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Heritage Corridor Routing Method From Historic Urban Landscape and Digital Footprint Perspectives —The Case of Historical Urban Area in Nanjing, China

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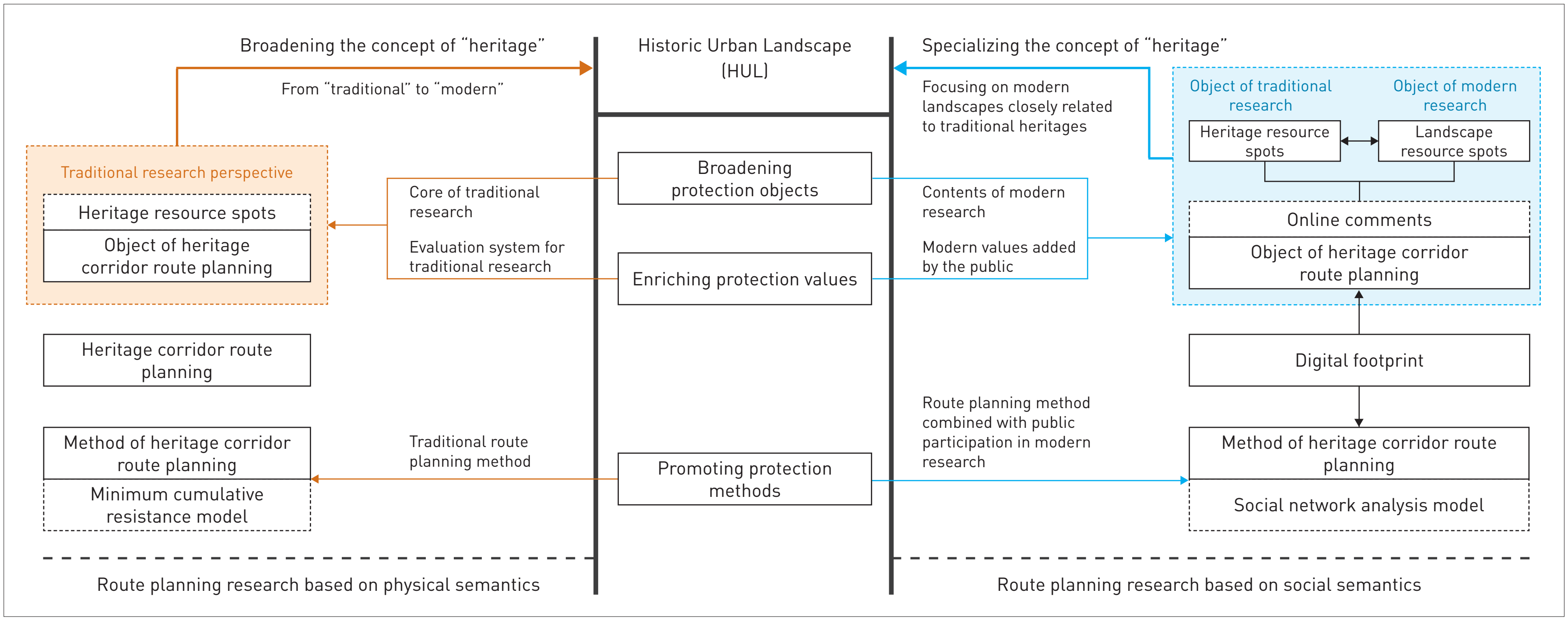
GRAPHICAL ABSTRACT



HIGHLIGHTS

- Defines the concepts of heritage and landscape resources based on the understanding of historic urban landscape, and establishes a new method for heritage corridor route planning
- Integrates factors of both physical environmental conditions and users' perception into route planning process of heritage corridors with analysis of digital footprint data
- Respects individual users as social entities in the construction of heritage corridors

KEYWORDS

Heritage Corridor;
Route Planning;
Historic Urban Landscape;
Minimum Cumulative Resistance Model;
Digital Footprint;
Social Network Model;
Urban Landscape Resources

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ABSTRACT

As a method of the systematic conservation of historical, cultural, and natural landscape resources, heritage corridor integrates contexts of humanism and nature and provides the public with continuous linear spaces for recreation, leisure, and fitness activities. Most traditional studies on heritage corridor route planning focus on the analysis of physical spatial conditions, while ignoring public perception and public participation mechanisms. Based on the concept of Historic Urban Landscape, this research excavates modern landscape resources that are closely connected with traditional heritages and analyzes users' digital footprints to incorporate public preferences of recreational behaviors into the process of heritage corridor route planning, realizing the combination of physical and social semantic data analyses. Basically, this study consists of three parts: 1) through analysis of digital footprints, select urban traditional heritage sites and landscape resource spots into the process of heritage corridor route planning, and fit the preliminary routes of urban heritage corridors with minimum cumulative resistance model; 2) construct a co-word matrix consisting of users' movement flows and online textual data in the digital footprints, to complete the route planning upon social semantic data analysis; and 3) superimpose the results of heritage corridor route planning generated by the above two steps, and optimize according to the reality of urban environment. The study realizes an effective integration of urban landscape resources with public recreational behaviors and spatial perception in the process of heritage corridor route planning, offering reference to the overall protection of urban heritages and the systematic improvement of public space.

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1 Research Background

1.1 Heritage Corridor and Historic Urban Landscape

The concept of "Heritage Corridor" originated in the United States, which initially refers to linear landscapes with clustered cultural resources of special significance, usually with obvious economic centers, booming tourism, and adaptive use and environmental improvement of historic sites[1]. As the broadening of application, research on heritage corridors has begun to emphasize the systematic promotion of socio-economic revitalization with linear spatial elements such as rivers, greenways, streets, and railroads, which can lead to a synergic development of heritage preservation and urban construction.[2]~[4]

As a method for regional heritage system protection linked up multiple cultural resources, heritage corridor focuses on the integration and optimization of linear landscape resources at varied scales, ranging from the protection designating of local historical sites towards the exploring of holistic protection of historical perception within a whole region[5], accentuating the use of comprehensive protection measures of nature, economy, and culture[6]~[8]. At the same time, the systematic research on the route planning of heritage corridors has received increasingly academic attention. In recent years, the disputes on heritage conservation caused by large-scale urban development have intensified along with the growth of globalization–localization conflicts[9]. In order to balance the relationship between heritage conservation and urban development, UNESCO issued the *Recommendation on the Historic Urban Landscape* in 2011, proposing to embrace the concept of Historic Urban Landscape (HUL) in the context of urban transformation and globalization to study the role and value of landscapes formed in different historical periods of a city's spatial development.[10][11]

In many countries, historic buildings and structures are maintained through the development of regional conservation policies and the designation of historic conservation areas, which, however, can no longer well reach the urban landscapes of artistic or cultural values[5], less contributing to today's ever-expanding scope of urban conservation[5]. The concept of HUL goes beyond the traditional discourse on historic conservation areas such as historic centers and relic ensembles towards a broader discussion on urban context and geography by highlighting a holistic concept and approach to addressing heritage conservation[12]. As a new landscape-based approach, HUL is used for the identification, conservation, and management of historic areas. It integrates the goals of heritage conservation and urban development, as well as various spatio-temporal elements, by balancing of demands between the built environment and natural resources, between the contemporary and the future[13]. Therefore, the perspective of HUL coincides the coupling of the intrinsic value with the socio-cultural importance of heritages and offers a new method for the studies on heritage corridors, which is not only key to protect and celebrate the uniqueness of urban heritages but also effective to vitalizing urban public spaces.

1.2 Research on Heritage Corridors in the Digital Era

At present, most of the research on heritage corridors, including route planning for tangible and linear landscape resources such as river valleys, cultural corridors, historic trails, etc.[7][14]~[16], reflects a macro, top-down perspective. Specifically, such research is conducted through combined lenses of urban function, spatial location, history and culture, and natural landscape on integrated resource planning and route planning of heritage corridors[17][18]. However, traditional methods for route planning less consider the influence of subjective factors such as visitors' individual behaviors, perception and experience, aesthetic preferences, resulting in public perception expression mechanism failed to be incorporated into the construction process of heritage corridors. It thus calls for an alternative construction method of heritage corridors that combines the analysis of public recreational behavior preferences into the process of heritage corridor route planning.

In the digital era, online social platforms are gradually becoming the core carriers for the public to record their recreational behaviors and post comments, and the public's digital footprints have reached an unprecedented data scale, which shows a huge potential for academic studies[19]. Digital footprint contains a large amount of spatio-temporal information generated through users' interface opertations, and records various spatial behaviors such as transportation, communication, recreation, photography, comments, and check-ins[20], which can be used to learn the public's behavioral patterns and perception preferences. This research attempts to incorporate digital footprints into the route planning of heritage corridors to identify the modern landscape resources in public recreational routes that have strong connections and interactions with traditional heritage resources. Also, from the perspective of HUL, this research establishes a social network analysis model to reveal users' spatial behavior characteristics and improves public perception expression mechanism that has been ignored in the traditional route planning method. This new research paradigm also provides a reference for heritage research and practice that combines the city's spatial factors and the public's subjective factors in the digital era.

1.3 The Contempotary Significance of the New Research Method of Heritage Corridor Route Planning

As an important part of urban landscape and urban heritage, urban heritage corridor has its complexity and, essentially, it is to protect and revitalize heritage resources and to improve the quality of urban public space by linking resource spots scattered throughout the city in form of corridors. The emergence of HUL has promoted heritage corridor studies to increasingly focus on the integration of historical and modern elements in the urban built environment. Considering that HUL emphasizes "living heritage"[21][22], contemporary landscape resources are paid more and more attention in the route planning of heritage corridors. At the same time, in order to avoid blindly broadening the connotation of "heritage," this paper defines that only the modern landscape resources closely connected with traditional heritages can be considered in the route planning of heritage corridors. In this sense, the study of heritage corridor route planning that takes both HUL and digital footprint perspectives into account is not only a process of forming a recreational flow of heritage resources in urban physical settings, but also an establishment of public spatial system based on the analysis of public perception preferences. Such dual attributes make this new method for heritage corridor route planning of great practical importance for urban heritage protection and urban development planning.

2 Literature Review

2.1 Heritage Corridor Research From the HUL Perspective

In 1984, the USA Congress legislated to designate the Illinois–Michigan Canal, which spans from the suburbs of Chicago to the center of Illinois, as a national heritage corridor, marking the formal establishment of the concept of "heritage corridor"[23][24]. This concept has been introduced and promoted into Chinese academia since 2001[25] and has witnessed fruitful outcomes in heritage corridor conservation planning, hierarchical construction, and related analyses and evaluations. For example, in terms of conservation planning, Xuesong Xi et al. reviewed the conservation and management methods of national heritage corridors in the USA, and offered suggestions for the sustainable utilization of linear heritages in China[26]. In terms of hierarchical construction, Wei Li et al. proposed a research framework for the overall protection of the Grand Canal of China by exploring the methods of heritage corridor construction[27]; Kongjian Yu et al. examined the heritage corridors in rapidly urbanized areas by analyzing the suitability of heritage corridors with a case study of Taizhou City, and attempted to build heritage corridors by using minimum cumulative resistance (MCR) model[8]. In terms of analyzing and evaluating heritage corridors, Long Lv et al. constructed an evaluation system for heritage corridors that can assess the overall tourism benefits of heritage corridors[28].

HUL, as a landscape-based approach that considers heritage resources as a holistic system, has become a new way of thinking to recognize a city's historical value[29]. By understanding the dynamic superposition of historical legacy and urban development, HUL provides a broader vision for research on heritage corridors. Regarding the complexity and diversity of heritage resources, recent studies have attempted to widen the scope of route planning of heritage corridors (towards ecological protection, tourism development, etc.)[23]. However, there is still little heritage corridor research that truly combines with the HUL concept.

At the technical and methodological level, foreign scholars have more focused on qualitative evaluation and theoretical discussion, and studies cencentrate on the evaluation of different landscape characteristics of heritage corridors, and on the improvement of management methods. For example, Mar Loren-Méndez et al. defined the landscape characteristics of the heritage of road corridors and conducted landscape evaluation on heritage corridors from the aspects of nature, culture, and history[30]. B. Bynum Boley et al. used deductive qualitative analysis to explore the tourism development, local participation, and management mechanism of heritage corridors[31]; Tegar Shigar et al. qualitatively analyzed the shortage of urban roads, green spaces, and public facilities based on the theories about comfort, and proposed to promote the integrity and comfort of heritage corridors by improving public resources[32]. Meanwhile, Chinese scholars' studies on the construction method of heritage corridor often employ expert scoring method to assess urban environmental conditions for the construction of heritage corridor. For example, Jinlong Hu et al. and Ru Wang et al. used MCR model to examine the resistance values of physical environmental factors such as land cover type, elevation, and slope, and determined the weights of such factors by expert scoring for the construction of the network of heritage corridors[33][34]. Ding He et al. by combining MCR model with multiple centrality assessment (MCA) model, besides the expert scoring method, developed an assessment framework and quantitatively evaluated the spatial structure of heritage corridors with multiple levels and categories[35].

Among the above studies, MCR model is the mainstream tool for the route planning of heritage corridors, which analyzes the suitability of different environmental factors to identify the aggregation and distribution patterns of landscape resources in the study area, and then select the most suitable route for targeted activities[33]. Most current studies focus simply on the heritage sites and landscape resources, or the surrounding environmental factors[36], seeing less consideration on users' recreational behaviors and perception preferences. At the same time, more and more efforts have proven the importance of the analysis of individuals' spatio-temporal data to urban studies[37]. Therefore, this study attempts to include the analysis of users' recreational behavior data into the route planning of heritage corridors.

2.2 Heritage Corridor Research From the Digital Footprint Perspective

In order to better reflect public perception expression mechanism, heritage corridor research can combine with big data analysis to probe into people's recreational behavior characteristics and perception preferences[20]. Currently, the user generated content (UGC) on social media has been widely utilized in heritage corridor research. For example, Xiang Zhou et al. used digital footprints to study the HUL in the Qinhuai River area in Nanjing, and primarily constructed an analysis and evaluation system of landscape visual characteristics and perception, based on the combination of expert scoring and public participation[38]. Qin Zhao et al. studied nighttime tourist attractions in Chongqing and quantitatively analyzed the structure of tourism flow network and the perception of the landscape image at both the overall and the individual levels[39]. Rui Wang et al. analyzed the statistics of concerns and co-occurrences of various types of heritage landscapes by comparing the official materials with tourists' digital footprints about heritage corridors[40]. Thus, digital footprint, on the one hand, provides an approach to in-depth assessing the spatial usage and perception of urban heritage, which can inform decision-making on heritage protection and management; on the other hand, because of containing huge authentic recreational perception data, it suggests a new way to reflect the public's perception in the research on heritage corridor route planning.

Digital footprint is mainly in two types: passive digital footprint, referring to the data generated by users' interface interactions with communication devices—for instance, the location logs and browsing records generated by cell phones when using them; and active digital footprint, including the data uploaded by social media users, such as comments and scores, travel photos, and trip records[41]. The latter type can be used to map individuals' actual perception when they visit different heritage sites and landscape resources[20][42]. In addition, since such data have sound diversity and extensibility without framework limitations, they can also effectively reflect users' interactions with HUL[43]. Therefore, this paper adopts the digital footprint perspective to identify users' flow intensity and recreational behavior preferences among landscape resource spots by using MCR model, and propose a new method for heritage corridor route planning that consists of an evaluation system of indicators covering both urban physical environmemt and public recreational perception.

3 Research Roadmap

The heritage corridor route planning method established in this paper mainly includes the following four steps (Fig. 1).

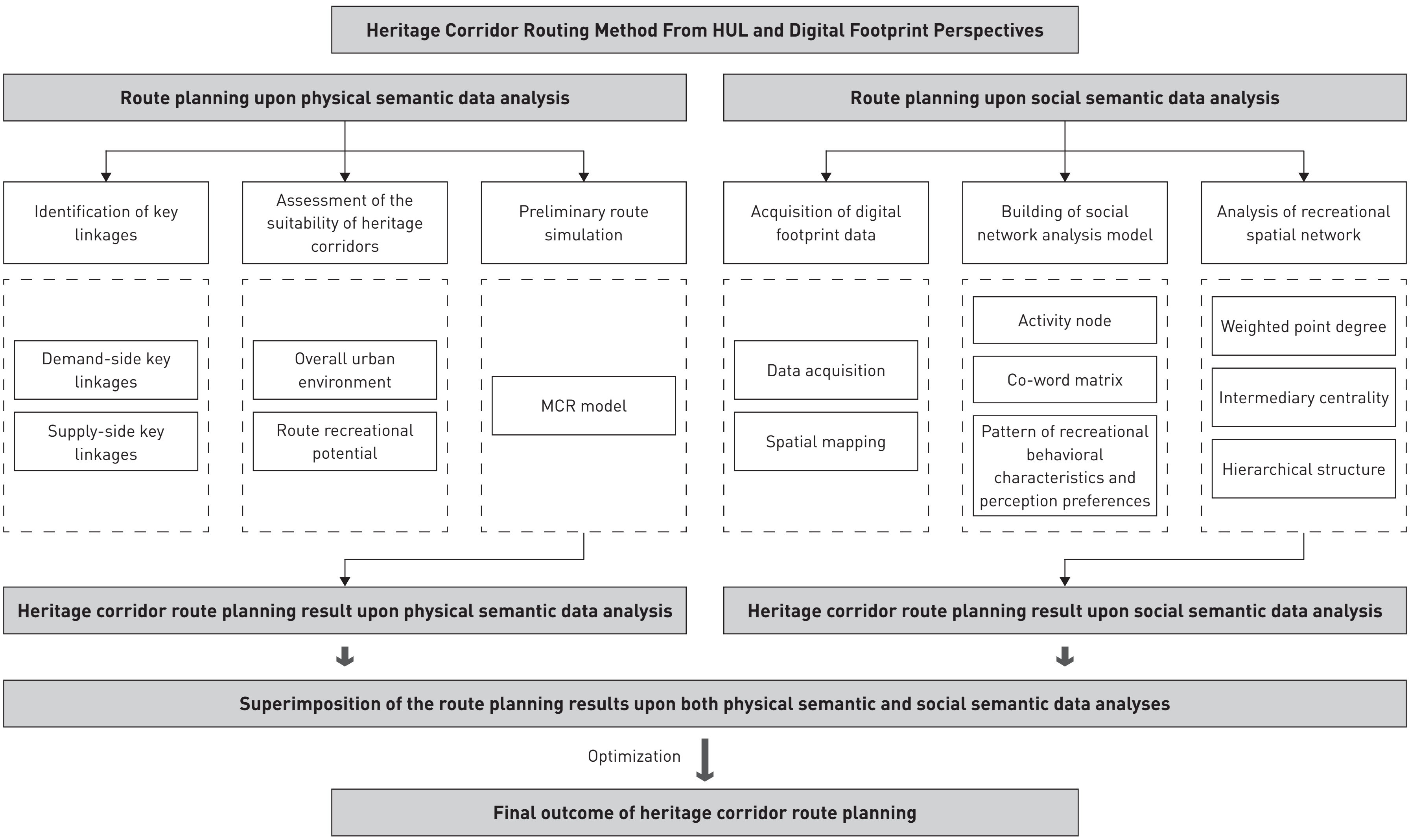
3.1 Data Acquisition and Processing

The data used for this study consist of physical semantics data and social semantics data. The former mainly includes spatial data, such as administrative division, transportation, green space, water system, elevation, and POIs in the study area. The latter mainly includes data such as activity location, travel movement, and comments on online travel platforms; these digital footprint data are then mapped and visualized. Then, the acquired digital footprint data are screened according to the definition of HUL, where only modern landscapes that are closely connected with traditional heritages can be selected as the landscape resource spots for the route planning of heritage corridors.

3.2 Route Planning Upon Physical Semantic Data Analysis—Urban Physical Environmemt Factors

The route planning upon physical semantic data analysis

1. Research roadmap



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includes three parts: identification of key linkages, assessment of the suitability of heritage corridors, and preliminary route simulation. The demand-side key linkages represent the public demand for recreation by heritage corridors; the supply-side key linkages indicate the potential spots for outdoor recreational activities in the city; such linkages are identified with the digital footprint data of heritage sites and landscape resources. Assessment of the suitability of heritage corridors includes the one on the overall urban environment and on the route recreational potential; then, the study utilizes MCR model to fit the preliminary routes of urban heritage corridors.

3.3 Route Planning Upon Social Semantic Data Analysis—Public Recreational Perception Factors

Different recreational behavior preferences in urban environment lead to different spatial patterns and characteristics[44]. This paper uses social network analysis model to establish functional relationships between users' recreational behaviors at all the nodes in digital footprints, such as comments, travel records, and trip plans, to form a co-word matrix, i.e. recreational spatial network; then, studies the pattern of recreational behavioral characteristics and perception preferences through the recreational spatial network. Finally, by calculating the weighted point degree (representing the importance of each landscape resource spot in public perception) and intermediary centrality (representing the intermediate degree of each landscape resource spot in users' recreational activities) of each node in the recreational spatial network, a hierarchical structure of the spatial distribution of landscape resource spots reflecting public perception preference is presented.

3.4 Optimization

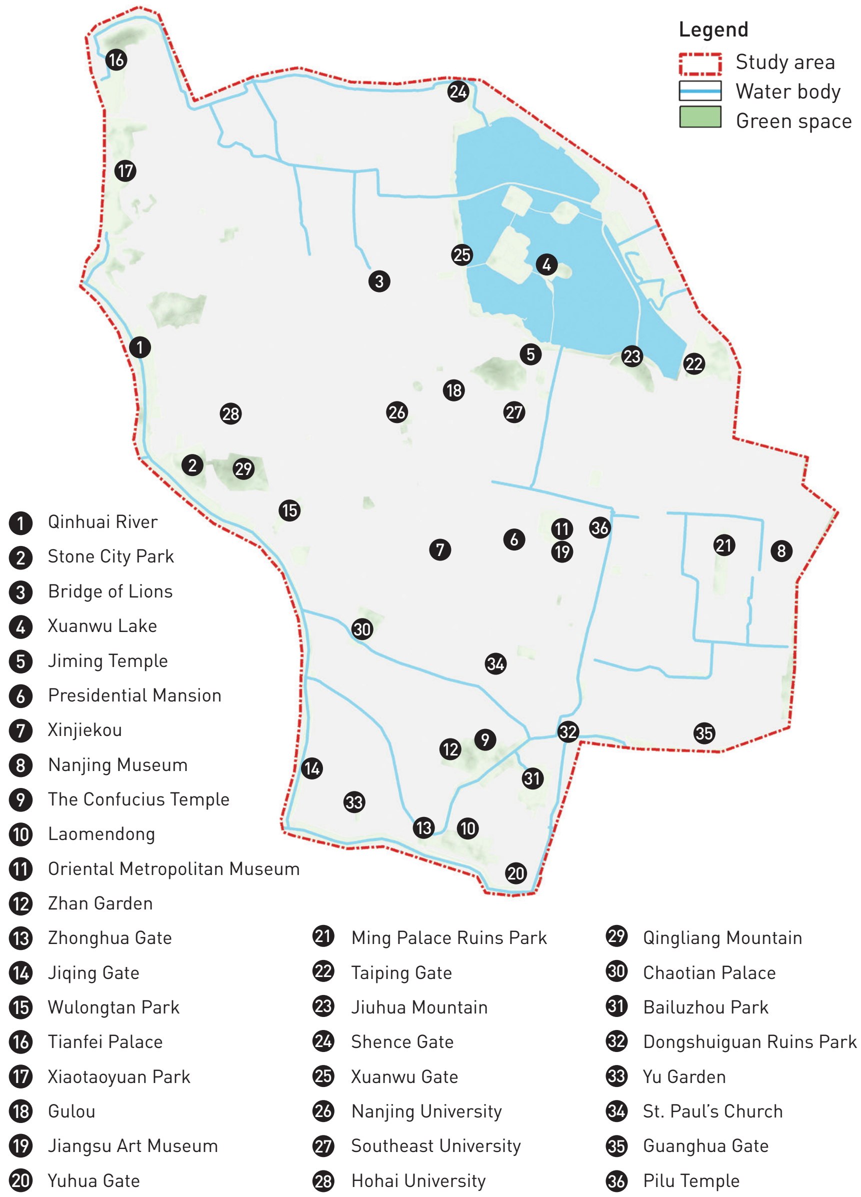
At last, the study superimposes the route planning results of the above two steps, and identifies the pattern of recreational behavioral characteristics according to the values of weighted point degree and intermediary centrality of each landscape resource spot. In order to improve the rationality of route planning, the superimposed result is fit with the actual environmental settings of the study area, and the optimized outcome of heritage corridor route planning is finally generated.

4 Case Study: Heritage Corridor Route Planning for the Historical Urban Area in Nanjing

4.1 Study Area

This research takes the historical urban area in Nanjing of Jiangsu Province, China as the study area. According to the delineated protection area of the historical precincts by the Territorial Spatial Master Plan of Najing (2021–2035), the city's historical urban area covers the space encircled by the Ming-Dynasty City Wall, the city moat (lake), and the surrounding buffer zone, with a total area of 50.9 km^2 [45] (Fig. 2). Nanjing is one of the first national historic cities in China, and enjoys rich historical landscape legacies of different times: not only does it possess the traditional style as a famous capital of ancient China, but also reflects the features as a vibrant metropolis in contemporary China sitting in the center of the Yangtze River Delta. The study area accommodates a large number

2. Study area



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of Internet users and a huge amount of digital footprints, which provides sufficient data samples for this research. Furthermore, with the accelerated urban renewals in the historical precincts, how to coordinate urban conservation and development has become a major challenge for the study area. Therefore, this case study is of great reference significance for relevant research.

4.2 Data Sources

4.2.1 Demand-side Data Sources

In this research, the public demand for heritage space and landscape resources is measured with the analyses of residential POI data, the heat data of users' travel, and the city nighttime light digital number (NTL-DN) values, to identify the demand-side key linkages. Specially, the residential POI data were sourced with the residential function from the Baidu Maps API interface in December 2021, and a total of 13,409 residential POIs in the study area were obtained. The heat data of users' travel were acquired from the city heat map and related raster data provided by Baidu Maps API interface, from April 26 to May 2, 2022, which covers a whole week including the May Day holiday. The NTL-DN values were obtained from the official website of Luojia1-01 Satellite in December 2021, with a data precision of 100 m.

4.2.2 Supply-side Data Sources

In this paper, the supply-side key linkages include 1) traditional heritage sites (remains and relics); and 2) the landscape resource spots that are closely connected with traditional heritage sites. These linkages were identified by the digital footprints on online travel platforms with high user activity, such as Ctrip.com, ly.com, and qunar.com. The real-time geographic coordinates of the landscape resource spots in the digital footprints were used to locate them in the geographic information system (GIS).

4.2.3 Resistance Surface Data Sources

For the overall urban environmental assessment, road vector data were obtained from OpenStreetMap and divided into 5 levels according to the urban road system planning of Nanjing; road density data were obtained through route density analysis of the road vector data; POI data of public facilities were obtained from the Baidu Maps API interface; terrain and slope data were obtained from the DEM elevation raster data provided by China Geospatial Data Cloud platform, with a data precision of 30 m; vegetation coverage data were obtained from the NDVI data of Luojia1-01 Satellite images, with a data precision of 100 m.

In terms of the assessment of route recreational potential, high-frequency activity routes were obtained by overlaying users' travel data with road vector data; the data of the distance from riverfront adopted the city water-buffer vector data from OpenStreetMap and were divided into 5 levels by proximity; the data of the type of urban green space were also obtained from OpenStreetMap and were categorized according to the Standards for Classification of Urban Green Space (CJJ/T85-2017). All the above data were acquired in December 2021.

4.2.4 Digital Footprint Data Sources

Given that data from different sources reflect varied information attributes, this research analyzes users' individual recreational perception and the characteristics of recreational spatial network by integrating multiple digital footprint sources. From December 1, 2020 to December 31, 2022, the researchers collected three types of digital footprints—comments from Ctrip.com, travel notes from ly.com, and trip records from qunar.com—by using the Bazhuayu crawler. Among them, the comments from Ctrip.com saw a larger data size and had more targeted information; the travel notes from ly.com were rich in content but often involve multiple recreational spots and redundant information; and the trip records from qunar.com could clearly show users' behavioral trajectory of tours, but the data size was relatively small. In order to ensure the route planning results cover modern landscape resource spots that are closely connected with traditional heritage sites, this study defines the types of such landscape resource spots in the study area as historical remains and relics, urban green spaces/squares, recreational sites (non-historical remains or relics; non-urban green spaces or squares), and universities/colleges and other cultural and sports venues (Table 1), and finally 140 landscape resource spots were selected. After cleaning and eliminating duplicates of the raw data through word frequency analysis, a total of 4,000 pieces of comments, 904 pieces of travel notes, and 1,609 pieces of trip records were kept.

4.3 Process of Route Planning Upon Physical Semantic Data Analysis

This route planning process mainly includes two steps: key linkages calculation and suitability assessment. The key linkages, as the starting points, nodes, and ending points of the heritage corridor in MCR model, were calculated for both demand-side and supply-side.

4.3.1 Calculation of Demand-side Key Linkages

Demand-side key points, as the starting points of the heritage

Table 1: Selection criteria for landscape resource spots in the study area

Type	Selection criteria
Historical remains and relics	Municipal-, county- and higher-level protected cultural and historical relics and sites
	District-level protected cultural and historical relics and sites, and with more than 50 comments on digital footprint platforms
Urban green spaces/squares	Within a distance of 500 m from a municipal-, county-, and higher-level protected cultural and historical relic or site
	Within a distance of 1 km from a municipal-, county-, and higher-level protected cultural and historical relic or site, and with more than 50 comments on digital footprint platforms
Recreational sites (non-historical remains or relics; non-urban green spaces or squares)	Within a distance of 1 km from a municipal-, county-, and higher-level protected cultural and historical relic or site
	Within a distance of 2 km from a municipal-, county-, and higher-level protected cultural and historical relic or site, and with more than 100 comments on digital footprint platforms
Universities/colleges and other cultural and sports venue	Within a distance of 1 km from a municipal-, county-, and higher-level protected cultural and historical relic or site, and open to the public
	Within a distance of 2 km from a municipal-, county-, and higher-level protected cultural and historical relic or site, and with more than 100 comments on digital footprint platforms

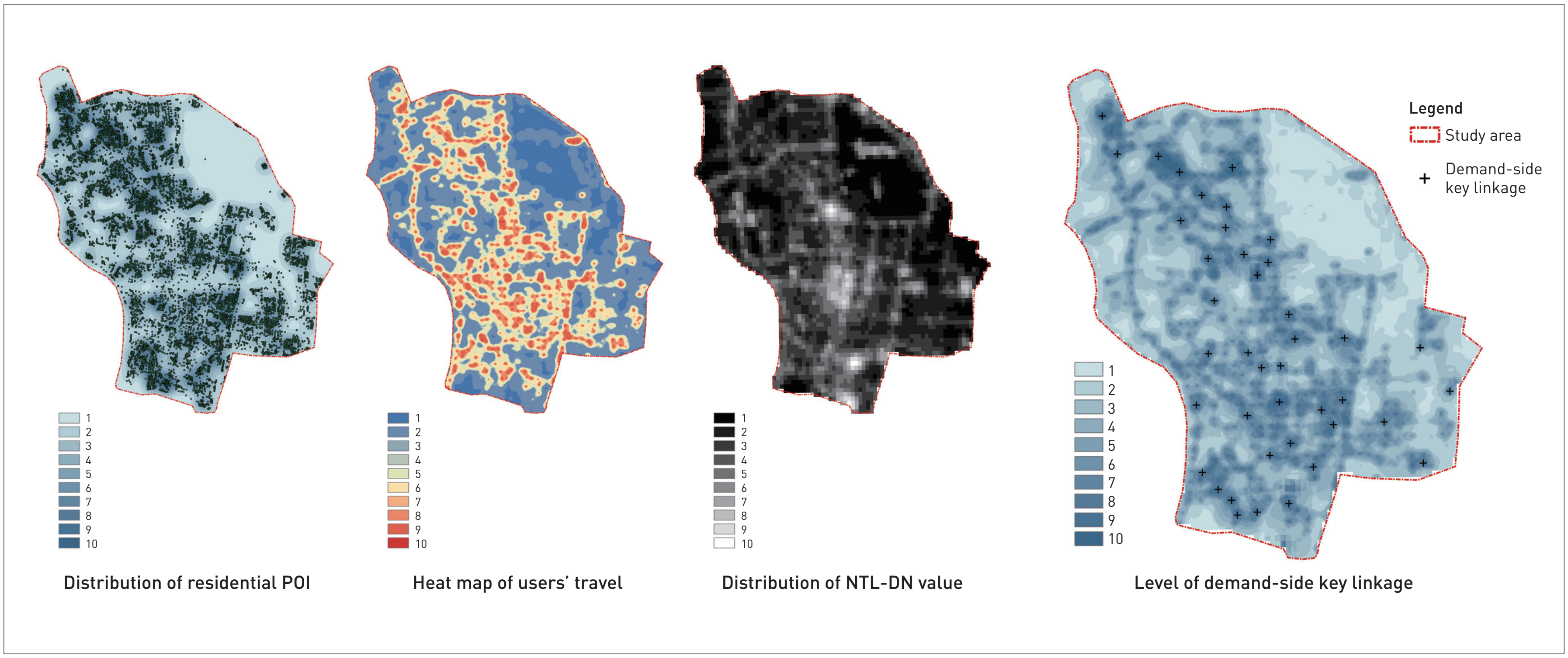
corridor, were identified upon the analyses of residential POI data, the heat data of users' travel, and the city NTL-DN values. First, the kernel density analysis of residential POI data was performed, and then the outcomes were normalized together with the heat data of users' travel and the city NTL-DN values before which three were equally weighted and superimposed. The normalization process used linear function to calculate the classification value of the fuzzy membership of each superposed outcome, which then were classified into 10 levels by natural breaks, respectively being assigned a value of 1 ~ 10—the higher the score, the higher the degree of crowd aggregation and behavioral vitality, suggesting a higher travel demand. In this paper, areas with a score of 7 or above were selected as crowd activity diffusion sources, i.e., demand-side key linkages, and 40 such linkages were mapped in total (Fig. 3).

4.3.2 Calculation of Supply-side Key Linkages

The supply-side key linkages include the nodes and ending points of the heritage corridor, and the areas with clustered landscape resource spots are taken as the supply source of recreational destinations. In this paper, the 140 selected landscape resource spots were normalized through kernel density analysis. The processing and valuation adopted the same method as that on the demand-side; the higher the score, the higher the degree of aggregation of landscape resource spots, indicating a stronger attraction for recreational activities. Areas with a score of 7 or above were selected as the crowd activity attraction sources, i.e. supply-side key linkages, and a total of 30 such linkages were found (Fig. 4).

4.3.3 Resistance Surface Analysis

Resistance surface analysis can simulate the difficulty degree of moving through a certain urban area—the higher the resistance value, the more difficult the movement. The resistance surface of the study area was measured through the assessments of overall urban environment and route recreational potential. Referring related research by Yi Shi[45] and Jingru Li et al.[46] that uses the same MCR model, as well as considering the actual situations within the study area, this research constructs an evaluation indicator system



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on resistance surface that is composed 5 aspects and 11 indicators (Table 2). Among them, each indicator was assigned a value from 1 to 9 according to the its resistance degree, from low to high. The traditional research commonly uses AHP hierarchical analysis to weight the indicators, which is largely subject to researcher's subjective judgment and might cause great disparities. Instead, this research adopts the CRITIC assignment method in the weighting of indicators, which is largely informed by the discriminabilities and conflicts between indicators, as well as considering the changes of data size[47], thus enhancing the accuracy of the results of MCR model analysis (Fig. 5).

4.3.4 MCR Model Fitting of Preliminary Route of Heritage Corridor

Finally, the resistance surface analysis results and key linkages obtained from the above steps were imported into the ArcGIS10.8 platform, and the Linkage Pathways tool was used to identify the minimum cost paths for users' movement flows from the demand side to the supply side in the study area, thus completing the heritage corridor route planning upon physical semantic data analysis (Fig. 6).

4.4 Process of Route Planning Upon Social Semantic Data Analysis

This route planning process includes two steps: digital footprint

3. Analysis process and result of demand-side key linkages
4. Analysis process and result of supply-side key linkages

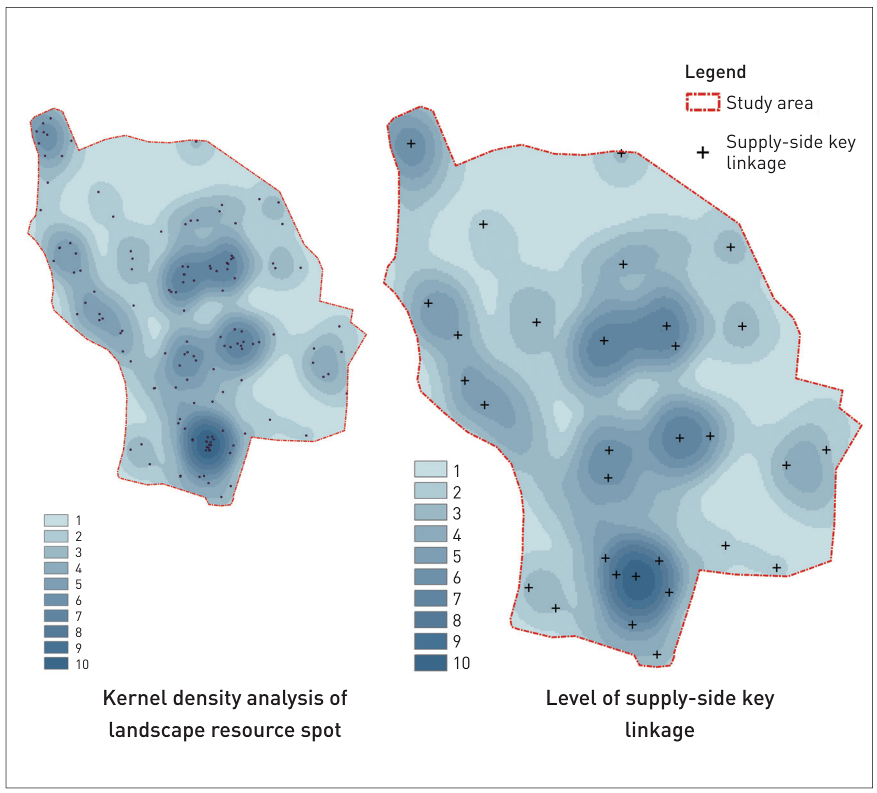

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Table 2: Evaluation system of resistance indicators of MCR model

Dimension	Aspect	Indicator	Interpretation	Resistance value	Total weight
Comprehensive urban environment	Built environment	Road level	Vacant land	9	4.16%
			Expressway	7	
			Main road	5	
			Secondary road	3	
			Branch road	1	
		Road density	Five categories divided by the natural breaks method upon the route density analysis of urban roads	1 ~ 9	9.15%
		Density of public service facility	Five categories divided by the natural breaks method upon the kernel density analysis of public service POIs	1 ~ 9	11.64%
	Natural environment	Terrain	Five categories divided by the natural breaks method upon DEM elevation data	1 ~ 9	10.53%
		Slope	> 12.0%	9	8.71%
			8.0% < x ≤ 12.0%	6	
			5.0% < x ≤ 8.0%	3	
			≤ 5.0%	1	
		Vegetation coverage	Five categories divided by the natural breaks method upon NDVI data	1 ~ 9	10.56%
Route recreational potential	Accessibility potential of recreational nodes	Accessibility of the demand-side	> 60 min (3,000 m)	9	9.53%
			45 min (2,250 m) < x ≤ 60 min (3,000 m)	7	
			30 min (1,500 m) < x ≤ 45 min (2,250 m)	5	
			15 min (750 m) < x ≤ 30 min (1,500 m)	3	
			≤ 15 min (750 m)	1	
		Accessibility of the supply-side	> 60 min (3,000 m)	9	11.86%
			45 min (2,250 m) < x ≤ 60 min (3,000 m)	7	
			30 min (1,500 m) < x ≤ 45 min (2,250 m)	5	
			15 min (750 m) < x ≤ 30 min (1,500 m)	3	
			≤ 15 min (750 m)	19	

Continued

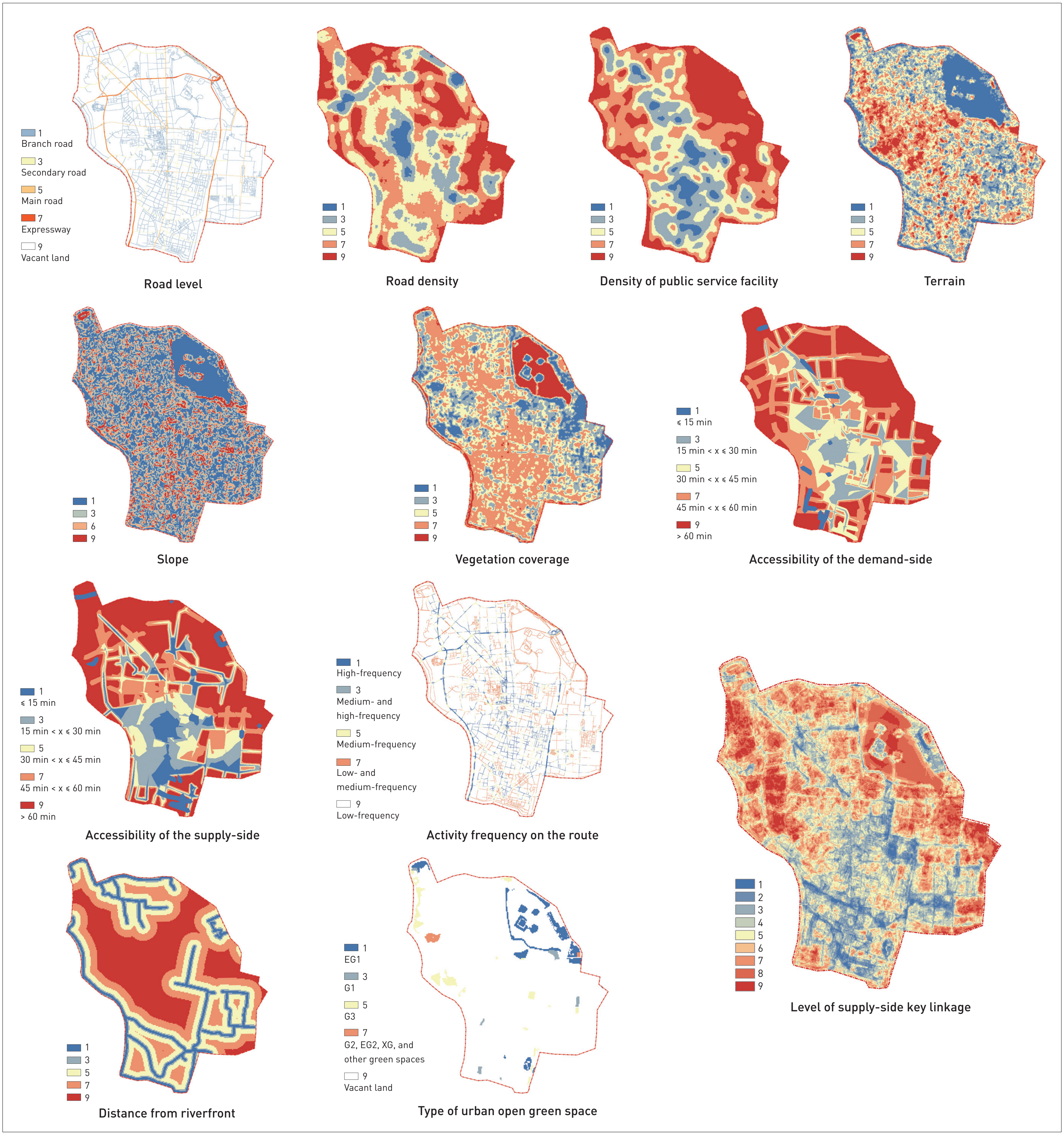
Table 2: Evaluation system of resistance indicators of MCR model

Dimension	Aspect	Indicator	Interpretation	Resistance value	Total weight
Route recreational potential	Potential of recreational activities	Activity frequency on the route	Route of low-frequency activity	9	3.51%
			Route of low- and medium-frequency activity	7	
			Route of medium-frequency activity	5	
			Route of medium- and high-frequency activity	3	
			Route of high-frequency activity	1	
		Distance from riverfront	> 600 m	9	12.24%
			300 m < x ≤ 600 m	7	
			100 m < x ≤ 300 m	5	
			50 m < x ≤ 100 m	3	
			≤ 50 m	1	
	Construction potential of recreation routes	Type of urban open green space	Vacant land	9	8.11%
			Green area for environmental protection (G2), green area for ecological conservation (EG2), attached green space (XG), and other green spaces	7	
			Land for square (G3)	5	
			Land for park (G1)	3	
			Green area for scenery recreation (EG1)	1	

analysis and recreational spatial network analysis. The former can reveal and visualize the spatial connections between public visits and landscape resource spots, while the latter can identify the public's preference in selecting recreational routes and the temporal characteristics of recreational behaviors.

4.4.1 Digital Footprint Analysis

First, a digital footprint library was established with the regular expressions of the textual data of comments, travel notes, and trip records. Second, ROST-CM6, a textual data mining tool, was used to analyze the co-occurrence of any two of the 140 landscape resource spots in the textual data (Fig. 7). Such a co-occurrence analysis can identify the relationship between users' flow direction and travel preference during recreational activities, and generate a co-word matrix reflecting the overall spatial movement preference. Then, the spatial pattern of the co-word matrix was obtained with GIS,



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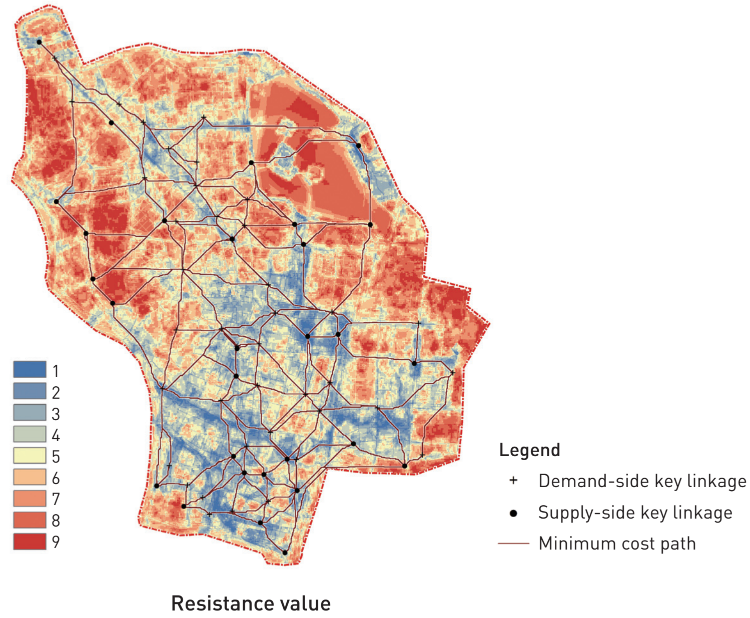
thus realizing an integrated display of users' spatial perception, recreational behavior, and temporal sequence of travel. After that, the flow intensity was divided into 5 levels by natural breaks, and the association strengths between landscape resource spots were visualized and a recreational spatial network was finally formed (Fig. 8).

4.4.2 Analysis of Recreational Spatial Network

This research further calculated the weighted point degree and intermediary centrality of every landscape resource spot in the recreational spatial network, to hierarchically characterize the spatial features of landscape resource spots. Specially, the value of weighted point degree ranged from 0 to 1,941—the higher the value, the higher subitability for the spot to become an important node of the heritage corridor. The value of intermediary centrality ranged from 0 to 636—the higher the value, the higher suitability for the spot to become an intermediary node of the heritage corridor. In this paper, the both indicators were divided into 5 levels by natural breaks, and then superimposed in the recreational spatial network, completing the route planning upon social semantic data analysis (Fig. 9).

4.5 Optimization of Route Planning Results

For the reasons of the dynamic changes of urban development status and of data accuracy, there is usually a discrepancy between the route planning results generated by MCR model with the actual urban environment. This makes adjustment and optimization of the heritage corridor route planning results necessary, where the following principles are followed. First, retaining the routes of level 3 and above and the routes passing through the landscape resource spots with a higher weighted point degree or a greater intermediary centrality. Second, based on the upper-level planning documents and the actual road network in the study area, the routes of level 1 or 2 would be deleted or shifted closer to the spots with a higher weighted point degree or a greater intermediary centrality.



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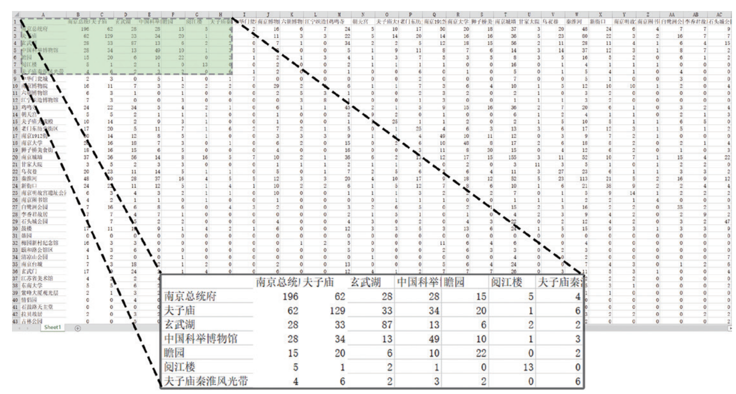

	南京总统	夫子庙	玄武湖	中国科举	瞻园	阅江楼	夫子庙秦
南京总统府	196	62	28	28	15	5	4
夫子庙	62	129	33	34	20	1	6
玄武湖	28	33	87	13	6	2	2
中国科举博物馆	28	34	13	49	10	1	3
瞻园	15	20	6	10	22	0	2
阅江楼	5	1	2	1	0	13	0
夫子庙秦淮风光带	4	6	2	3	2	0	6

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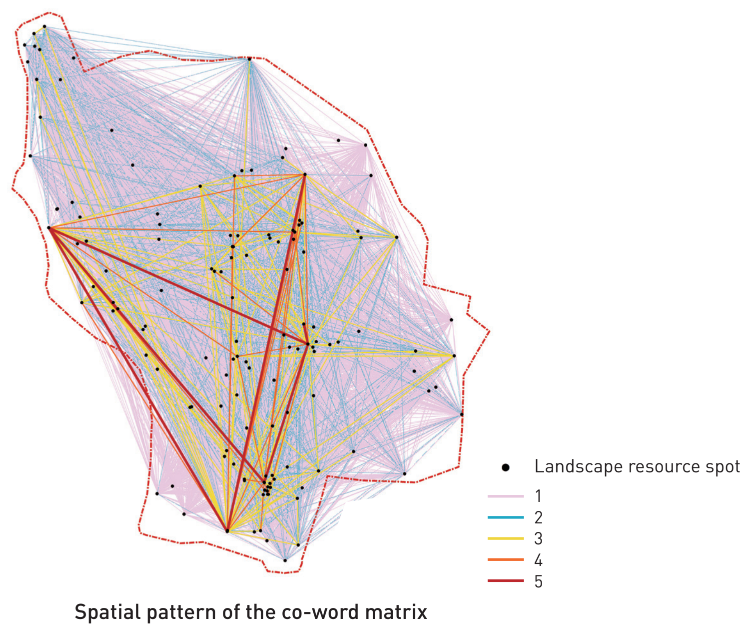

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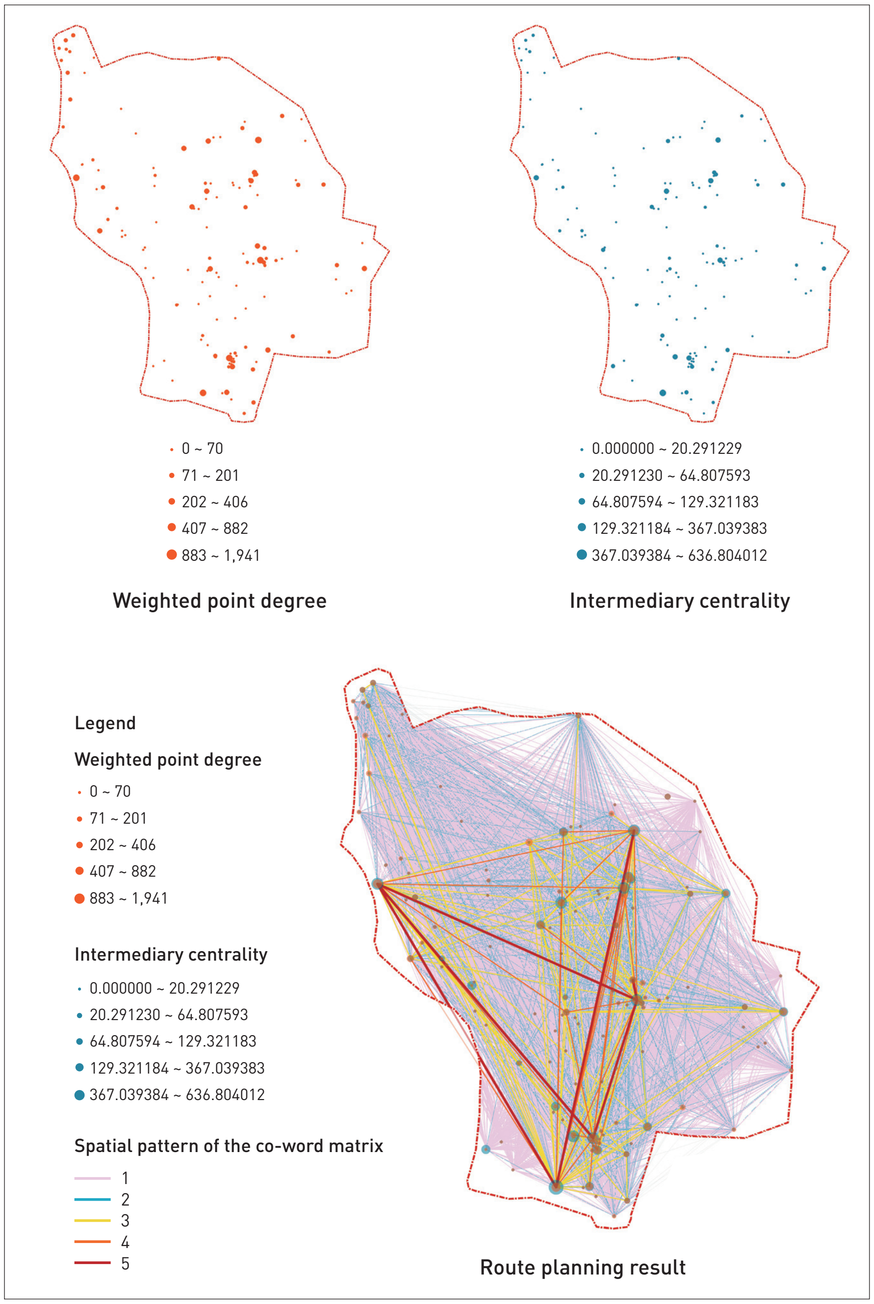
5. Evaluation indicator system on resistance surface and the analysis results of each indicator
6. Results of heritage corridor route planning upon physical semantic data analysis
7. Co-word matrix among the landscape resource spots: the numbers in the table represent the times of mentions of vertically-listed landscape resource spots in the textural data about the horizontally-listed landscape resource spots.
8. Creational spatial network



9. Results of heritage corridor route planning upon social semantic data analysis

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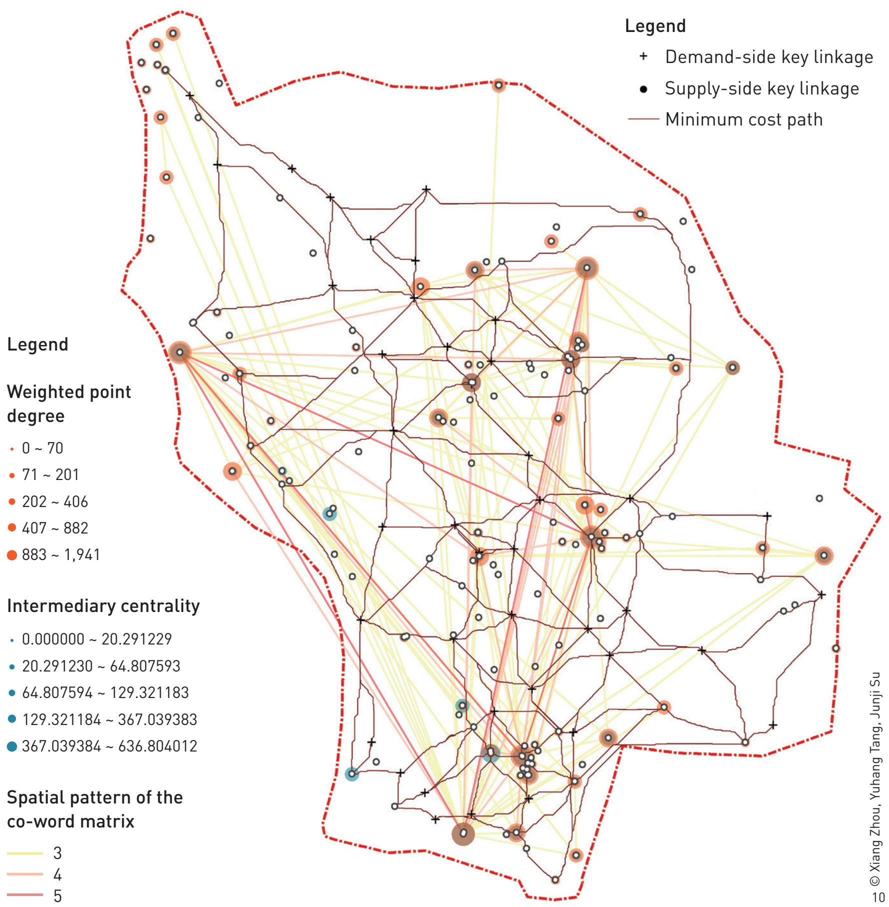
By superimposing the route planning results upon both physical semantic and social semantic data analyses (Fig. 10), it is found that the landscape resource spots with higher weighted point degrees are mainly distributed around the Qinhuai River and Stone City Park located in the west of the study area; the Bridge of Lions, Xuanwu Lake, and Jiming Temple located in the north; Presidential Mansion and Xinjiekou in the center; Nanjing Museum in the east; and The Confucius Temple and Laomendong in the south. Quite often, due to the high aggregation of landscape resource spots in the study area, the spots with a higher weighted point degree are also witnessed a greater intermediary centrality. The landscape resource spots that have a lower weighted point degree but a greater intermediary centrality are found around the Oriental Metropolitan Museum, Zhan Garden, Zhonghua Gate, Jiqing Gate, Wulongtan Park, etc. These landscape resource spots can be used as important intermediary nodes of the heritage corridor. For instance, the route section from Qinhuai River to Tianfei Palace in the west side of the study area was not covered in the route planning results based upon physical semantic data analysis, due to terrain reasons. However, the weighted point degree and intermediary centrality of the landscape resource spots cluttered along this section points are mostly high. So such spots as Xiaotaoyuan Park and Tianfei Palace should be included into the routes to make the final planning results fit with the reality better. The results of the optimized heritage corridor route planning are shown in Figure 11.

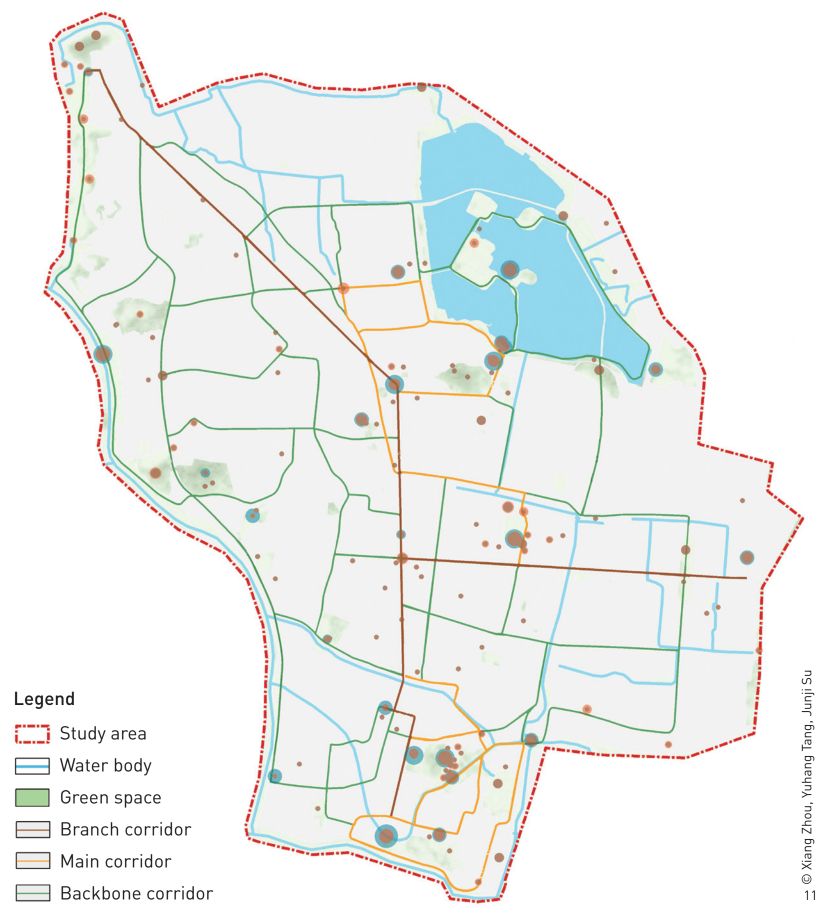
4.6 Significance of the Application of Heritage Corridor Route Planning Results

The application of the above heritage corridor route planning results can effectively supplement to the public participation mechanism in urban planning process, realizing the synergy of HUL and public space system of the historical urban area in Nanjing. In view of the fact that Nanjing has not yet issued a complete plan of heritage corridors for the city or the historical urban area, the results of this research will provide a direct reference for the quality improvement of public spaces in the city's historical urban area. Based on the number of landscape resource spots and urban roads passing through the heritage corridor routes, the weighted point degree of each landscape resource spot, and the route strength in the recreational spatial network, this study classified the planned heritage corridors into three grades: backbone, main, and branch (Table 3).

Backbone corridors connect the landscape resource spots with the highest weighted point degree and the strongest route strength in the recreational spatial network, and can play a role in supporting the overall image and structure of Nanjing's historical urban area. Backbone corridors mainly cover three city axes: Tianfei Palace–Gulou in the north of the study area; Gulou–Zhonghua Gate in the center area; and Xinjiekou–Nanjing Museum in the eastern part, spanning a total length of 11.5 km.

Main corridors can play an important role in improving the accessibility and reasonableness of the recreational flows within the city's historical urban area. They are largely distributed in the





10. Superimposition of the route planning results upon both physical semantic and social semantic data analyses

11. Optimized of heritage corridor route planning results

Table 3: Grading of heritage corridor route planning results

Grade of heritage corridor	Corridor passing conditions
Backbone corridor	No less than 3 landscape resource spots with a 5-level weighted point degree
	1) Expressways or main roads; and 2) no less than 4 landscape resource spots with a 5-level weighted point degree
Main corridor	No less than 2 landscape resource spots with a 5-level weighted point degree
	1) Main roads or secondary roads; and 2) no less than 3 landscape resource spots with a 5-level weighted point degree
Branch corridor	—

area of Bridge of Loins–Gulou–Jiangsu Art Museum in the middle part of the study area, as well as in the area of Zhonghua Gate–Yuhua Gate–The Confucius Temple in the south, running a total length of 18.4 km.

Branch corridors can play a key role in promoting the quality of the public space system in the historical urban area. Such corridors are distributed throughout the whole study area, and total length is up to 43.2 km.

5 Conclusions and Discussion

5.1 Research on Heritage Corridors From the Perspective of HUL

As a holistic heritage conservation concept and spatial practice approach, HUL, which emphasizes the integration of tradition and modernity and recognizes the values left by different historical periods and the evolution over time, is thus able to better juxtapose the contemporary landscapes with historical heritages. Compared with the traditional research on heritage corridor route planning, this study from the HUL perspective enriches the research dimension: it not only expands the study objects from historical monuments built in certain eras to layered urban heritages structured by different periods (including the contemporary), but also extends the research purpose from simply historical conservation towards the protection of overall urban environment of both natural and cultural values, understanding and embracing the concept of heritage corridors into a broader geographic–social context. The method for heritage corridor route planning established in this paper integrates public spatial perception, represented by digital footprints, with traditional spatial analysis, making the research on heritage corridor goes beyond urban material environments, becoming an attempt that integrates the public perception expression mechanism into the studies on urban heritage corridor route planning.

5.2 Improvement of Public Expression Mechanism Supported by Digital Footprints

In the Internet era, we easily notice the size of users and the data generated through users' interactions with urban infrastructure, but sometimes overlook the nature and manner of data usage. Analyzing intuitive structured data can tell us what is happening, while analyzing complicated unstructured data can help us understand why. Digital footprints and other sorts of unstructured or semi-structured data contain huge unexplored information, so how to convert them into structured data that is easy to analyze quantitatively becomes a key issue to studies on digital footprints. The current advance of technologies such as semantic web analytics, spindle coding, and data visualization supports a direct conversion of data, and research paradigms related to digital footprints can help dissect the interactions between users and landscape resource spots, allowing us to understand users' spatial perception and recreational behaviors at a macro level. More importantly, the rise of social media has inspired new ways for public participation, and the public's role in urban management has begun to change profoundly—from the perspective of digital footprint, people's behavioral preferences and perceptions can be better translated into planning tools.

5.3 From Physical Space to Social Entities

If the use of digital footprint can transform disordered, random recreational behaviors into semantic forms of socio-spatial organization, another contribution of this study lies in not only examining users' recreational experience in the HUL as a kind of activity, but also respecting individual users as social entities, tangibly combining the objective and the subjective, the quantitative and the qualitative. However, it is worth stressing that although the user-generated data on the Internet can reflect people's spatial demands, emotional experiences, and perceptual preferences, studies on digital footprint also face problems such as lack of user background information, high technological dependence on platform or device, and large differences in the degree of data availability. In other words, at present, digital footprint can only offer complementary assistance in selecting the route planning of heritage corridors. At the same time, the selection of landscape resource spots necessitates the re-defining the information contents of digital footprint to avoid an unlimited expansion of targets, it also is expected to further limit the targets by narrowing data types or sources, in order to enhance the effectiveness of route planning results. Besides, how to improve data precision, enhance date representativeness, incorporate more public participation mechanisms, and advance the coupling algorithm model of subjective and objective factors are also important topics for the future research on heritage corridor route planning.

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基于历史性城市景观与数字足迹视角的遗产廊道选线方法——以中国南京市历史城区为例

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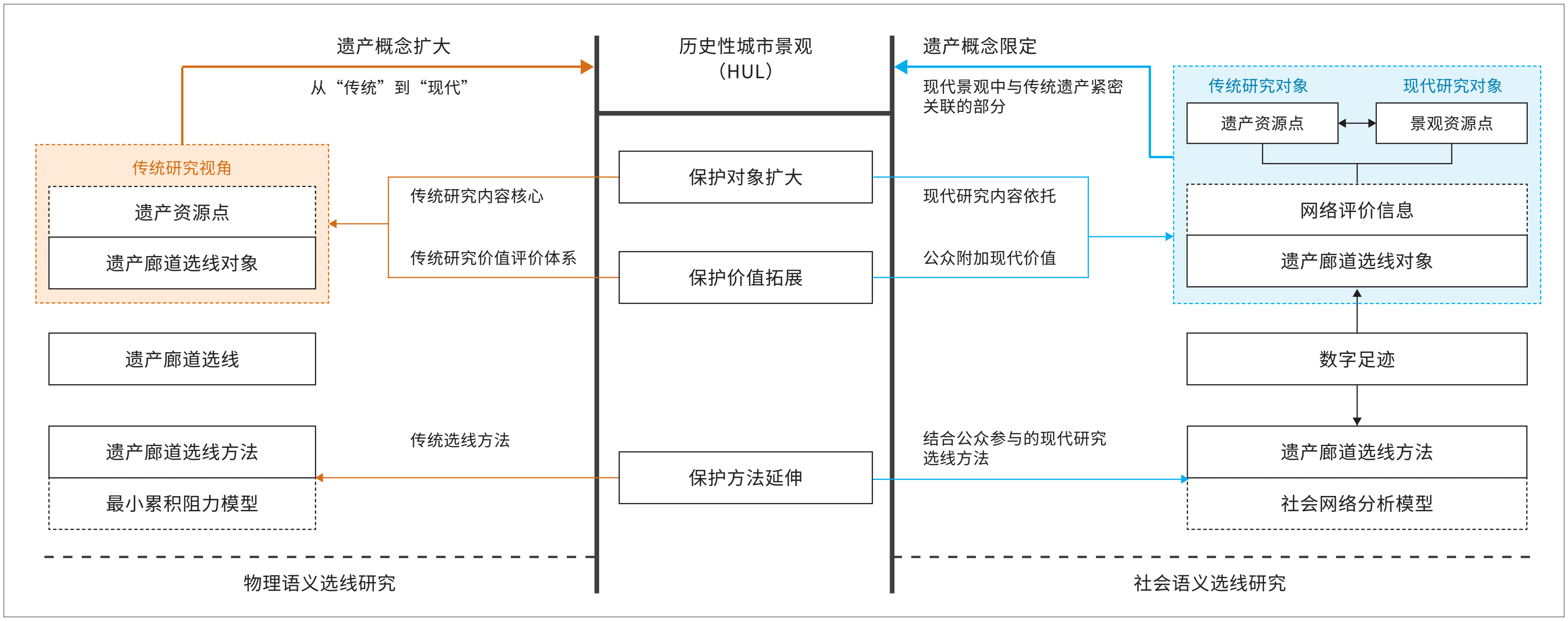
图文摘要



文章亮点

- 基于历史性城市景观对遗产的概念及景观资源进行界定，构建遗产廊道选线新方法
- 通过数字足迹数据分析将客观环境条件与游憩者主观感知相融合，纳入遗产廊道选线过程
- 将具备主观情感的游憩者作为遗产廊道构建的社会实体，体现对社会实体的重视

关键词

遗产廊道；
选线；
历史性城市景观；
最小累积阻力模型；
数字足迹；
社会网络模型；
城市景观资源

摘要

遗产廊道作为一种串联历史文化与自然景观资源的系统性保护方法，融合了人文环境与自然环境，可以为公众提供休闲娱乐、游憩健身等活动的连续线性空间。传统的遗产廊道选线研究大多聚焦于分析物质空间条件，忽略了公众感知表达和公共参与机制。基于历史性城市景观理念挖掘与传统遗产内容紧密关联的现代景观

资源，通过解析游憩者的数字足迹，将人群游憩行为偏好与空间感知纳入遗产廊道选线过程，可实现城市物理语义选线与社会语义选线的结合。基于此，本研究包括三个部分：1）通过数字足迹分析，将城市传统遗产与景观资源点纳入遗产廊道选线过程，通过最小累积阻力模型拟合物理语义选线结果；2）利用数字足迹中的人群流动轨迹与网络文本信息构建共词矩阵，完成社会语义选线；3）耦合物理语义选线与社会语义选线结果，结合实际情况优化遗产廊道选线结果。研究实现了在遗产廊道选线过程中，将城市景观资源与公众游憩行为和空间感知的有效整合，有利于城市遗产的整体保护与公共空间的系统提升。

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1 研究背景

1.1 遗产廊道与历史性城市景观

“遗产廊道”（heritage corridor）的概念发端于美国，最初是指拥有特殊文化资源集合的线性景观，通常表现出明显的经济中心、蓬勃发展的旅游，以及对于历史遗迹的适应性利用与环境改善[1]。随着应用范畴的扩大，遗产廊道研究开始强调通过河流、绿道、街道与铁路等线性空间要素，从整体层面系统性推动社会经济的复兴，由此带动遗产保护与城市建设的协同发展。[2]-[4]

作为一种集成了多元文化资源的区域性遗产体系保护方法，遗产廊道聚焦于不同尺度的线性景观资源的整合与优化，涉及从划分历史地段的局部保护到关注全域历史感知信息的整体保护[5]，尤其强调自然、经济、文化三者并举的综合性保护措施[6]-[8]。与此同时，对于遗产廊道选线方法的系统性研究开始受到学界重视。近年来，随着全球化与本土化冲突的加剧，由大规模城市开发所引起的遗产保护争端不断增多[9]。为了平衡遗产保护与城市发展的关系，联合国教科文组织于2011年通过《关于历史性城市景观的建议书》（以下简称“建议书”），提议将历史性城市景观（Historic Urban Landscape，HUL）概念置于城市转型和全球化的背景中，研究不同历史时期形成的景观在城市空间发展中的作用与价值。[10][11]

众多国家通过建立地区性的保护政策及划定“历史保护区”等手段来维护历史文物建筑。然而，在保护范畴不断拓展的当今，这些方法已不能完整地覆盖具有艺术或文化价值的城市景观[5]。HUL的概念则超越了“历史中心”与“文物建筑群”等“历史保护区”的传统讨论范畴，囊括了更加广阔的城市背景与地理环境，是一种更加整体的遗产保护理念与方法[12]。其倡议以一种基于景观的方法来识别、保护和管理历史地区，并在平衡城市建成环境与自然资源、当代需求与未来发展的基础上，将遗产保护和城市发展等目标及不同时空要素进行有效整合[13]。因此，遗产的内在价值与社会—文化属性的耦合催生了HUL视域下的遗产廊道研究，其既是保护和延续城市遗产独特性的关键举措，也是激发城市公共空间活力的有效途径。

1.2 数字化时代的遗产廊道研究

目前，有关遗产廊道的研究大多因循自上而下的宏观视角，对包括河流峡谷、文化线路、古道走廊等有形、线性景观资源开展选线研究[7][14]-[16]。而在具体操作方式上，这些研究大多从城市功能、空间区位、历史文化、自然景观相互结合的视角进行资源整合规划与线路选择研判[17][18]。然而，传统的选线方法较少考虑游憩者自身的行为方式、感知体验、审美偏好等主观因素对选线过程的影响，公众感知表达机制无法较好地纳入遗产廊道的构建过程中。在这种背景下，将大众游憩行为偏好分析纳入遗产廊道选线过程，成为了优化遗产廊道构建方法的创新研究方向。

进入数字化时代，网络社交平台正逐渐成为公众记录游憩行为及发表评论的核心载体，公众留存在互联网的数字足迹也已达到前所未有的数据规模，拥有巨大的研究潜力[19]。数字足迹中包含大量由用户交互产生的时空信息，并且记录了公众的交通、通讯、游憩、摄影、点评、签到等各类空间行为[20]，因此可用于识别人群的行为规律与感知偏好。基于此，本文尝试将数字足迹纳入遗产廊道的选线过程，挖掘公众游憩路线中与传统遗产资源呈现强相关性与高交互性的现代景观资源；并基于HUL视角，利用社会网络分析模型来识别游憩者的空间行为特征，以此修正传统选线方法中因忽略公众感知表达机制而产生的局限性。这一研究范式的转型也为数字化时代下城市物理空间因素与公众主观感受因素相结合的遗产研究与实践提供了参考。

1.3 遗产廊道选线范式研究转型的现实意义

作为城市景观和城市遗产的重要组成部分，城市遗产廊道具有复杂性，其核心目标在于保护、活化遗产资源，通过串联散布于城市各处的资源点形成廊道，实现城市公共空间的活力维系与品质提升。随着HUL概念的提出，遗产廊道研究开始注重城市建成环境中历史文化与现代要素的融合。出于对HUL中“活态遗产”[21][22]的考量，当代景观资源被纳入遗产廊道的选线范畴。与此同时，为了避免“遗产”概念的无限扩大，本文强调，与传统遗产紧密关联的现代景观资源才是遗产廊道选线中需要考量的内容。因此，兼顾HUL与数字足迹两种视角的遗产廊道选

线研究，既是一种城市物理空间上的遗产资源形成游憩流线的过程，也是一种基于公众主观感知偏好分析的公共空间体系构建。正是由于这种双重属性，此种遗产廊道选线方法对于城市遗产保护和城市发展规划具有重要的现实价值。

2 研究综述

2.1 基于HUL视角的遗产廊道研究现状

1984年，美国国会立法将从芝加哥郊区延伸至伊利诺伊州中心的“伊利诺伊—密歇根运河”指定为国家遗产廊道，“遗产廊道”的概念正式由此确立[23][24]。这一概念自2001年引入中国[25]，已引发众多学者的讨论，在保护规划、体系建构、分析评价等方面产生了大量的研究成果。例如，在保护规划方面，奚雪松等人通过分析美国国家遗产廊道的保护与管理方法，对中国线性遗产的可持续利用提出建议[26]。在体系建构方面，李伟等人通过探讨遗产廊道的实践方法，初步建构起大运河整体保护的研究框架[27]；俞孔坚等人通过分析遗产廊道的适宜性，以台州市为实践对象，对快速城市化地区的遗产廊道进行了探讨，并尝试利用最小累积阻力（MCR）模型构建遗产廊道[8]。在遗产廊道的分析评价方面，吕龙等人基于旅游价值构建遗产廊道的评价指标，从整体效益出发评估了遗产廊道的游憩价值[28]。

随着HUL概念的提出，利用基于景观的方法将遗产资源视为一个整体系统，成为一种认识城市历史价值的新思维[29]。在历史层积与城市发展的动态叠加下，HUL理念为遗产廊道的相关研究提供了更加综合的视野。考虑到遗产资源的复杂性与多样性，近些年，有研究尝试扩大遗产廊道的选线范围（如纳入生态保护、旅游开发等内容）[23]，但与HUL理念切实结合的遗产廊道相关研究仍较少。

在技术与方法层面，国外学者的研究以定性评价和理论分析为主，聚焦于对遗产廊道景观特征的分类评价，以及管理方法的优化提升等。例如，玛·洛伦—门德斯等人定义了公路型遗产廊道的景观特征，并从自然、文化、历史三个方面对遗产廊道的景观价值进行了定性评价[30]；B. 拜纳姆·博利等人利用演绎定性分析法对遗产廊道的旅游开发、地方参与及管理机制进行了探讨[31]；泰加尔·希加尔等人则基于舒适性理论，定性分析了城市道路、绿地、公共服务设施配套缺失等问题，提出通过改善公共资源提升遗产廊道完整性与舒适性的设想[32]。国内学者对于遗产廊道构建方法的研究，主要是基于专家打分法分析城市环境，进而拟合生成遗产廊道线路。例如，胡金龙、王茹等人运用MCR模型，依据土地利用类型、高程、坡度等物理环境的阻力值，通过专家打分法判定影响因子权重，进而构建遗产廊道网络[33][34]；贺鼎等人则将MCR模型与多中心性评价模型相结合，基于专家打分法制定评估框架，并对遗产廊道多层级、多类别的空间结构进行了定量评价[35]。

在上述研究中，MCR模型是当前遗产廊道选线的主流技术手段，即通过分析不同环境因子的适宜性，判别研究区域内景观资源点的聚集与分布状态，进而从中甄选出目标行为轨迹的适宜线路[33]。而在选线内容上，目前的研究大多关注遗产空间与景观资源本身，或者周边环境要素[36]，缺少对于游憩主体的行为与感知偏好的考量。与此同时，越来越多的研究表明，在城市研究中加入对于个体时空数据的分析愈发重要[37]。因此，本研究也尝试在遗产廊道选线过程中纳入对于游憩主体空间行为数据的分析。

2.2 基于数字足迹视角的遗产廊道研究现状

为了构建广泛的公众感知表达机制，遗产廊道研究可基于大数据分析探知人群的空间行为特征与游憩感知偏好[20]。目前，社交媒体用户生成内容（UGC）已被广泛应用于遗产廊道研究领域。例如，周详等人利用数字足迹对南京秦淮河流域的HUL展开研究，初步构建起基于专家打分法与公众参与融合视角的景观视觉特征分析与感知评价体系[38]；赵琴等人将重庆夜间旅游景点作为研究对象，从整体和个体两个层面对旅游流网络结构与景观形象感知展开定量分析[39]；王瑞等人通过比较官方与游客两方面关于遗产廊道的网络文本，统计分析了各类遗产景观的关注次数与共现次数，由此探讨二者关注偏好与共现效应的差异[40]。由此可见，一方面，数字足迹为我们提供了详细评估城市遗产使用方式与空间感知的途径，从而有助于制定遗产保护与管理决策；另一方面，因其包含游憩者丰富而真实的感知偏好，也为遗产廊道选线研究提供了可体现公众感知表达的途径。

数字足迹主要包含两种类型：一种是由公众与通讯设施相互作用而产生的数据，如手机在使用过程中产生的位置日志和浏览记录等，属于被动型数字足迹；另一种是由公众上传到社交平台上的数据，如评价打分、旅行照片、行程记录等，属于主动型数字足迹[41]。其中，可从后者中探知公众在游览不同遗产空间与景观资源时真实的主观感受[20][42]。加之，由于没有固定的框架，此类数据具有较强的多样性与延展性，还能有效反映游憩者与HUL之间的互动关系[43]。因此，本文旨在基于数字足迹视角，采用MCR模型识别使用者在各景观资源点间的流动强度与游憩行为偏好，从而构建一套能够涵盖城市物理空间因素与公众主观感受因素两方面评价因素的遗产廊道选线方法。

3 研究技术路线

本文构建的遗产廊道选线方法主要包括以下4个流程（图1）。

3.1 数据挖掘与处理

基础信息涵盖物理语义和社会语义两个方面。前者主要包括研究

区域内的行政区划、交通网络、绿地、水系、高程信息，以及兴趣点（POI）等空间数据；后者主要包括旅游平台提供的活动定位节点、行程、评论等数字足迹数据，并将数字足迹数据进行空间定位。基于HUL定义，对获取到的数字足迹数据进行处理，对现代景观资源点的选取范围进行限定，仅将与传统遗产联系紧密的现代景观纳入遗产廊道景观资源选点。

3.2 物理语义选线——城市物理空间因素

物理语义选线研究分为关键连接点识别、适宜性评价与MCR模型模拟初步选线三部分。需求关键连接点表征公众对于遗产廊道的游憩需求程度；供给关键连接点揭示城市能够供给户外游憩活动的潜在空间，将遗产空间与景观资源点的数字足迹作为供给端的信息来源。遗产廊道适应性评价方面包括城市综合环境评价和路径游憩潜力评价两方面，研究基于分析结果利用MCR模型拟合城市遗产廊道初步选线。

3.3 社会语义选线——公众主观感受因素

人群在城市环境中的不同游憩行为偏好具有不同的空间特征[44]。基于此，本文利用社会网络分析模型，将网络评论、游记信息与行程计划等数字足迹活动节点中蕴含的游憩行为通过函数关系相整合，形成共词矩阵，然后透过形成的游憩空间网络来研究游憩者行为特征与感知偏好的规律性。最后，通过计算游憩网络中各个节点的加权点度与中介中心度——加权点度表示各景观资源点在公众感知中的重要程度，中介中心度则体现各景观资源点在人群活动的中间程度——分级刻画景观资源点在公众感知层面上的空间分布特征。

3.4 线路优化

最后，研究将物理语义选线结果与社会语义选线结果进行叠合，并根据各景观资源点的中介中心度与加权点度等识别空间结构特征。为了提升线路的合理性及与现状的契合性，对遗产廊道选线结果进行修正和优化。

4 实证研究：南京市历史城区遗产廊道选线

4.1 研究区域

本文以中国江苏省南京市历史城区为研究区域。根据《南京市国土空间总体规划（2021—2035年）》划定的老城历史文化保护范围，南京历史城区主要由明城墙、护城河（湖）及周边缓冲地带环抱的空间组成，研究区域面积总计50.9km^2 [45]（图2）。首先，南京是中国首批国家级历史文化名城，历史城区范围内包含城市发展过程中具有不同时代特征的历史景观：不仅拥有历代传统古都风貌，还体现着中国近现代都市特征。其次，南京是长江三角洲地区的中心城市，研究区域内的网络使用人群较多、数字足迹容量较大，具备充足的数据样本条件。再者，随着旧城改造与城市更新进程的加速，如何协调城市保护与开发成为南京历史城区面临的一大挑战。因此，将南京历史城区作为研究区域具有重要的示范意义与样本价值。

4.2 数据来源

4.2.1 需求端数据来源

为揭示公众对于遗产空间与景观资源的需求情况，本文将居住区POI数据、居民出行热力数据、城市夜间照明遥感影像像元亮度值（简称“夜间照明DN值”）作为需求端关键点识别的依据。其中，居住区POI数据通过提取百度地图API接口提供的POI数据中的居住功能获得，采集时间为2021年12月，共获取研究区域内居住区POI13 409个。居民出行热力分布数据来自百度地图API接口提供的城市热力图及相关栅格数据，获取时间为2022年4月26日至5月2日，为期一周并覆盖“五一”假期。城市夜间照明DN值于2021年12月通过珞珈一号卫星官网获得，数据精度为100m。

4.2.2 供给端数据来源

本文将携程网、同程网、去哪儿网等用户活跃度较高的网络旅行平台中包含的传统遗产点（遗址遗迹）及与之紧密相连的、通过数字足迹筛选出来的景观资源点，作为供给端关键点选取的主要依据。其中，根据通过数字足迹筛选出来的景观资源点发布时的实时地理坐标，在地理信息系统（GIS）中进行定位。

4.2.3 阻力面数据来源

在城市综合环境评价方面，道路矢量数据通过OpenStreetMap获得，并根据南京城市道路规划划分为5级；道路密度数据通过对道路矢量数据进行线密度分析获得；公共服务设施POI数据从百度地图API接口提供的POI数据获得；地形、坡度数据从中国地理空间数据云平台提供的DEM高程栅格数据中获得，数据精度为30m；植被覆盖度数据通过珞珈一号卫星影像的NDVI数据获得，数据精度为100m。

在路径游憩潜力评价方面，人群高频活动路径通过出行热力数据与道路矢量数据叠加获得；河流缓冲区数据通过对获取自OpenStreetMap的城市水域矢量数据进行缓冲区计算得出，并根据与水域的距离划分为5级；城市开放绿地类型数据同样来自OpenStreetMap，并根据《城市绿地分类标准》（CJJ/T85-2017）进行划分。上述数据获取时间均为2021年12月。

4.2.4 数字足迹数据来源

鉴于不同数据源反映的信息侧重点不同，本研究通过整合不同数字

足迹源来分析游憩群体的主观评价与游憩空间网络特征。数字足迹采集时间为2020年12月1日至2022年12月31日，采集对象包括携程网的评论信息、同程网的游记信息，以及去哪儿网的行程记录三种数字足迹类型，使用八爪鱼网络平台数据爬取器获取。其中，携程网的评论数据量庞大且针对性较强；同程网的游记内容丰富，但游记中通常会涉及多个游憩点，信息量较为冗杂；去哪儿网独特的行程功能可清晰地展现游客的行为轨迹，但数据量相对较少。为了使选线结果包含与传统遗产紧密关联的现代景观资源，本研究对于研究区域内的遗址遗迹、城市绿地／广场、非遗址遗迹类和非城市绿地／广场类游憩场所、高校／文体活动场所等景观资源点进行了筛选（表1），最终选取了140个景观资源点。在利用词频分析法对初始数据进行清洗、去重后，共采集到符合分析要求的评论信息4 000条、游记信息904篇、行程记录1 609篇。

4.3 基于城市物理空间因素的物理语义选线

该阶段主要包括关键连接点计算与适宜性评价两部分。其中，关键连接点作为MCR模型中遗产廊道的起点、节点与终点，分为需求端与供给端两类。

4.3.1 需求端关键连接点计算

需求端关键连接点作为遗产廊道的起点，主要通过居住区POI数据、居民出行热力数据、城市夜间照明DN值来识别作为人群活动扩散点源。首先，对居住区POI数据进行核密度分析，然后将其与居民出行热力数据和城市夜间照明DN值进行归一化处理并等权叠加。归一化处理过程选择线性函数计算各项数据模糊隶属度的分类值；然后，对叠加结果进行分类，并按照自然断点法依次划分为10个等级，分别赋值1~10；分值越高，表示该区域中人群聚集程度与行为活力越高，出行需求也越高。本文将7分以上的区域作为人群活动扩散点源（即需求端关键连接点），共识别出需求端关键点40个（图3）。

4.3.2 供给端关键连接点计算

供给端关键点包括遗产廊道的节点与终点，主要将景观资源点较为集中的区域作为游憩目的地供给来源。本文将筛选出的140个景观资源点在核密度分析的基础上进行归一化处理。处理过程和赋值逻辑与需求端关键点的分析相同，分值越高，表示某一区域内景观资源点的聚集程度越高，对人群游憩活动的吸引效能越明显。同理，本文将7分以上的区域作为人群活动吸引点源（即供给端关键点），共识别出供给端关键点30个（图4）。

4.3.3 阻力面分析

阻力面分析可以模拟人群在通过城市空间时的难易程度，阻力值

表 1：研究区域内景观资源点筛选标准

点位类型	选取标准
遗址遗迹	市县级文物保护单位及以上
	区级文物保护单位且数字足迹平台评论数量超过 50 条
城市绿地／广场	与市县级文物保护单位及以上的文物保护单位距离不超过 500m
	与市县级文物保护单位及以上的文物保护单位距离不超过 1km 且数字足迹平台评论数量超过 50 条
游憩场所（非遗址遗迹、非城市绿地／广场）	与市县级文物保护单位及以上的文物保护单位距离不超过 1km
	与市县级文物保护单位及以上的文物保护单位距离不超过 2km 且数字足迹平台评论数量超过 100 条
高校／文体活动场所	与市县级文物保护单位及以上的文物保护单位距离不超过 1km 且向公众开放
	与市县级文物保护单位及以上的文物保护单位距离不超过 2km 且数字足迹平台评论数量超过 100 条

越高，表示人群空间流动越困难。本文主要通过城市综合环境评价与路径游憩潜力分析来计算研究区域的空间阻力情况。基于时萱[45]、李静茹等人[46]对于MCR模型的研究，同时考虑到南京历史城区的实际情况，本研究构建起一个包含5个评价方面、11项指标的阻力因子评价体系（表2）。其中，各因子依照阻力程度由低至高分别赋值1~9。传统研究常用AHP层次分析法评价权重，但容易产生因人为主观判断而偏差较大的问题，因此本文在因子权重计算过程中采用CRITIC赋权法，并利用指标间的辨别力、冲突性，以及数据自身信息量变化情况确立指标的客观权重[47]，从而提升MCR模型分析结果的准确性（图5）。

4.3.4 MCR模型拟合遗产廊道初步选线

最后，将上述阻力面分析结果与关键连接点导入到ArcGIS10.8平台，使用Linkage Pathways工具，识别人群在空间流动过程中的最小成本路径，形成从需求端到供给端的适宜线路，由此完成基于城市物理空间因素的遗产廊道选线（图6）。

4.4 基于公众主观感受因素的社会语义选线

该阶段主要分为数字足迹分析与游憩空间网络特征分析两部分。其中，前者可通过可视化的方式揭示公众与到访景观资源点之间的空间联系，后者则可识别公众对于游憩线路的选择偏好及游憩行为的时序特征。

4.4.1 数字足迹分析

首先，将上述筛选出的文本数据（即4 000条评论信息、904篇游记信息和1 609篇行程记录）利用正则表达式构建数字足迹库。其次，使用文本挖掘工具ROST-CM6分析文本数据中同时出现140个景观资源点中任意两个的共词情况（图7）。通过共词分析能够识别公众在空间移动中

表 2：MCR 模型阻力因子评价体系

评价维度	评价方面	具体指标	阻力说明	阻力值	总体权重
城市综合环境	建成环境	道路等级	空地	9	4.16%
			快速路	7	
			主干道	5	
			次干道	3	
			支路	1	
		道路密度	根据城市道路线密度分析，以自然断点法划分为 5 类	1 ~ 9	9.15%
		公共服务设施密度	根据公共服务 POI 核密度分析，以自然断点法划分为 5 类	1 ~ 9	11.64%
	自然环境	地形	根据 DEM 高程数据，以自然断点法划分为 5 类	1 ~ 9	10.53%
		坡度	＞ 12.0%	9	8.71%
			8.0% ＜ x ≤ 12.0%	6	
			5.0% ＜ x ≤ 8.0%	3	
			≤ 5.0%	1	
		植被覆盖度	根据 NDVI 数据，以自然断点法划分为 5 类	1 ~ 9	10.56%

续表见下页

表 2：MCR 模型阻力因子评价体系

评价维度	评价方面	具体指标	阻力说明	阻力值	总体权重
路径游憩潜力	游憩节点可达性潜力	游憩需求点可达性	＞60 分钟（3000m）	9	9.53%
			45 分钟（2 250m）＜ x ≤ 60 分钟（3 000m）	7	
			30 分钟（1 500m）＜ x ≤ 45 分钟（2 250m)	5	
			15 分钟（750m）＜ x ≤ 30 分钟（1 500m）	3	
			≤ 15 分钟（750m）	1	
		游憩供给点可达性	＞60 分钟（3 000m）	9	11.86%
			45 分钟（2 250m）＜ x ≤ 60 分钟（3 000m）	7	
			30 分钟（1 500m）＜ x ≤ 45 分钟（2 250m）	5	
			15 分钟（750m）＜ x ≤ 30 分钟（1 500m）	3	
			≤ 15 分钟（750m）	1	
	游憩活动潜力	路径活动频次	低频活动路径	9	3.51%
			中低频活动路径	7	
			中频活动路径	5	
			中高频活动路径	3	
			高频活动路径	1	
		河流缓冲区距离	＞600m	9	12.24%
			300m ＜ x ≤ 600m	7	
			100m ＜ x ≤ 300m	5	
			50m ＜ x ≤ 100m	3	
			≤ 50m	1	
	游憩线路建设潜力	城市开放绿地类型	空地	9	8.11%
			防护绿地（G2）、生态保育绿地（EG2）、附属绿地（XG）等其他绿地	7	
			广场用地（G3）	5	
			公园绿地（G1）	3	
			风景游憩绿地（EG1）	1	

的流量流向及行程偏好关系，生成反映人群空间移动整体偏好的共词矩阵。然后，在GIS中对上述矩阵关系进行空间转化，形成共词矩阵空间格局，从而实现空间感知、游憩行为与观览时序的一体化表达。最后，通过自然断点法，将流向强度由强至弱分为5级，对景观资源点之间的关联强度进行可视化，生成游憩空间网络（图8）。

4.4.2 游憩空间网络特征分析

研究进一步计算上述游憩空间网络中各景观资源点的加权点度和中介中心度，以分级刻画网络的空间特征。其中，加权点度数值区间为0~1 941，数值越高，越适宜成为遗产廊道的重要节点；中介中心度数值区间为0~636，数值越高，越适宜成为遗产廊道的中间节点。本文分别将上述两个指标划以自然断点法分为5级，并将游憩空间网络与加权点度和中介中心度叠加，完成基于公众主观感受因素的社会语义选线（图9）。

4.5 遗产廊道选线优化

鉴于城市发展建设更新与数据精度的影响，基于MCR模型的选线结果与城市真实环境之间通常会存在出入，许多线路与实际道路有所偏差，需基于现实情况与公众主观感知情况加以修正。本文在对遗产廊道选线进行修正时，主要遵循以下原则：1）优先保留网络中强度较高的线路（3~5级），以及途经加权点度较高节点或中介中心度较大节点的线路；2）结合研究区域的上位规划与真实路网情况，删除部分网络强度较低（1~2级）的线路，或将其向加权点度较高节点或中介中心度较大节点偏移调整。

研究将基于城市物理空间因素的遗产廊道选线结果与基于公众主观感受因素的社会语义选线结果进行叠合（图10）。研究发现，加权点度较高的景观资源点主要包括位于研究区域西部的秦淮河、石头城公园，位于北部的狮子桥、玄武湖、鸡鸣寺，中部的总统府、新街口，东侧的南京博物院，以及南部的夫子庙、老门东等。此外，由于研究区域内景观资源点较为密集，还存在着部分加权点度较高的节点中介中心度也较高的现象。而加权点度不高但中介中心度较高的景观资源点包括六朝博物馆、瞻园、中华门、集庆门、乌龙潭公园等，这些景观资源点可以作为遗产廊道的过渡性节点。以位于研究区西侧的秦淮河至天妃宫段为例，受地形影响，基于城市物理空间因素的选线结果中并未包含此段廊道；然而，小桃园公园至天妃宫等景观资源点的加权点度与中介中心度都较高，因此，为了提升线路的合理性及与现状的契合性，将小桃园等景观资源点也纳入了遗产廊道选线中。修正优化后的遗产廊道选线结果如图11所示。

4.6 遗产廊道选线结果的应用价值

研究依据上述遗产廊道选线结果可形成城市规划过程中公众参与机制的有效补充，实现南京历史城区中HUL与公共空间体系的协同发展。鉴于南京市目前尚未出台完整的市域或历史城区范围内的遗产廊道相关规划，为了使遗产廊道选线结果对南京历史城区公共空间的品质提升起到更为直接的参考作用，本文分别以遗产廊道途经的景观资源点和城市道路的数量、各景观资源点的加权点度，以及游憩空间网络强度作为依据，将选线结果划分为骨干廊道、重要廊道与细化廊道三级（表3）。

骨干廊道将加权点度最大及共词矩阵强度最高的景观资源点相连接，此类遗产廊道能够对南京历史城区的整体结构起到风貌支撑作用；主要包括研究区域北部的天妃宫—鼓楼、中部的鼓楼—中华门，以及东部的新街口—南京博物院三条轴线，全长约11.5km。

重要廊道能够对南京历史城区范围内游憩流线的可达性与合理性起到重要的优化、调节作用；重要廊道主要呈组团分布，集中在研究区中部的狮子桥—鼓楼—江苏省美术馆区域，以及南部的中华门—雨花门—夫子庙区域，全长约18.4km。

细化廊道则能够对南京历史城区中公共空间体系的品质提升起到关键作用；细化廊道分布于研究区全域，全长约43.2km。

5 结论与讨论

5.1 HUL视角下的遗产廊道研究

HUL作为一种整体性的遗产保护理念与空间实践方法，其强调传统与现代的融合，承认不同历史时期、不同发展变化所具备的积极意义，能够较好地将当代景观与历史遗产并置。相较于传统的遗产廊道选线研

表 3：遗产廊道选线结果分级

遗产廊道级别	廊道途经条件
骨干廊道	5 级加权点度的景观资源点数量至少 3 个
	1）城市快速路或主干道 2）5 级加权点度的景观资源点数量至少 4 个
重要廊道	5 级加权点度的景观资源点数量至少 2 个
	1）城市主干道或次干道 2）5 级加权点度的景观资源点的数量至少 3 个
细化廊道	—

究，基于HUL视角的选线过程可以使研究维度变得更加丰富：不仅在时间层面将阶段性的历史遗迹拓展到包含当代在内不同时期的城市遗产切片，还在空间层面从单一的“历史保护区”延伸至兼具自然与文化价值的城市整体环境上来，从而使遗产廊道的概念与更加宏大的地理环境与社会背景相贴合。本文构建的遗产廊道选线方法在传统物质空间分析的基础上融入了以数字足迹为代表的公众空间感知信息，使遗产廊道的关注点不再局限于城市物质环境的现状条件，是在城市遗产廊道选线研究中融入公众感知表达机制的一次有益尝试。

5.2 数字足迹支持下公众表达机制的完善

在互联网时代，我们通常能够注意到用户数量及其产生的数据如何与城市基础设施进行互动，但有时却忽略了数据使用的性质与方式。分析直观的结构化数据能够告诉我们正在发生什么，分析复杂的非结构化数据则能帮助我们理解为什么会发生。以数字足迹为代表的非结构和半结构化数据包含大量潜在信息，由于非结构和半结构化数据的语境信息较为繁杂，因此，如何将其转换为易于定量分析的结构化数据便成为研究数字足迹的关键问题。当前，随着语义网络分析技术、主轴编码技术，以及数据可视化技术的发展，这种转换便能以更加直观的形式实现。与数字足迹相结合的研究范式可有效解析游憩者与景观资源点之间的互动关系，让我们得以从宏观层面理解人们的空间感知与游憩行为规律。更为重要的是，社交媒体的崛起激发了新的公众参与方式，普通民众在城市管理中的作用也开始发生重大转变，在数字足迹的帮助下，也可以将民众的行为偏好与感知应用于规划手段中。

5.3 从关注物质空间到重视社会实体

如果说数字足迹的使用可使无序随机的游憩行为转变为有意义的社会空间组织形式，那么本研究的另外一层意义在于，不仅把HUL中的游憩体验当作一种活动去研究，同时还将具备主观情感的游憩者作为社会实体去分析，实现客观与主观、量化与质性的融合。然而，值得注意的是，尽管来自互联网的用户共享数据可以反映互联网活跃用户在城市中的空间诉求、情绪体验与感知偏好，但数字足迹也面临着用户背景信息不完善、对平台技术设施依赖度高、数据公众开放程度差异性大等问题，因此目前仅能作为一种补充性的数据来辅助遗产廊道选线。同时，在景观资源点的筛选过程中，除了需要对数字足迹信息进行有效限定，以免出现遗产廊道选线对象无限扩大的情形之外，仍需通过其他类型/来源的数据进一步限定选线对象，以提升选线结果的针对性与有效性。此外，如何提升数据精度、扩大数据代表程度、纳入更加多元的公众参与机制、完善主客观因素的耦合算法模型也是未来优化遗产廊道选线研究的重要方向。

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