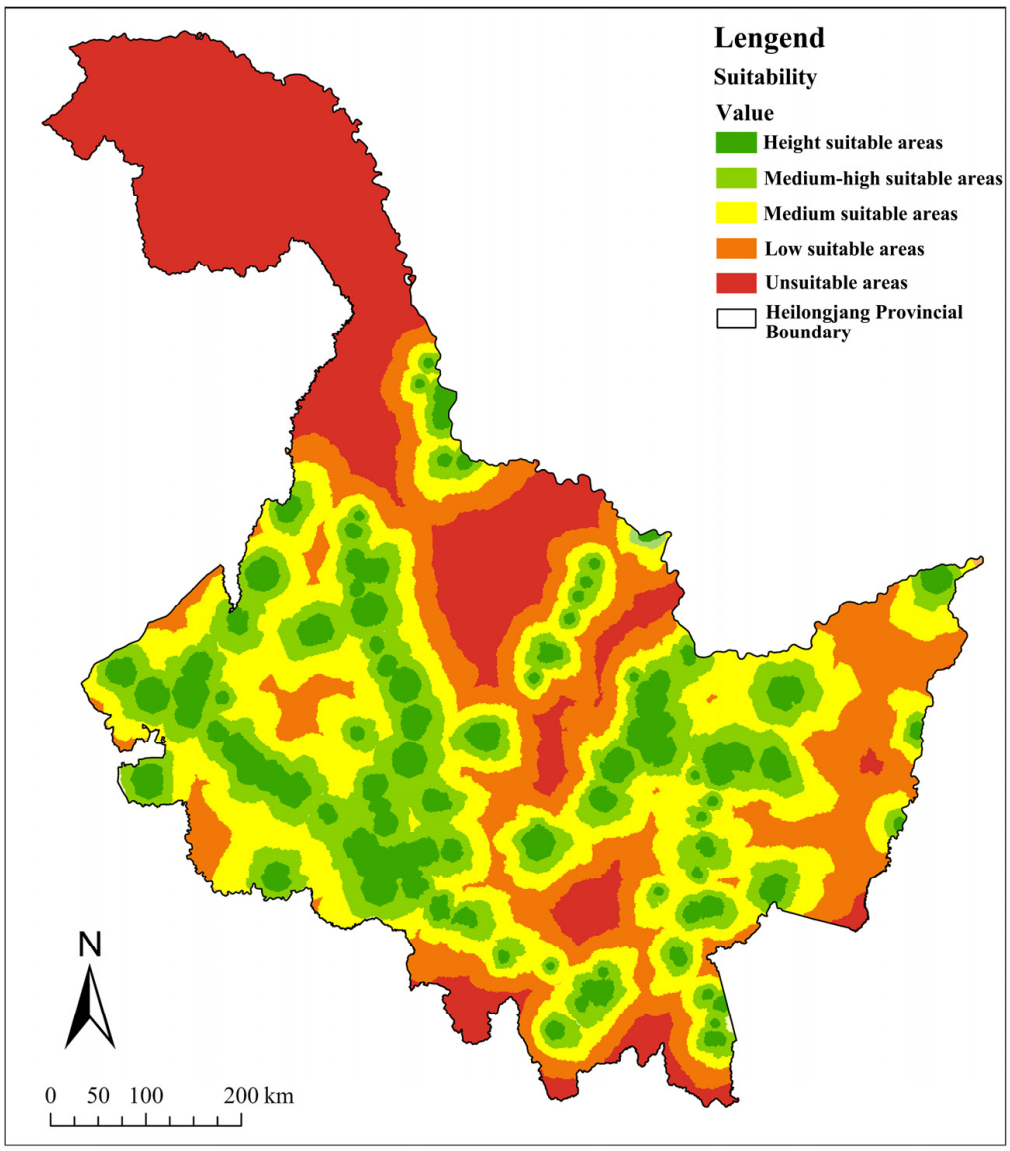


Figure 8. Suitability analysis.

The analysis reveals that the highly suitable and moderately high suitability zones are primarily located in the central and southern parts of Heilongjiang Province, encompassing cities such as Harbin, Qiqihar, Mudanjiang, southern Heihe, southeastern Hegang, southwestern Jiamusi, Shuangyashan, and northern Daqing. These areas generally feature flat terrain, well-developed transportation, and comprehensive infrastructure, with strong cultural service support capabilities, providing inherent advantages for constructing heritage corridors. Notably, the region between Harbin, Mudanjiang, and Qiqihar not only represents the most concentrated area of historical building resources but also has a high level of existing cultural tourism development. Therefore, these areas should be prioritized as key zones for heritage corridor construction, with their integration into the spatial planning of main routes and core stations.

The medium-suitability zones are mostly transitional areas between highly-suitability and low-suitability zones. They are distributed in a ring-like or transitional pattern, often located on the outskirts of small and medium-sized cities or around regional node towns. These areas exhibit moderate accessibility and potential resource allocation, serving as crucial transitional bridges for constructing secondary corridors to connect core areas with peripheral regions. By rationally planning auxiliary corridors in these zones, the connectiv-

ity and coverage of the entire corridor system can be effectively enhanced, extending the spatial reach of cultural dissemination.

The moderately low-suitability and low-suitability zones are mainly concentrated in the northern and eastern remote areas of Heilongjiang Province, such as the Greater Khingan Mountains, southeastern Heihe, Qitaihe, and some hilly regions. These areas are characterized by significant terrain undulation, poor transportation, weak infrastructure, low population density, and high corridor operation costs, making them unsuitable for primary corridor development. However, it is noteworthy that these regions are home to scattered ethnic settlements with potential cultural value. Therefore, a balanced approach should be adopted to establish reasonable development goals.

4.3. Corridor Network Generation Results

4.3.1. Source Classification

Before generating the heritage corridor network, it is essential to classify the hierarchical structure of "sources." Given the non-uniform spatial clustering of historical buildings and the significant differences in cultural value, node density, and accessibility across regions, the scientific classification of "sources" is necessary to support the hierarchical construction and network organization of subsequent corridor paths [52]. This study employs a combination of kernel density analysis (threshold adjustment method) and local peak extraction to classify "sources," ultimately identifying three levels: provincial-, municipal-, and district-level sources.

Kernel density analysis is used to quantify the spatial clustering of historical buildings and classify "sources" by setting different density thresholds. Experiments reveal that variations in kernel density thresholds directly affect the number and spatial coverage of identified "sources," indirectly influencing corridor length, quantity, and network density [53]. Specifically, higher density thresholds extract "sources" primarily concentrated in core areas with high building density, rich cultural resources, and strong node integration, suitable as provincial "sources" for constructing main corridors. Lower thresholds identify relatively dispersed, smaller-scale yet culturally significant clusters. These are appropriate municipal "sources" that can be embedded into secondary corridor systems [54]. This kernel density-based classification strategy follows a spatial hierarchy from dense to sparse and core to periphery, facilitating the gradient identification and hierarchical control of "source" nodes.

However, kernel density analysis has limitations, particularly in edge regions with minor density differences, where "blurred boundaries" or the omission of key nodes may occur. To address this, the study introduces local peak extraction to assist in identifying micro-cluster centers with relatively prominent features under low thresholds [55]. This method supplements kernel density analysis by extracting local maxima from the density surface, identifying small-scale yet culturally representative sources or "sources" of transportation hub potential.

In practice, raster data such as digital elevation models (DEMs) or vegetation coverage are imported into GIS, and appropriate data types are selected based on research objectives. Using the "Focal Statistics" tool in the "Spatial Analyst" module, a neighborhood range is defined, and "maximum" is selected as the statistical type to calculate the maximum value within each pixel's neighborhood. In the analysis results, if a pixel's value equals its neighborhood maximum, it is considered a potential local peak. After overlaying analysis and filtering points that do not meet attribute and spatial conditions based on the study area's context, the retained local peaks are identified as district-level "sources." This method compensates for the insufficient precision of kernel density analysis in low-density

regions, enhancing the completeness and spatial adaptability of "source" classification and providing critical support for constructing a multi-level heritage corridor network.

Through the integration of these two methods, 9 provincial, 31 municipal, and 108 district-level sources were ultimately extracted (Figure 9).

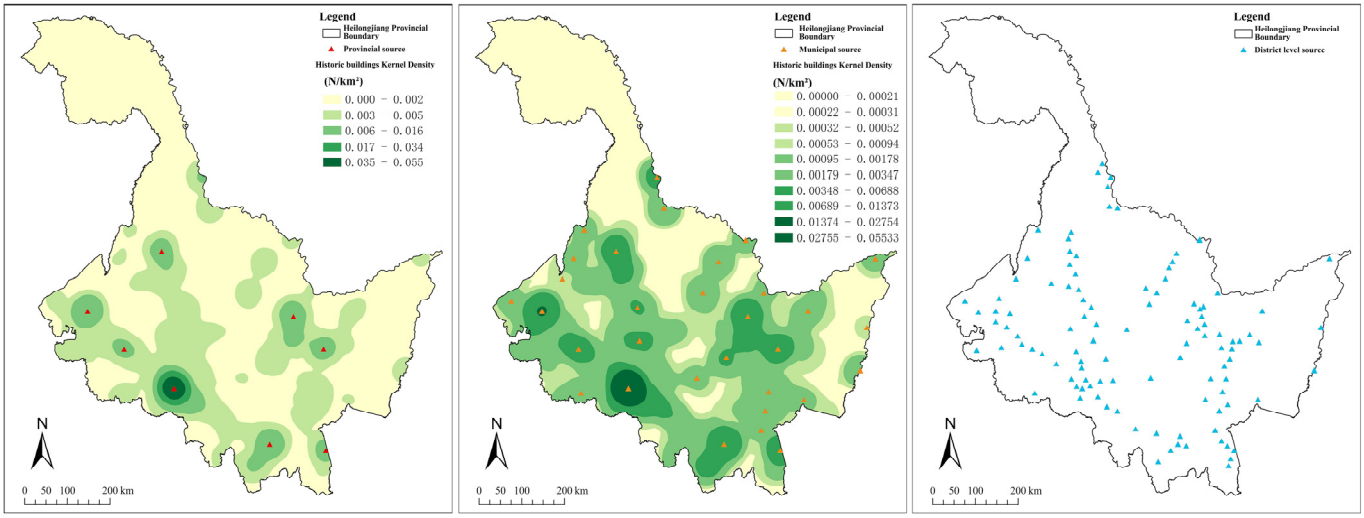


Figure 9. Source classification.

4.3.2. Corridor Generation Results

Based on the completion of source classification and the construction of the comprehensive resistance surface, this study further introduces circuit theory to simulate and generate heritage corridor paths. By analogizing the diffusion of electric current in a conductor, circuit theory treats historical building nodes as "current sources" and the comprehensive resistance surface as "resistive media." Using indicators such as voltage and current density, it spatially identifies the optimal paths between multiple "sources." In practice, the study utilizes the Build Network and Map Linkages modules within the LM plugin on the GIS platform. This involves inputting the classified provincial, municipal, and district-level "source" data and the resistance raster surface into the model for simulation, generating a potential heritage corridor network across the entire region.

A total of 401 corridors were identified and categorized into three levels: provincial-, municipal-, and district-level. Among them, 307 district-level corridors form a widespread supporting network; 81 municipal corridors establish regional interconnections; and only 13 provincial corridors, with an average length of 211.7 km, serve as the core backbone of the corridor system (Table 6).

Table 6. Statistical table of heritage corridors at all levels.

Level	Road Classification	Number of Corridors	Average Minimum Path Length	Average Current Flow Betweenness Centrality
1	County Road	307	100,936.04234527687	−1.0
2	Municipal Road	81	175,527.9012345679	
3	Provincial Road	13	211,725.53846153847	−1.0

From a spatial distribution perspective, the generated corridor system exhibits a "multi-center–multi-node–multi-channel" structural pattern. Harbin, Mudanjiang, and Qiqihar form typical backbone network hubs, with provincial corridors primarily concentrated around these areas of dense historical buildings, characterized by high connection density, wide paths, and stable network structures. Municipal corridors serve to connect the

main corridors with surrounding secondary nodes, while district-level corridors enhance the linkage of local micro-scale cultural nodes, improving the network's edge coverage (Figure 10).

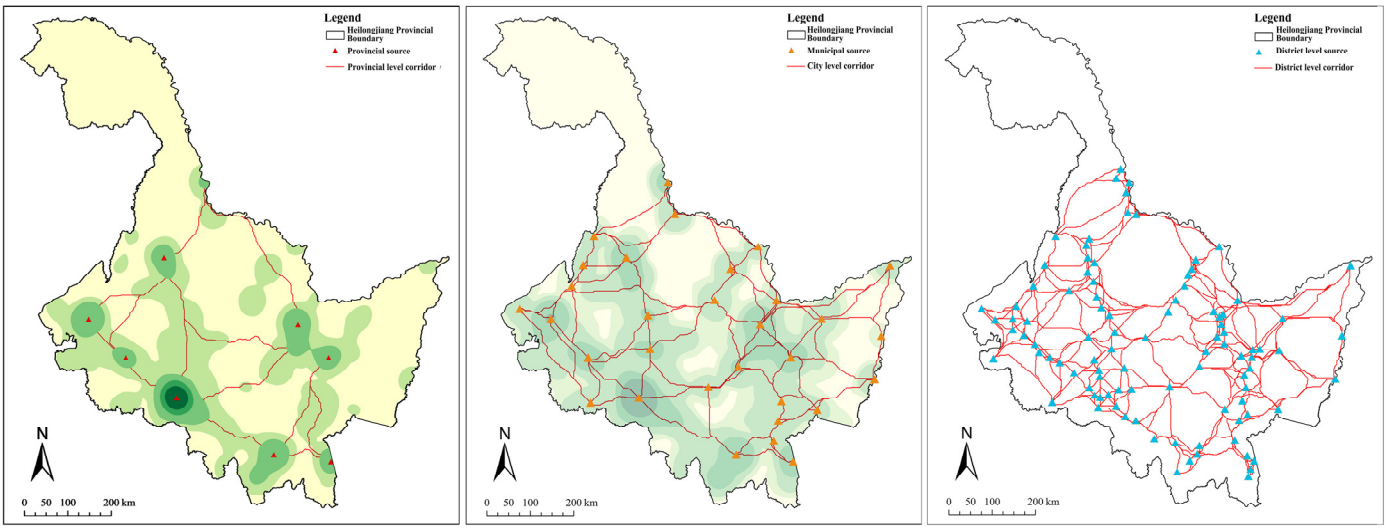


Figure 10. Classification of corridors.

Additionally, the network is densely structured with clear branches in the southern region. It aligns well with areas of high historical building density and major transportation routes, demonstrating strong adaptability and cultural accessibility. In contrast, in the northern and topographically complex peripheral areas, ecological constraints have led to interruptions or dispersion in some corridor paths.

Compared to the conventional Least-Cost Path (LCP) model, which typically generates a single, deterministic route, circuit theory offers a probabilistic multipath framework that better reflects the real-world dynamics of cultural transmission. Its inherent capacity for redundancy allows the system to maintain connectivity even if certain nodes or paths become disrupted. In the context of heritage corridor planning, this redundancy not only helps prevent systemic failure due to the loss of individual links but also facilitates multipoint dissemination and the decentralized diffusion of cultural resources.

In summary, the heritage corridor network constructed using circuit theory not only fully responds to the hierarchical characteristics and spatial distribution patterns of the sources but also effectively enhances the system's integrity and multipath redundancy capabilities, laying a foundation for the subsequent identification of key areas and optimization of node layouts.

4.3.3. Identification of Key Corridor Areas and Extraction of Relay Stations

Given the vast territory, complex topography, and uneven regional development levels of Heilongjiang Province, significant differences in natural conditions and infrastructure exist across different areas. This heterogeneity directly impacts the accessibility and cost distribution of heritage corridor construction. To further enhance system efficiency and ensure convenience for rest and transfer during cultural experiences, this study, based on the circuit theory model, identifies key circulation areas and high-accessibility nodes within the corridor network using current density, thereby determining the locations of heritage corridor relay stations.

Circuit theory emphasizes the simulation of the diffusion of "current" across the comprehensive resistance surface. Within this framework, areas with lower resistance values and higher path accessibility exhibit higher "current density," indicating greater

circulation potential and aggregation capacity in space. Thus, current density not only reflects the likelihood of path selection but also predicts the probability distribution of cultural travelers stopping or transferring along paths, providing a quantitative basis for relay station siting.

In practice, the study utilizes the Pinchpoint Mapper tool in the LM plugin on the GIS platform, inputting the constructed historical building "sources" and the comprehensive resistance surface raster. Through the "All-to-One" mode, a regional current density distribution map is generated. The results reveal that high-current-density areas are concentrated at typical path intersections, such as Harbin–Hegang, Daqing–Qiqihar, southern Heihe–northern Heihe, Heihe–Hegang, Harbin–Mudanjiang, western Mudanjiang–eastern Mudanjiang, and Mudanjiang–Shuangyashan. These areas are both high-density clusters of cultural node resources and cross-accessibility zones between multi-level "sources". They combine transit potential with service demand, making them priority locations for relay stations.

Building on this, the study captures current density peaks along different corridors based on the raster data, forming relay station nodes at various levels (Figure 11). Specifically, relay stations are categorized into three levels—primary (regional hubs), secondary (transfer points), and tertiary (endpoint supply)—constructing a functionally hierarchical, service-precise, and highly accessible relay station system. This system alleviates traffic pressure on main paths, provides multi-level services for tourists, optimizes transfer and rest processes, and enhances the operational efficiency of heritage corridors.

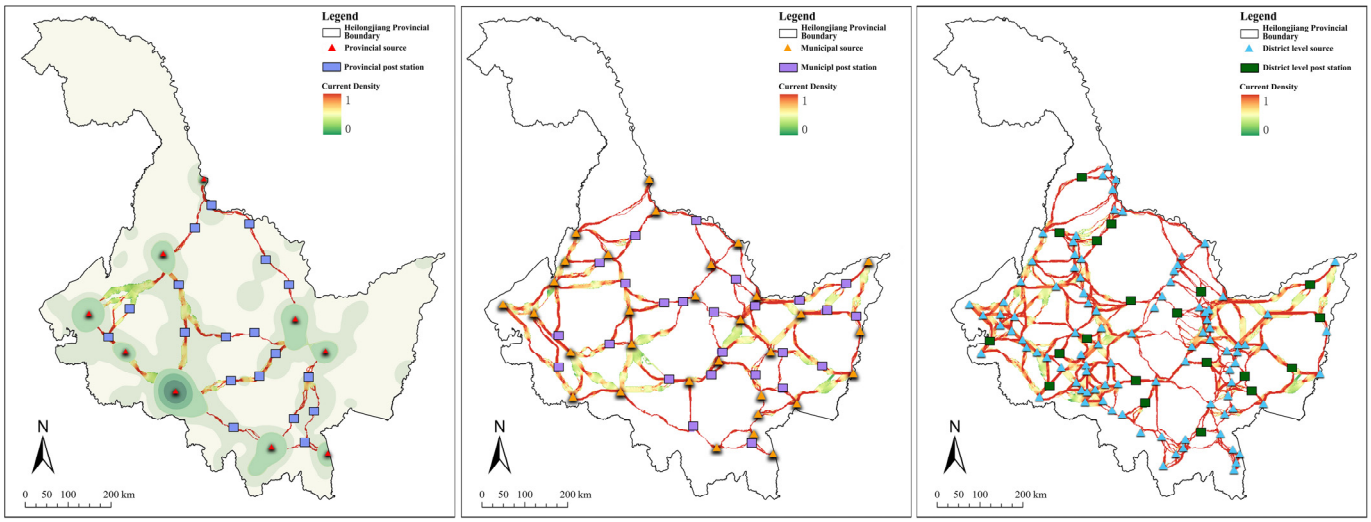


Figure 11. Current density map of the corridor.

4.4. Connectivity Verification of Corridors

After the construction of the corridor network, this study employs three key metrics from network structure analysis—α index (cyclomatic number), β index (line-point ratio), and γ index (connectivity index)—to verify the connectivity of the historical building heritage corridor network in Heilongjiang Province, assessing both the overall structural complexity and accessibility.

The calculation results of the indices are as follows: $\alpha = 0.872852$, $\beta = 5.418918$, and $\gamma = 0.915525$. The α value of 0.872852, ranging between 0 and 1 and approaching 1, indicates the presence of numerous circular connection paths within the heritage corridor system. This suggests a closed network structure that effectively mitigates single-path dependency issues, enhancing the system's redundancy and resilience in the event of node degradation. The β value of 5.418918, which exceeds 3 and is significantly higher than

the theoretical "ideal grid structure" threshold, demonstrates that the heritage corridor network has a far greater number of connections than the minimum required standard. This reflects a high level of complexity and branching within the overall network, indicating extensive redundant connections and interactive nodes across different hierarchical paths in Heilongjiang Province's heritage corridor system, with a well-organized and functionally differentiated network. The γ value of 0.915525, close to 1, indicates that the actual number of connections in the network is nearing the theoretical maximum possible, with high coverage and balanced node connectivity. This results in excellent overall accessibility that meets the requirements for regional heritage resource integration and cultural transmission (Table 7).

Table 7. Corridor connectivity verification index.

Index	Edges	Nodes	Actual Number of Loops/Maximum Possible	α Value	β Value	Maximum Possible Number of Connections	γ Value
1	401	148	252/288	0.872852			
2	401	148			5.418918		
3	401	148				10,878	0.915525

In summary, the verification results demonstrate that the historical building heritage corridor system in Heilongjiang Province has established a multipath, high-coverage, and strongly connected spatial network. The network structure exhibits good closure and accessibility, supporting the systematic development of future heritage conservation and cultural tourism. Additionally, the hierarchical connections in the three-level corridor system (provincial, municipal, and district) are clear, forming a multi-level accessibility system from main corridors to edge extensions. This ensures the accessibility of core resources while also effectively connecting peripheral heritage nodes.

5. Discussion

5.1. Analysis of Heilongjiang's Architectural Heritage Corridor Pattern

5.1.1. Potential Relationship Between Corridor Patterns and Historical Culture

The kernel density analysis and corridor network construction of historical buildings in Heilongjiang Province reveal a relatively clear "one horizontal, three vertical" main structure (Figure 12). The horizontal axis extends from Qiqihar in the west, through Harbin, to Suifenhe in the east, forming the province's primary east–west cultural corridor. The three vertical axes run along Qiqihar–Heihe, Harbin–Heihe, and Mudanjiang–Luobei, establishing north–south heritage accessibility paths. Notably, the nodes between Qiqihar, Harbin, and Wudalianchi form a stable triangular pattern, facilitating regional cultural exchange networks.

This study further compares the spatial structure described above with the historical and cultural development axes of Heilongjiang Province. The analysis reveals that the "one horizontal" main corridor aligns closely with the modern China Eastern Railway, highlighting the dominant influence of railway transportation on the distribution of historical buildings. Meanwhile, the "three vertical" branches extend into multiple ethnic minority regions, forming a high degree of coupling with the distribution of ethnic cultures. This "mainline–branchline" spatial pattern can be summarized as a cultural network structure with "railways as the backbone and ethnic groups as the wings," reflecting the dual nesting characteristics of the historical building corridor system between modern transportation influences and ethnic cultural spaces.

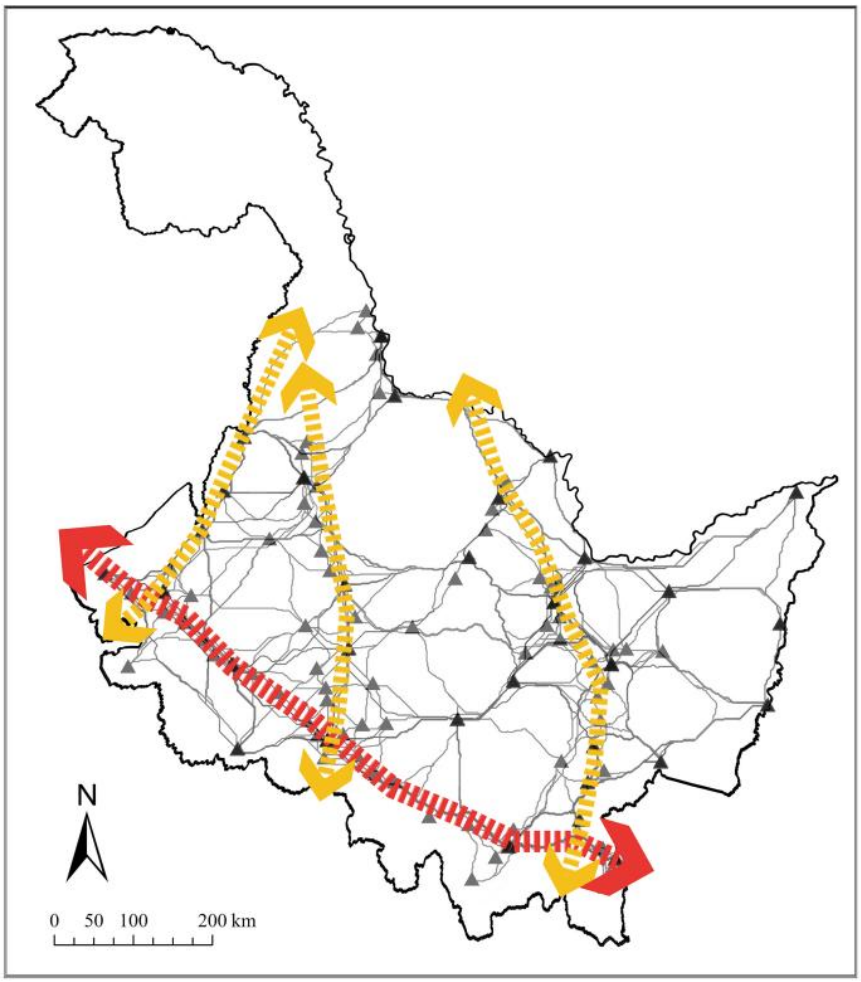


Figure 12. The "one horizontal and three verticals" pattern of Heilongjiang historical heritage corridors.

(1) Relationship with the China Eastern Railway Culture

The overlay of historical building kernel density analysis and the China Eastern Railway routes shows that Heilongjiang's heritage corridor system is highly integrated with the railway, forming a "cultural main axis" centered on Harbin, extending westward to Qiqihar and eastward through Mudanjiang to Suifenhe (Figure 13). As a key hub along the railway, Harbin accumulated a significant number of historical buildings with Russian and Sino-Western architectural styles during the modern era of Sino-Russian cultural exchange, trade, and industrial development. Harbin exhibits the highest kernel density (0.035–0.055 units/km^2) in the analysis, serving as the primary "source" in the corridor network. Additionally, cities along the railway, such as Anda, Shangzhi, Muling, and Suifenhe, have formed distinct secondary clusters, becoming important components of municipal and district-level corridors.

This pattern indicates that the China Eastern Railway not only served as a transportation artery but also played a pivotal role as a "heritage transmission axis" in the cultural space. The corridor system naturally developed along the railway, demonstrating a high degree of synergy between the spatial distribution of historical buildings and the cultural transmission mechanisms of the railway. Furthermore, certain cultural nodes (e.g., Muling, Hailin, Suifenha), despite their remote locations, exhibit high current density and corridor connectivity due to railway access, functioning as significant "bridges" for cultural transmission in the circuit model simulation.

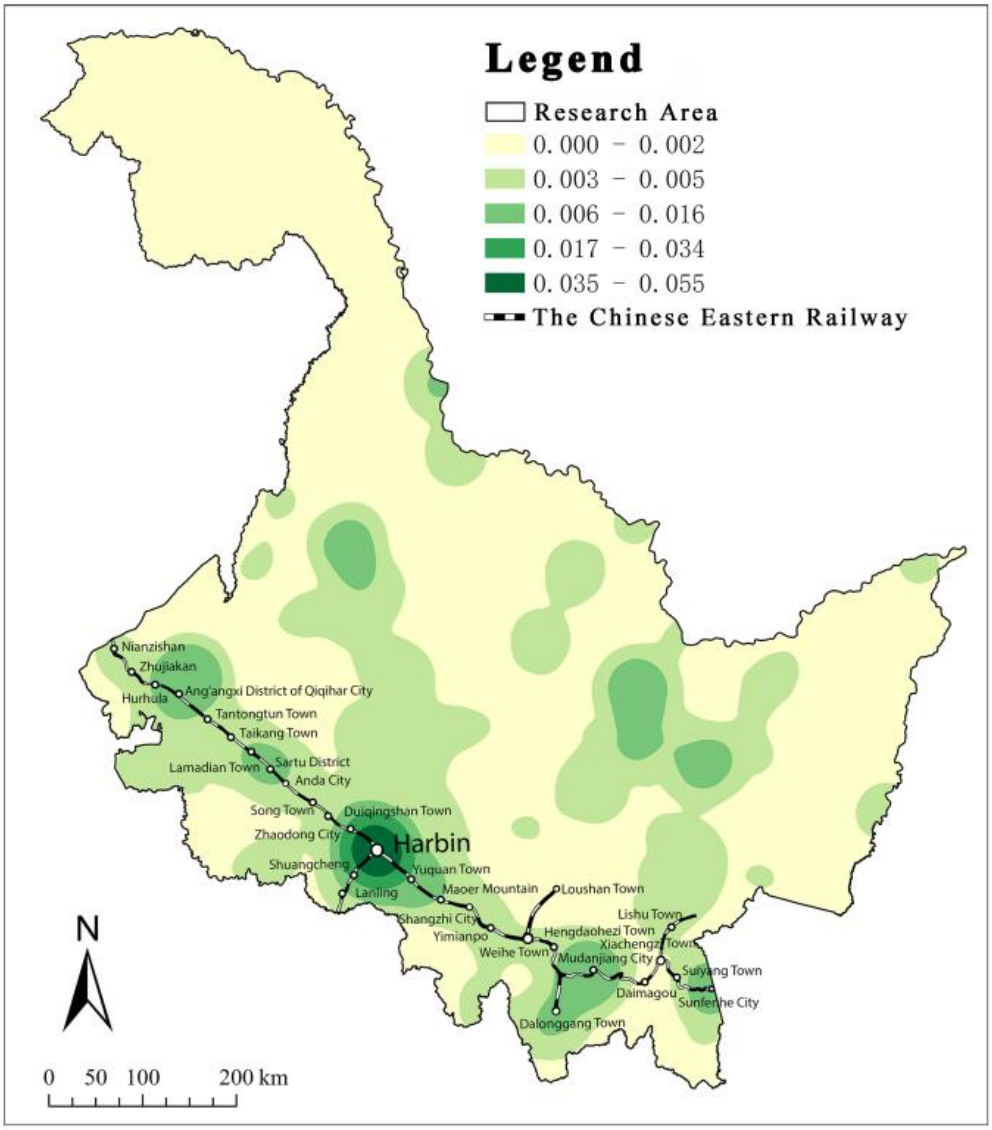


Figure 13. Overlay comparison of kernel density and China's eastern railway routes.

(2) Relationship with Multi-Ethnic Cultures

The "three vertical" corridor structure of Heilongjiang's historical buildings extends into multi-ethnicity regions, connecting historical building nodes while aligning closely with the spatial distribution of ethnic cultures (Figure 14).

The first vertical axis, the Harbin–Heihe corridor, traverses Suihua, Hailun, and Bei'an, covering areas inhabited by the Manchu, Daur, and Oroqen ethnic groups. Extending further to Xunke and Jiayin, this corridor not only serves as a border opening zone but also functions as a hub for border management and ethnic cultural transmission. Although its kernel density is lower than that of the horizontal axis, it acts as a crucial cultural intermediary in the current density simulation.

The second vertical axis runs northward from Mudanjiang through Hailin, Muling, Jixi, Jiamusi, and Shuangyashan to Luobei, corresponding to areas densely populated by the Korean, Manchu, and Xibe ethnic groups. This corridor includes 19 Korean ethnic townships and features heritage sites such as the Muling Anti-Japanese Allied Forces Site, Mishan Revolutionary Site, Hulin Border Buildings, and Korean folk residences, showcasing distinct ethnic characteristics and wartime historical memory. Extending to surrounding areas like Mishan, Baoqing, Jidong, and Jixi, although not prominent in

traditional building density, its cultural transmission function is significantly amplified by railways, highways, and regional transportation hubs, making it a key node in the current "cultural transmission line."

The third vertical axis, the Qiqihar–Nenjiang–Heihe corridor, covers regions inhabited by the Xibe, Hui, and Mongolian ethnic groups. Qiqihar and its surrounding areas, such as Fuyu, Keshan, and the Meilisi Daur District, are typical zones of ethnic autonomy and cultural integration, with railways and highways forming a strong transportation corridor.

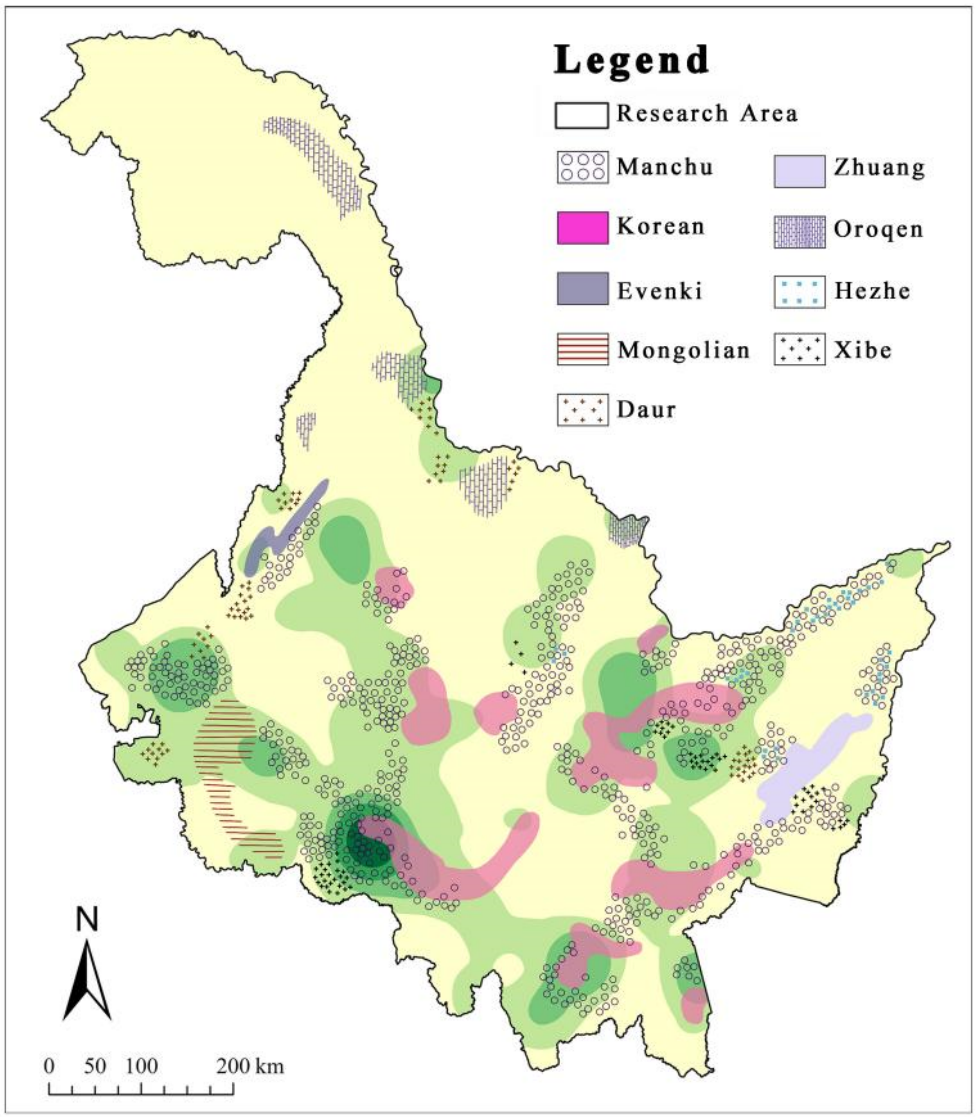


Figure 14. Overlay comparison of kernel density and ethnic distribution.

In summary, the formation of heritage corridors not only reflects the evolution of modern cities in Heilongjiang but also embodies the spatial reorganization of multi-ethnic cultural patterns. Additionally, the corridors integrate frontier culture, industrial heritage, and revolutionary memory into a unified network, enhancing the cultural diversity and boundary extensibility of the heritage corridor system.

5.1.2. Potential Relationship Between Heritage Corridor Patterns and Ecological Patterns

In the cultural heritage corridor network constructed for Heilongjiang Province in this study, ecological factors were considered as critical spatial variables influencing corridor generation paths. By setting ecologically sensitive areas such as natural forests, water

bodies, wetlands, and ecological redlines as high-resistance factors, the cultural corridors demonstrated the active avoidance of ecological patterns during spatial simulation, resulting in an ecologically compatible spatial layout. This spatial effect was not only theoretically predicted in the model design but also empirically validated in the simulation results.

The analysis of the corridor network current density distribution and the comprehensive ecological resistance surface reveals that key natural conservation areas, such as the Greater Khingan Mountains, Yichun Forest Region, and Heihe River wetlands, predominantly fall into "low-access zones" or "current blank zones" in corridor generation. This "avoidance outcome" is a spatially adaptive process driven by the ecological resistance settings in the model, indicating that methods for the construction of cultural corridor systems can simultaneously perceive and avoid ecological spaces. This further underscores the inherent compatibility of the proposed methodology with ecological conservation.

5.2. Identification of Gaps and Repair Strategies for Heilongjiang's Heritage Corridor Network

Building on the constructed historical building heritage corridor network of Heilongjiang Province, this study further compares the corridor network with the current railway and highway networks. The comparison reveals that while there is significant overlap between heritage corridors and transportation networks, enabling effective resource utilization, there are also notable disconnections and misalignments in multiple regions. These issues manifest as weak transportation support in high-density corridor areas, insufficient connections between cultural hubs, and service gaps in peripheral regions. Therefore, it is necessary to propose targeted network repair strategies from a multi-level corridor system perspective to enhance the overall connectivity, accessibility, and operational efficiency of the system.

5.2.1. Gaps in Primary Corridors and Integration with High-Speed Railway Systems

Primary corridors, the backbone of the heritage corridor system, connect core source areas with high building density and significant cultural value, exhibiting significantly higher traffic demand (current density) than other levels. Overlay analysis of primary corridors and rail transit shows that some primary corridors already align well with existing high-speed railways, such as the Qiqihar–Daqing–Harbin–Mudanjiang–Suifenhe corridor and the Mudanjiang–Jixi–Jiamusi route, where high-speed rail effectively supports core cultural accessibility and complements heritage pathways. However, certain primary corridors fall outside current high-speed rail coverage, particularly the Jiamusi–Hegang–Wuyiling–Heihe section. Despite being a high-frequency cultural transmission zone in current density simulations, this area lacks adequate transportation infrastructure, with only a conventional railway connecting Jiamusi and Hegang and no direct highway connection from Yichun to Heihe (Figure 15).

Given its status as both a kernel density hotspot and a key northern hub in the cultural corridor, it is recommended to prioritize the Jiamusi–Hegang–Heihe section for future high-speed rail network optimization. Extending high-speed rail northward would enhance rapid response and support capabilities for heritage corridors, fostering deeper cultural and economic integration in the northern frontier region.



Figure 15. Overlay comparison of primary and secondary corridors with existing railway lines.

5.2.2. Gaps in Secondary Corridors and Coordination with Conventional Railway Networks

Secondary corridors, the intermediate layers of the heritage corridor systems, connect primary corridors with secondary nodes and expand cultural influence. While less concentrated than primary corridors, they play a critical role in "filling gaps" and "extending coverage." Comparison with railway networks shows that certain secondary corridors align well with existing railways, such as the Qiqihar–Nenjiang–Heihe axis, the Fuyu–Beian–Sunwu branch, the Shuangyashan–Tongjiang–Fuyuan route, and the Jiamusi–Yichun line, which largely meet the transportation needs at this level.

However, connectivity is notably limited in eastern and northern peripheral regions, with specific issues including the following: (1) the Youyi–Hulin–Baoqing corridor and Hulin–Fuyuan connection lack effective rail transit support, creating cultural transmission gaps; (2) cultural hubs like Wudalianchi and Yichun lack railway access, resulting in "breakpoints" in the corridor network; (3) there are incomplete rail connections in Beian–Yichun, Qing'an–Yichun, Nenjiang–Wudalianchi, and Shangzhi–Fangzhi. It is recommended to address these gaps by adding branch railways or introducing flexible transit solutions such as light rail or trams to enhance connectivity and node responsiveness in secondary corridors.

Notably, Wudalianchi, a core "source" cultural cluster, boasts a prime location and rich cultural resources but remains unconnected to any railway system, severely limiting its role as a hub in the corridor network. Renowned for its unique Cenozoic volcanic landscapes and mineral springs, Wudalianchi is a national and global geopark with significant natural and cultural value. It also preserves Soviet-era architecture, revolutionary memorials, and

regional ethnic settlements, combining natural and red tourism appeal. Given its dual heritage of geological and historical sites and its role as a convergence point for multiple northern cultural corridors, Wudalianchi should be prioritized for rail development. Establishing a circular cultural branch connecting Beian, Nenjiang, and Heihe would enhance its hub function and unlock its full cultural potential (Figure 15).

5.2.3. Gaps in Tertiary Corridors and Edge Repair Strategies with Highway Systems

Tertiary corridors primarily facilitate the fine-grained connection between historical building sites and the detailed linkage of regional cultural nodes. With extensive coverage and dispersed service targets, they rely on dense and flexible transportation systems. Overlay analysis of tertiary corridors and the existing highway network reveals that Heilongjiang's highway system is generally well-developed, providing "capillary-like" transportation support in most tertiary corridor areas and effectively connecting surrounding cultural heritage sites and small settlements.

However, several critical gaps hinder the accessibility of peripheral cultural nodes, such as (1) the Hegang–Wuying (Yichun) section, where low-grade roads and weak traffic capacity impede node interactions in the northern region, and (2) the Shuangyashan–Luobei area, where sparse road networks and poor traffic organization hinder the activation of corridor endpoints (Figure 16). It is recommended to prioritize the construction of county and township roads in these areas and enhance node connectivity. Additionally, introducing high-frequency cultural tourism bus routes would improve transportation accessibility for end-users and strengthen the "endpoint vitality" of cultural corridors.



Figure 16. Overlay comparison of tertiary corridors with existing road networks.

5.2.4. Optimization of Relay Nodes and Coupling with Transportation Facilities

In terms of relay node layout, this study extracted high-accessibility nodes through current density analysis, forming a three-tier relay system. Analysis of existing railway and highway nodes shows that some corridors already overlap with existing transportation hubs, allowing the direct utilization of current stations as cultural transfer platforms (e.g., Harbin Station, Mudanjiang Station, Jiamusi Station). However, in certain high-current density areas, such as Tieli–Yichun, Beian–Yichun, and Hegang–Wuyiling, the lack of matching transportation facilities limits the efficiency of cultural flow. It is recommended to use these high-current nodes as anchors to establish or upgrade corresponding transfer stations (e.g., tourism hubs, small transit stations) and integrate cultural display, rest, and service functions, creating a comprehensive relay system that combines transportation, culture, and services.

In summary, through the systematic comparison of heritage corridor generation results with the current transportation network and considering the travel choice hierarchy of "high-speed rail > express trains > conventional trains > cars > cycling > walking," this study proposes a multi-level network repair strategy based on the coupling of "primary corridors—high-speed rail," "secondary corridors—conventional rail," and "tertiary corridors—highways." This approach aims to establish an integrated coupling mechanism of "corridor level–transportation level–relay level," promoting the systematic optimization and integrated development of Heilongjiang's historical building heritage in terms of spatial structure, transportation support, and cultural transmission. At the same time, the proposed multi-level coupling strategy achieves a dynamic alignment between the functional capacity of heritage nodes and the strength of corridor flows, enabling the system to automatically adapt to the carrying limits of heritage sites. This mechanism effectively mitigates the risks of resource overexploitation and spatial congestion, thereby enhancing the overall resilience and sustainability of the network.

5.3. Overall Construction Strategy for Heilongjiang's Historical Heritage Corridors

5.3.1. Hierarchical Collaboration: Establishing a Clear and Functionally Complementary Network Governance Framework

Under the integrated framework of circuit theory and the minimum cumulative resistance (MCR) model, this study constructed the historical building heritage corridor network of Heilongjiang Province, forming a three-tier hierarchical system of "province–city–Ddistrict" (Table 8, Figure 17). This system not only reflects the spatial aggregation and transmission characteristics of cultural resources but also demonstrates the synergistic relationship between cultural value levels, physical accessibility, and node service radii.

Table 8. Characteristics of each level of corridor.

Level	Corresponding Source Area Level	Current Density Level	Path Length Characteristics	Main Functional Positioning
First level	Between provincial -level source areas	High (main channel)	Medium to long distance, laminar	Regional cultural main corridor
Second level	Between municipal -level source areas	Medium density	Medium to short distance, supplementary line	Regional secondary connecting corridor
Third level	District-level source areas and micro-nodes	Low (branch channel)	Short distance, terminal node	Micro-cultural extension passage

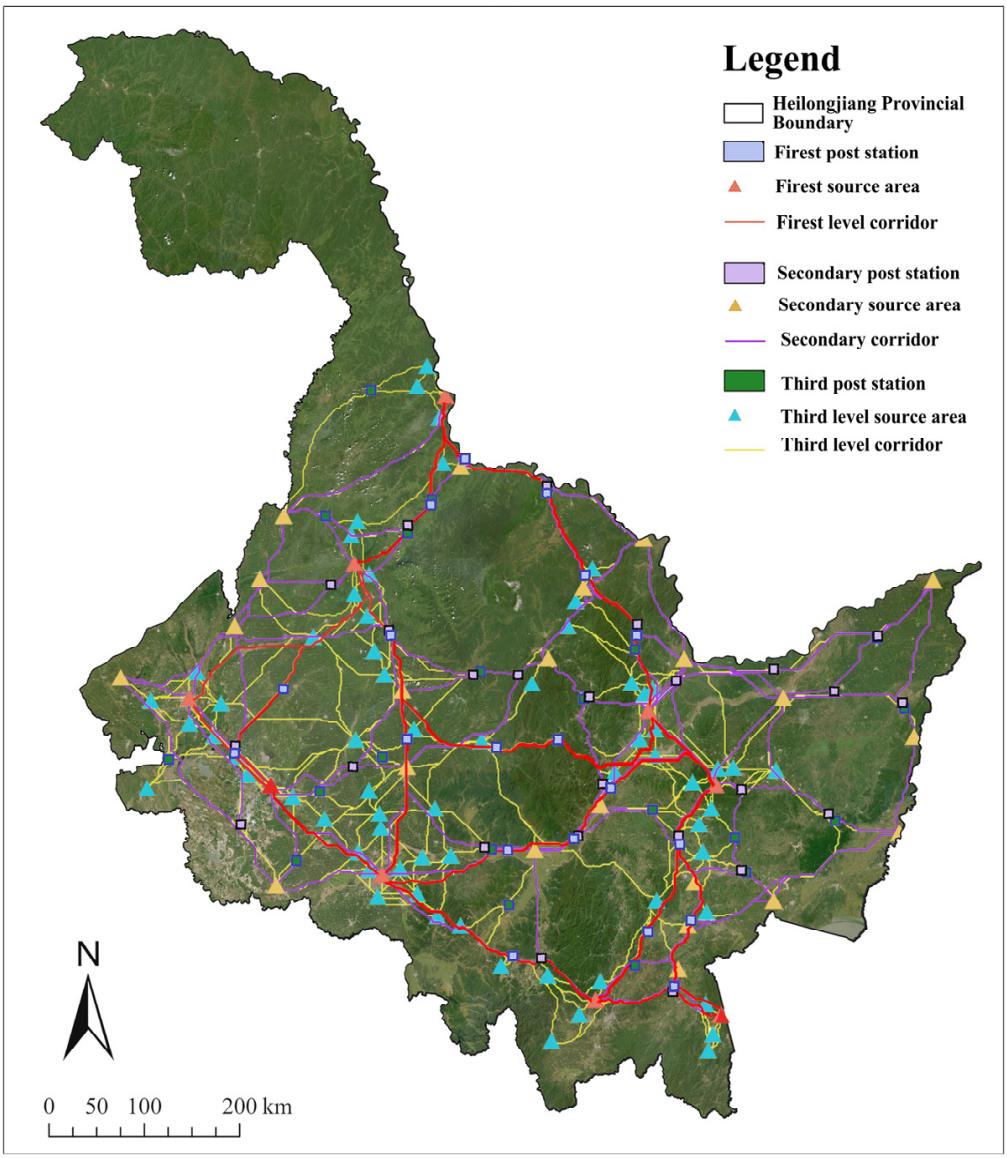


Figure 17. Overall planning classification.

Based on this, to achieve the scientific preservation and sustainable utilization of heritage resources and integrate the findings from previous research, this study proposes a hierarchical and coordinated development strategy from a holistic perspective, summarizing a "recognition–analysis–optimization" paradigm for historical building heritage corridors (Figure 18). On one hand, enhancing the accessibility between railway and highway nodes and cultural source areas can improve the physical reach of cultural pathways. On the other hand, emphasis should be placed on constructing multifunctional cultural relay stations in ethnic settlement areas, embedding functions such as cultural display, ethnic education, and tourism services to activate regional cultural dissemination and spatial identity. Ultimately, this aims to transition from "static preservation" to the "dynamic transmission" of heritage.

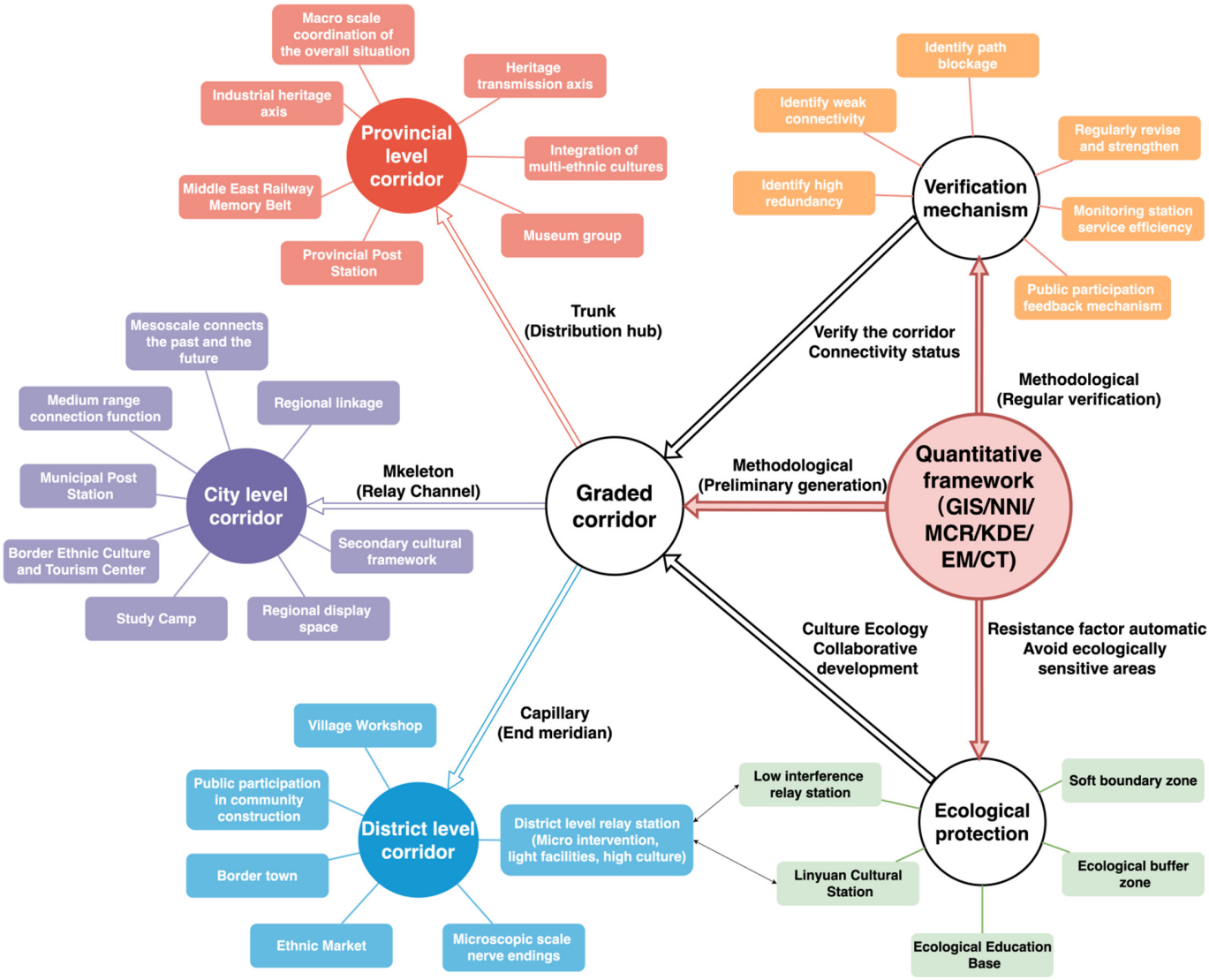


Figure 18. Heilongjiang heritage corridor strategic framework.

(1) Provincial Corridors: Strengthening Main Axis Traction and Coordinating Regional Cultural Resources

Provincial corridors primarily connect core cities with dense historical buildings and high cultural significance, such as Harbin, Qiqihar, Mudanjiang, and Jiamusi. These paths often follow the Middle East Railway, national highways, and historical evolution axes, exhibiting high current density and medium- to long-distance "laminar flow" characteristics. These corridors should serve as the main conduits for Heilongjiang's cultural resources, forming a cultural transmission framework that spans from east to west and connects areas from north to south.

Strategically, priority should be given to the protection and functional revitalization of historical districts, modern industrial sites, and cultural venues along provincial corridors, creating cross-regional cultural belts. Examples include the "Middle East Railway Memory Belt" and the "Black Soil Industrial Heritage Axis." Additionally, Class I relay stations with multifunctional capabilities (e.g., exhibition, education, tourism, and exchange) should be established, forming service clusters centered around transportation hubs and cultural core areas to enhance their central traction in the provincial cultural network.

(2) Municipal Corridors: Undertaking Main Functions and Strengthening Regional Coordination

Municipal corridors serve as secondary cultural frameworks connecting historical building nodes between cities and provincial main corridors. They cover a wide range and diverse paths, facilitating meso-scale cultural integration and regional coordination. Typical paths include Qiqihar–Wudalianchi, Daqing–Hailun, Nenjiang–Heihe, Hegang–Yichun, and Luobei–Fuyuan. Their role is to strengthen medium-range links between heritage clusters, promoting collaborative development and the functional integration of local cultural resources.

It is recommended to focus on constructing Class II cultural relay stations along municipal corridors, incorporating regional exhibition spaces, intangible cultural heritage research bases, and ethnic tourism cooperation centers to activate and disseminate regional culture. Through policy guidance and fiscal support, intergovernmental collaboration should be encouraged to achieve the horizontal integration and co-branding of cultural resources.

(3) District-level Corridors: Penetrating Peripheral Spaces and Activating Cultural Nodes

District-level corridors primarily connect micro-nodes, local heritage sites, and rural historical–cultural spaces, serving as the "nerve endings" of the cultural transmission system. They are densely distributed, covering villages, border towns, and ethnic settlements. These corridors have short paths, high density, and low current values but are rich in cultural diversity, making them crucial for rural revitalization, community participation, and cultural identity building.

Guided by the principles of "micro-intervention, light facilities, and high cultural value," Class III relay stations such as village cultural workshops, ethnic markets, border memory halls, and cultural theaters should be developed. These stations should encourage community participation in cultural construction, promoting heritage revitalization and community governance. In ethnic and ecologically sensitive areas, a low-impact layout of "cultural services not entering forests, service nodes reaching forest edges" should be adopted to establish green cultural boundaries.

(4) Validation Mechanism: Building a Dynamic Feedback and Evaluation-Optimization Framework

To ensure the scientific and adaptive implementation of the heritage corridor system, a validation mechanism covering pre-, mid-, and post-construction phases should be established, enabling the monitoring of the full process and dynamic optimization from planning to operation. This mechanism should be based on multi-source spatial data and key indicators, integrating quantitative evaluation and multidimensional feedback to provide systematic support for the effective operation of cultural corridors.

On the one hand, accessibility assessments at the path level can be conducted using core parameters such as current density distribution and minimum path distance from the circuit theory model. This helps identify high-redundancy, weak-connectivity, or blocked nodes, with regular network structure corrections and enhancements achieved through graph theory optimization algorithms.

On the other hand, the evaluation framework should integrate cultural node hierarchies (source levels) with functional carrying capacity by establishing a dynamic indicator system that includes service radius, visitor pressure, and node activity. By setting acceptable usage thresholds for each node, this system can monitor actual reception capacity and cultural diffusion effects, helping to prevent overdevelopment and environmental overload, and ensuring the sustainable operation of heritage spaces and the security of the cultural ecosystem.

Additionally, public participation and multi-stakeholder feedback mechanisms can be introduced. For example, digital platforms can record visitor behavior trajectories, community satisfaction, and cultural participation rates, forming a closed-loop evaluation system integrating spatial data, usage feedback, and operational assessments.

5.3.2. Ecological Synergy: Coordinated Development of Cultural Heritage Corridors and Ecological Protection

Heilongjiang Province, located at the intersection of national ecological barriers and borderland cultures, exhibits a high degree of spatial overlap between historical heritage resources and natural ecological elements. The construction and development of heritage corridors must ensure cultural continuity while maintaining the integrity and safety of ecosystems. This study introduced ecological resistance factors during the corridor modeling process and effectively avoided ecologically sensitive areas such as forests, wetlands, and water bodies through current density simulation, preliminarily validating the adaptability of cultural pathways to ecological patterns. Building on this, this paper proposes the spatial concept of the "coordinated development of cultural heritage corridors and natural ecological corridors."

Specifically, at the structural level, cultural corridors can be designed as "soft boundary zones" around ecological core areas, serving as cultural buffer zones connecting urban, rural, and ecological protection areas. At the functional level, some cultural nodes can be transformed into ecological education bases, natural research sites, or cultural landscape exhibition points, achieving the dual goals of cultural display and ecological awareness dissemination. For example, in forested areas such as Yichun, Jiayin, and Tieli, heritage nodes can function as "forest-edge cultural relay stations," showcasing the evolutionary logic of ecosystem–regional history interactions to the public.

Simultaneously, the construction of relay stations should adhere to the principle of low ecological disturbance, prioritizing service points outside ecologically sensitive areas and adopting mobile, renewable, and lightweight designs to provide cultural services while ensuring ecological safety. This forms a green boundary governance model of "culture not entering forests, services reaching forest edges." Such service nodes not only alleviate the pressure on ecological core areas but also optimize cultural experience processes by guiding visitation paths and stopover points, enhancing overall spatial resilience.

The coordinated development of cultural heritage corridors and ecological protection is crucial to addressing the "isolation" of historical buildings in Heilongjiang and a key strategy for achieving both ecological civilization and cultural revitalization goals. During corridor construction, ecological sensitivity should serve as a bottom-line control factor, with cultural resources acting as the spatial guiding principle as we optimize pathway layouts and node settings to promote the deep integration of culture and ecology. The two complement each other in spatial structure, synergize in functional goals, and overlap in value realization, forming a composite "dual-chain integration" pattern. Future efforts should focus on policy guidance, strengthening spatial data integration, ecological assessment mechanisms, and the collaborative design of cultural transmission functions to establish a new high-quality development paradigm of culture–ecology symbiosis.

Based on the above strategic research, a "recognition–analysis–optimization" paradigm for historical building heritage corridors is summarized (Figure 18).

6. Conclusions

This study systematically explores the spatial structure, modeling strategies, and planning implications of architectural heritage corridors in Heilongjiang Province. First, spatial quantitative analysis reveals a "single-core, multi-zone" distribution pattern centered on

Harbin, providing a solid foundation for enhancing regional cultural connectivity. Second, by integrating the nearest neighbor index, kernel density analysis, an entropy-weighted MCR model, and circuit theory, the study develops a replicable corridor generation methodology that effectively addresses issues such as subjectivity in traditional path design and the insufficient consideration of ecological factors. Third, the research proposes a multi-tiered strategy encompassing transportation coupling, relay station systems, and ecological coordination, thereby expanding the application of heritage corridors in regional planning and governance. The proposed methodological framework can be widely applied to cultural tourism planning, ecological landscape design, and smart heritage management.

Nevertheless, certain limitations remain, such as restricted data resolution and insufficient behavioral modeling. Future research will focus on incorporating real-time travel behavior data, expanding the modeling dimensions of micro-scale cultural nodes, and conducting cross-regional adaptation studies in other provinces.

Author Contributions: Author Contributions: Conceptualization, L.F. and M.M.; methodology, J.S.; software, J.S.; validation, J.S. and T.Z.; formal analysis, L.F., J.S. and T.Z.; investigation, T.Z.; resources, G.Y.; data curation, J.S. and T.Z.; writing—original draft preparation, L.F., T.Z. and J.S.; writing—review and editing, L.F.; visualization, J.S. and T.Z.; supervision, G.Y.; project administration, L.F.; funding acquisition, L.F. All authors have read and agreed to the published version of the manuscript.

Funding: 2021 Heilongjiang Provincial Philosophy and Social Sciences Research Planning Project: Research on the Protection and Renewal Strategies of Historical and Cultural Districts along the Middle East Railway in Heilongjiang Province (21YSC235); 2024 Heilongjiang Provincial Philosophy and Social Sciences Research Planning Project: Digital Protection and Virtual Experience Research of Middle East Railway Architectural Heritage in Harbin (24YSB015).

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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

References

1. Zhang, J.; Jiang, L.; Wang, X.; Chen, Z.; Xu, S. A Study on the Spatiotemporal Aggregation and Corridor Distribution Characteristics of Cultural Heritage: The Case of Fuzhou, China. *Buildings* **2024**, *14*, 121. [CrossRef]
2. Cui, Y. Research on Big Data 3D Scanning Empowering the Protection and Inheritance of Historical Building Cultural Heritage: A Case Study of Deqing Confucian Temple. In Proceedings of the 3rd Conference on Digital Cultural Heritage, Zhengzhou, China, 11 January 2025; pp. 142–144. (In Chinese) [CrossRef]
3. Lv, R.; Liu, Y.; Zhang, L.; Kong, D. Urban Historic Heritage Buffer Zone Delineation: The Case of Shedian. *Herit. Sci.* **2022**, *10*, 64. [CrossRef]
4. Zhou, X.; Tang, Y.; Su, J. Heritage Corridor Routing Method from Historic Urban Landscape and Digital Footprint Perspectives—The Case of Historical Urban Area in Nanjing, China. *Landsc. Archit. Front.* **2023**, *11*, 11–38. [CrossRef]
5. Zhang, T.; Yang, Y.; Fan, X.; Ou, S. Corridors Construction and Development Strategies for Intangible Cultural Heritage: A Study about the Yangtze River Economic Belt. *Sustainability* **2023**, *15*, 13449. [CrossRef]
6. Yue, F.; Li, X.; Huang, Q.; Li, D. A Framework for the Construction of a Heritage Corridor System: A Case Study of the Shu Road in China. *Remote Sens.* **2023**, *15*, 4650. [CrossRef]
7. Xu, H.; Zhao, G.; Fagerholm, N.; Primdahl, J.; Plieninger, T. Participatory Mapping of Cultural Ecosystem Services for Landscape Corridor Planning: A Case Study of the Silk Roads Corridor in Zhangye, China. *J. Environ. Manag.* **2020**, *264*, 110458. [CrossRef]
8. Wang, Y. Research on the Value Cognition of Cultural Heritage in the Gansu Section of the Silk Road from the Perspective of Heritage Corridor. *Soc. Sci. Rev.* **2021**, *36*, 107–115. (In Chinese)
9. Chang, Y.; Zhou, C. Research on the Construction and Application Strategies of Exhibition Corridors for Historical Sites in China's Border Areas: A Case Study of National Protected Historical Sites in Jilin Province. *Archit. Cult.* **2017**, 226–227. (In Chinese)
10. Wang, Q.; Yang, C.; Wang, J.; Tan, L. Tourism in Historic Urban Areas: Construction of Cultural Heritage Corridor Based on Minimum Cumulative Resistance and Gravity Model—A Case Study of Tianjin, China. *Buildings* **2024**, *14*, 2144. [CrossRef]
11. Wang, Q.; Liu, W.; Mao, L. Spatial Evolution of Traditional Village Dwellings in Heilongjiang Province. *Sustainability* **2023**, *15*, 5330. [CrossRef]

12. Yan, S.; Geng, S.; Chau, H.W.; Wang, T.; Jamei, E.; Vrcelj, Z. Adaptive Reuse of Russian-Influenced Religious Architecture in Harbin: Architectural Identity and Heritage Tourism. *Heritage* **2024**, *7*, 7115–7141. [CrossRef]
13. Jin, H.; Zhao, J.; Liu, S.; Kang, J. Climate Adaptability Construction Technology of Historic Conservation Areas: The Case Study of the Chinese–Baroque Historic Conservation Area in Harbin. *Sustainability* **2018**, *10*, 3374. [CrossRef]
14. Ji, X.; Shao, L. The Application of Landscape Infrastructure Approaches in the Planning of Heritage Corridor Supporting System. *Procedia Eng.* **2017**, *198*, 1123–1127. [CrossRef]
15. Shen, Y.; Liu, J.; Han, J.; Wan, X. Reconstructing the Silk Road Network: Insights from Spatiotemporal Patterning of UNESCO World Heritage Sites. *Land* **2024**, *13*, 1401. [CrossRef]
16. Wu, Y.; Miao, M.; Wu, Y.; Zhu, H.; Li, X.; Candeias, A. The Research on the Construction of Traditional Village Heritage Corridors in the Taihu Lake Region Based on the Current Effective Conductance (CEC) Theory. *Buildings* **2025**, *15*, 472–510. [CrossRef]
17. Lee, J.A.; Chon, J.; Ahn, C. Planning Landscape Corridors in Ecological Infrastructure Using Least-Cost Path Methods Based on the Value of Ecosystem Services. *Sustainability* **2014**, *6*, 7564–7585. [CrossRef]
18. Zhang, J.; Shen, H. The Impact of Urban River Corridors on Landscape Patterns Based on GIS and RS Technology. *J. Shandong Agric. Univ. (Nat. Sci. Ed.)* **2018**, *49*, 769–771. (In Chinese)
19. Wang, Z.; Sun, P. Heritage Corridor: A New Approach to Heritage Conservation. *Chin. Landsc. Archit.* **2001**, 86–89. Available online: https://www.cnki.com.cn/Article/CJFDTOTAL-ZGYL200105035.htm (accessed on 3 April 2025). (In Chinese).
20. Gao, C.; Li, Y. A Review of Heritage Corridor Research in China. *J. Kunming Univ. Sci. Technol. (Soc. Sci. Ed.)* **2018**, *18*, 101–108. (In Chinese)
21. Ye, H.; Yang, Z.; Xu, X. Ecological Corridors Analysis Based on MSPA and MCR Model—A Case Study of the Tomur World Natural Heritage Region. *Sustainability* **2020**, *12*, 959. [CrossRef]
22. Li, X.; Zhu, R.; Shi, C.; Yang, X.; Chen, J.; Wei, K. Research on the Construction of Intangible Cultural Heritage Corridors in the Yellow River Basin Based on Geographic Information System (GIS) Technology and the Minimum Cumulative Resistance (MCR) Model. *Herit. Sci.* **2024**, *12*, 1–18. [CrossRef]
23. Wang, X. Construction of the Beijing-Shenyang-Qing Cultural Heritage Corridor Based on Analytic Hierarchy Process. Master′s Thesis, Xi′an University of Architecture and Technology, Xi′an, China, 2009. (In Chinese).
24. Chen, P. Construction of Landscape Evaluation System for the China Eastern Railway Corridor under the AHP Method. *Shanxi Archit.* **2014**, *40*, 32–33. (In Chinese)
25. Liu, L. Holistic Conservation and Utilization of Linear Industrial Heritage along the China Eastern Railway. *J. Shenyang Norm. Univ. (Soc. Sci. Ed.)* **2013**, *37*, 24–28. (In Chinese)
26. Zhou, C.; Zhou, L.; Zhang, X. Spatial Differentiation and Driving Factors of Multi-Category Intangible Cultural Heritage Projects in China. *Geogr. Geo-Inf. Sci.* **2023**, *39*, 72–80. (In Chinese)
27. Yu, K.J.; Li, W.; Li, D.H.; Li, C.B.; Huang, G.; Liu, H.L. Exploring Suitability Analysis Methods for Heritage Corridors in Rapid Urbanization Areas: A Case Study of Taizhou City. *Geogr. Res.* **2005**, *69–76*, 162. (In Chinese)
28. Xu, D.; Guo, X.; Watanabe, T.; Liang, K.; Kou, J.; Jiang, X. Ecological Security Pattern Construction in Rural Settlements Based on Importance and Vulnerability of Ecosystem Services: A Case Study of the Southeast Region of Chongqing, China. *Sustainability* **2023**, *15*, 7477. [CrossRef]
29. Zhang, P.; Zhang, N. Quantitative Analysis of Narrative Environment in Urban Historic Districts Based on Space Syntax. *Urban Dev. Stud.* **2017**, *24*, 17–22. (In Chinese)
30. Lin, F.; Zhang, X.; Ma, Z.; Zhang, Y. Spatial Structure and Corridor Construction of Intangible Cultural Heritage: A Case Study of the Ming Great Wall. *Land* **2022**, *11*, 1478. [CrossRef]
31. Li, X.; Xia, H. Evaluation of Regeneration Value for Railway Heritage Corridors: A Case Study of the Beijing-Zhangjiakou Railway (Beijing Section). *S. Archit.* **2023**, 40–51. (In Chinese) [CrossRef]
32. Wang, Y.; Zeng, G. Research on the Construction of Silk Road Cultural Heritage Corridor from a Spatial Perspective. *World Reg. Stud.* **2022**, *31*, 862. (In Chinese)
33. Zhang, Z.; Niu, J.; Cheng, Q.; Wang, Z. Construction of Ecological Tourism Corridors and Ecotourism Zones in the Xinyang Section of the Huaihe River Basin. *J. Xinyang Norm. Univ. (Nat. Sci. Ed.)* **2023**, *36*, 517–5222. (In Chinese)
34. Ognyanova, K.; Rawlings, C.M.; Smith, J.A.; Moody, J.; McFarland, D. Network Analysis: Integrating Social Network Theory, Method, and Application with R. *J. Soc. Struct.* **2024**, *25*, 22–24.
35. Chen, Y.; Dang, A.; Peng, X. Building a Cultural Heritage Corridor Based on Geodesign Theory and Methodology. *J. Urban Manag.* **2014**, *3*, 97–112. [CrossRef]
36. Du, C.; Pan, D.; Liu, Q. The Construction of a Protection Network for Traditional Settlements Across Regions: A Case Study of the Chengdu–Chongqing Ancient Post Road Heritage Corridor in China. *Land* **2025**, *14*, 327. [CrossRef]
37. Li, Y.; Zhang, Y. Spatial Distribution Characteristics and Influencing Factors of World Architectural Heritage Sites. *Heritage* **2021**, *4*, 164. [CrossRef]

38. Jiang, L.; Cai, J. Research on the Spatial and Temporal Distribution and Evolution Characteristics of Ancient Architectural Heritage in Southeastern Zhejiang. *Sustainability* **2023**, *15*, 16618. [CrossRef]
39. Wang, J.; Zhang, H.; Xie, C.; Wang, H.Y.; Tao, L.; Li, Y.T.; Huang, Y.F. Suitability Evaluation of Intangible Cultural Heritage Corridor Construction in the Grand Canal Cultural Belt Based on GIS. *Acta Ecol. Sin.* **2025**, 1–18. (In Chinese) [CrossRef]
40. Huang, Y.; Shen, S.; Hu, W.; Li, Y.; Li, G. Construction of Cultural Heritage Tourism Corridor for the Dissemination of Historical Culture: A Case Study of Typical Mountainous Multi-Ethnic Area in China. *Land* **2023**, *12*, 138. [CrossRef]
41. Du, R.; Chen, J. Evaluation of Green Space Landscape Systems in the Fringe Zone of Nanjing's Main Urban Area Based on Social Network Analysis. *Chin. Landsc. Archit.* **2022**, *38*, 68–73. (In Chinese)
42. Feng, L.; Gong, Y.; Liang, Z. Integrating Cross-Regional Ecological Networks in Blue–Green Spaces: A Spatial Planning Approach for the Yangtze River Delta Demonstration Area. *Sustainability* **2025**, *17*, 4193. [CrossRef]
43. McRae, B.H.; Beier, P. Circuit Theory Predicts Gene Flow in Plant and Animal Populations. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19885–19890. [CrossRef]
44. Clark, P.J.; Evans, F.C. Distance to Nearest Neighbor as a Measure of Spatial Relationships in Populations. *Ecology* **1954**, *35*, 445–453. [CrossRef]
45. Rosenblatt, M. Remarks on Some Nonparametric Estimates of a Density Function. *Ann. Math. Stat.* **1956**, *27*, 832–837. [CrossRef]
46. Parzen, E. On Estimation of a Probability Density Function and Mode. *Ann. Math. Stat.* **1962**, *33*, 1065–1076. [CrossRef]
47. Knaapen, J.P.; Scheffer, M.; Harms, B. Estimating habitat isolation in landscape planning. *Landsc. Urban Plan.* **1992**, *23*, 1–16. [CrossRef]
48. Shannon, C.E. A Mathematical Theory of Communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
49. Cui, M. Theoretical Methods and Research in Cultural Ecology. *J. Yunnan Norm. Univ. (Philos. Soc. Sci. Ed.)* **2012**, *44*, 58–64. (In Chinese)
50. Li, H.; Wang, Z. Exploring the Anti-Japanese War Heritage Corridor System Based on GIS Spatial Analysis. *Urban Dev. Stud.* **2017**, *24*, 86–93. (In Chinese)
51. Zhang, Q.; Ge, J. Research on the Construction of Huizhou Heritage Corridor Network from the Perspective of Cultural Ecology. *Ind. Constr.* **2024**, *54*, 20–29. [CrossRef]
52. Ma, X.; Xu, X. Connectivity Optimization and Management of Ecological Conservation Red Lines at Regional Scale: A Case Study of the Yangtze River Delta. *J. Nat. Resour.* **2022**, *37*, 3088–3101. (In Chinese)
53. Wei, K.; Jiang, X.; Zhu, R.; Duan, X.; Yang, J. Spatial and Temporal Distribution Characteristics of Heritage Buildings in Yangzhou and Influencing Factors and Tourism Development Strategies. *Buildings* **2025**, *15*, 1081. [CrossRef]
54. Gao, H.; Wang, Y.; Zhang, H.; Huang, J.; Yue, X.; Chen, F. Spatial Distribution and Typological Classification of Heritage Buildings in Southern China. *Buildings* **2023**, *13*, 2025. [CrossRef]
55. Liu, Y.; Ding, J.; Wang, H.; Du, Y. A Clustering Algorithm Based on the Detection of Density Peaks and the Interaction Degree Between Clusters. *Appl. Sci.* **2025**, *15*, 3612. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.