

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

ScienceDirect

journal homepage: [www.keaipublishing.com/foar](http://www.keaipublishing.com/foar)SOUTHEAST  
UNIVERSITY

## RESEARCH ARTICLE

# Evaluating visual experience in heritage-rich areas: A case study of the Inner Ring Road of West Lake, Hangzhou



Yan Huang <sup>a,\*</sup>, Zhixiang Fan <sup>a</sup>, Chongxiao Wang <sup>b</sup>, Ran Yan <sup>a</sup>,  
Yilu Shi <sup>a</sup>, You Li <sup>a</sup>

<sup>a</sup> Academy of Arts and Design, Tsinghua University, Beijing 100084, China

<sup>b</sup> College of Landscape Architecture, Nanjing Forestry University, Nanjing 210037, China

## KEYWORDS

Visual experience  
evaluation;  
Heritage area;  
West Lake;  
Street view image;  
Semantic  
segmentation

**Abstract** Streets constitute dynamic landscape perception essential in heritage-rich area planning. They facilitate immersive user experiences. However, urbanization intensifies infrastructure-heritage conflicts. This necessitates improved street space evaluation, management, and enhancement. This study focuses on an Inner Ring Road of West Lake in Hangzhou, developing an index system that encompasses naturalness, openness, artificiality, and traffic, suitable for the visual assessment of unique heritage areas. We used images crawled from Baidu Street View for semantic segmentation and analyzed the landscape element composition, visual quality, extreme values, and spatial distribution of the West Lake Inner Ring Road. The findings indicate that: (1) West Lake has good landscape quality, but the visibility of the water is very low. (2) West Lake can be divided into the artificial scenic area in the northeast and the natural scenic area in the southwest, but the over-dense plant planting and route planning have led to serious homogeneity of spatial continuity. (3) The existence of closed spaces such as tunnels also prevents people from experiencing it continuously. This study investigates heritage areas as spatial media, quantifying visual experience-space use relationships to provide practical visual landscape assessment, informing future heritage street management and development.

© 2025 The Authors. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

\* Corresponding author.

E-mail address: [yyhuang1118@163.com](mailto:yyhuang1118@163.com) (Y. Huang).

Peer review under the responsibility of Southeast University.

## 1. Introduction

The swift proliferation of the street network is a direct consequence of accelerated urbanization and increasing travel demand. The growth of urban populations necessitates the construction of transportation infrastructure as a critical solution to this issue. Offering diverse transportation alternatives can successfully mitigate traffic congestion, diminish environmental consequences, and foster sustainable growth (Gopal and Shin, 2019). Streets serve not just as transit centers but also include distinct service characteristics (Su et al., 2020). Users depend on the topological configuration of the internal street network to facilitate spatial cognition and landscape perception via autonomous route selection (Smirnov and Kudinov, 2021). However, this phenomenon also entails significant potential risks (Wang and Chen, 2017), with various transportation systems threatening public utilities and numerous stakeholders. Specifically, transportation infrastructure, such as roadways, poses the most significant risk to heritage-rich areas amid fluctuating socio-political contexts (Ali et al., 2020). It is essential to consider both the structural integrity of heritage assets and their visual aesthetic value, as well as to explore effective methods for integrating and presenting these heritage resources to users through a rational combination of elements.

Designing heritage areas to serve both decorative and touristic purposes is a strategy for revitalizing heritage resources and promoting sustainable economic development. Enhancing, standardizing, or utilizing local culture will elevate the city's overall image and appeal, hence facilitating urban redevelopment and marketing efforts (Jones and Ponzini, 2021). The cultural promotion-led revitalization plan also enhances heritage development and fosters contact with locals, reinforcing community pride and identity (Ali et al., 2020). However, traditional static spaces have significant experience defects, such as over-reliance on visual performance of elements (Dong et al., 2024), while ignoring multi-sensory comprehensive experiences such as hearing and touch (Lai et al., 2024; Liu et al., 2013). Or the lack of changes in the time dimension, such as seasonal changes (Lee et al., 2024), weather changes, etc., makes people feel monotonous and boring. The weakening of cultural and emotional connections caused by insufficient experience interactivity is also one of the main defects (Ding et al., 2023). The lack of expression of local culture and history makes it difficult to arouse emotional resonance among tourists (Liang and Zou, 2023). In contemporary times, with the advancing growth of the experience economy paradigm, the production logic of street space is experiencing a fundamental transformation, the conventional unstructured tour model based on static spatial arrangements is being supplanted by a dynamic and ordered scene experience paradigm (Snyder, 2022). This process utilizes a linear spatial carrier to create a continuous field of vision reconstruction, effectively transcending the limitations of traditional fixed-point viewing. It establishes a novel mechanism for spatial and temporal interaction with the landscape, facilitating a narrative reconstruction of the landscape interconnected by streets. This media conversion from discrete attraction viewing to

continuous spatial experience effectively actualizes the localized advancement of spatial production theory, necessitating theoretical and practical validation of the street's role as a novel cultural medium.

In the process, heritage spaces transform into experience media. Researchers have begun to focus on how heritage areas should be used to create memorable experiences (Su and Ismail, 2024), and to explore the impact of this shift on people's perceptions and behavioral intentions. For example, how heritage resources can be utilized and their experiential value assessed from the perspective of a heritage area manager (Hussein and Hapsari, 2021; Verma et al., 2024). Or how heritage can be preserved and communicated through augmented reality to extend the experience (Jang and Kim, 2023; Nofal et al., 2018). There are also strategies for modernizing and transforming heritage areas by examining the spatial structure of their environments (He et al., 2024), and so on. But none of these touches on a fundamental question: how to make people better experience the real presence of heritage under the existing conditions? Despite the challenges, heightened awareness has resulted in augmented efforts to reconcile the requirements of urban expansion with historical preservation.

Heritage areas serve a variety of roles, including political (Zhu, 2025), tourism (Bak et al., 2019), and religious (Guriță and Scortescu, 2023). There has been a great deal of scholarship to explore these values and implications. However, little has been said about how to use streets to rationalize the planning and design of heritage areas. It is essential to not only preserve these heritage resources effectively but also to enhance transportation infrastructure to ensure the seamless movement of individuals and optimal visual experiences (Ma et al., 2025). Consequently, assessing whether the streets of existing heritage areas offer an aesthetically pleasing landscape under logical planning for user perception and experience remains a necessary area of research. Previous studies have shown that the configuration and design of space can significantly affect people's visual accessibility, thereby influencing their different behavioral cognition (Wang et al., 2025). In street spaces, the quality of spaces linked by them can also significantly influence visitors' emotional responses and cognitive schema development (Mouratidis, 2021). The visual quality of streets, their physical aesthetic value, and the distinctiveness of the location all provide a fundamental set of characteristics for brand competitiveness (Zhang et al., 2025). Subpar visual quality can elicit a range of detrimental consequences. For example, environmental psychology indicates that the threshold of visual pollution or the tendency toward landscape standardization can trigger Scenic Aesthetic Fatigue (SAF) among tourists (Xu and Zhao, 2023). Such inputs will ultimately result in a heightened cognitive burden, thus inducing a spatial alienation effect that poses a significant contradiction to the area's sustainable development.

Consequently, the development of a quantitative evaluation system for assessing the visual quality of streets is essential for achieving sustainable regional development (Park et al., 2019). This governance model offers scientific decision support for spatial optimization and facilitates the transmission of cultural capital by reconstructing visual

order, thereby managing and coordinating heritage-rich locations to enhance the visitor experience (Ma et al., 2021). In addition, a reasonable assessment of the physical environment of streets can also improve urban infrastructure, enhance social cohesion and economic development (Boukrouh and Bouchair, 2024). Recent advancements in street view images analysis technology and deep learning have facilitated a transition in the evaluation of spatial visual quality in tourist destinations from subjective qualitative assessments to objective quantitative research. Mainstream methods primarily depend on extensive street data and utilize semantic segmentation to extract visual elements, which are employed to assess street color (Han et al., 2023), urban perception (Lei et al., 2024), ecological quality (Wen et al., 2022), greening index (Li et al., 2015), urban traffic (Zhang et al., 2019), and building quality (Li et al., 2022). A large number of studies cover diverse scenarios in the urban domain, which integrates visual indicators from various landscape elements to assess street users' perceptions. However, case studies for heritage-rich areas remain scarce. There is a particular lack of case studies with general applicability. This has led to fragmented evidence for assessment and a lack of organization and establishment of indicators system.

A loop located in the scenic area of West Lake serves as a valuable subject to address this gap. West Lake is situated to the west of Hangzhou, the capital of Zhejiang Province, China, and is in proximity to the city center (Wang et al., 2023). It is commonly referred to as "paradise on earth." In the Southern Song Dynasty (1127 AD–1276 AD), ten poetically named scenic spots were identified as exemplifying idealized classic landscapes that represented the harmonious integration of humanity and nature (Zhang and Taylor, 2020), referred to as the "Ten Scenes of West Lake." Their attainment represents the ultimate objective of the ideal environmental art design for West Lake. In 2011, West Lake was added to UNESCO's World Heritage List due to its significance as a cultural testament to the enhancement of landscapes, exemplifying the ideal integration of humanity and nature. Prior to its inscription on the World Heritage List, it was already recognized as a culturally rich tourist destination in China. West Lake is also a common research object in the academic world. Researchers have conducted many studies on its cultural and landscape heritage (Liu et al., 2022), tourism economic development (Xu et al., 2017), ecological value of water (Jin et al., 2015), and conflict of power interests (Lu et al., 2019), among others. However, even though the spatial planning methods and design features of West Lake have been summarized, the overall visual quality of West Lake has still not been systematically assessed.

The rising demand for the utilization of West Lake has established elevated expectations for both the contemporary West Lake scenic area and the city of Hangzhou as a whole. On March 11, 2023, the Hangzhou Municipal Government enhanced the Inner Ring Road and the Outer Ring Road surrounding West Lake. The regional transportation network centered around West Lake has been enhanced, offering increased convenience for both residents and tourists. The Inner Ring Road encircles West Lake in a clockwise direction, traversing notable landmarks such as the Long Bridge, Leifeng Pagoda, and Su Causeway,

among other significant heritage areas. Does this circular route effectively connect the historical and cultural resources of the scenic area, and does it offer an adequate visual representation of these heritages? Additionally, what is the method for establishing a universal application scenario to assess the visual quality of streets in heritage-rich areas, as demonstrated by the case study of West Lake?

In summary, this study utilizes the Inner Ring Road of West Lake Scenic Area as a case study to develop a methodological framework for assessing the spatial visual quality of streets in tourist destinations. It aims to enhance understanding of the visual experience within heritage-rich environments and inform future route planning, design, management, and optimization.

## 2. Materials and methods

### 2.1. Research framework

This study is divided into three stages (Fig. 1):

- (1) In the first stage, we gathered and processed the street network and image data of the study object.
- (2) In the second stage, we conducted feature segmentation of street scene data utilizing the ADE20K dataset. Based on the results of image segmentation, the landscape features in the study area were quantified. Furthermore, considering the unique conditions of the heritage area, we developed a visual evaluation system to assess the streets in the West Lake scenic area, which facilitated the analysis of the change characteristics of each index.
- (3) In the third stage, we conducted a thorough analysis of the landscape quality of the Inner Ring Road streets following a visual evaluation. We proposed optimization methods that emphasize overall connectivity and the visitor experience, particularly regarding the comprehensive utilization of heritage resources.

### 2.2. Study area

The area of this study is located in the West Lake scenic area of Hangzhou, Zhejiang Province. The lake's total area is approximately 6.38 km<sup>2</sup>. This study focuses on an internal street surrounding the lake, as planned by the government. The route encircles West Lake in a clockwise direction, spanning approximately 12 km, and is referred to as "the closest route to West Lake" (Fig. 2). This route links several heritage sites, including the "Ten Scenes of West Lake".

Historically, West Lake has consistently been a significant landmark in Hangzhou. During the Southern Song Dynasty, Hangzhou, known as Lin'an, served as the capital, resulting in substantial prosperity throughout the West Lake region. The *Xianchun Lin'an Chronicle* states, "West Lake is situated on the western side of Hangzhou city, formerly known as Qiantang Lake, encompassing an area of thirty miles." Since the Tang Dynasty, West Lake has consistently been an esteemed destination for visitors to appreciate.

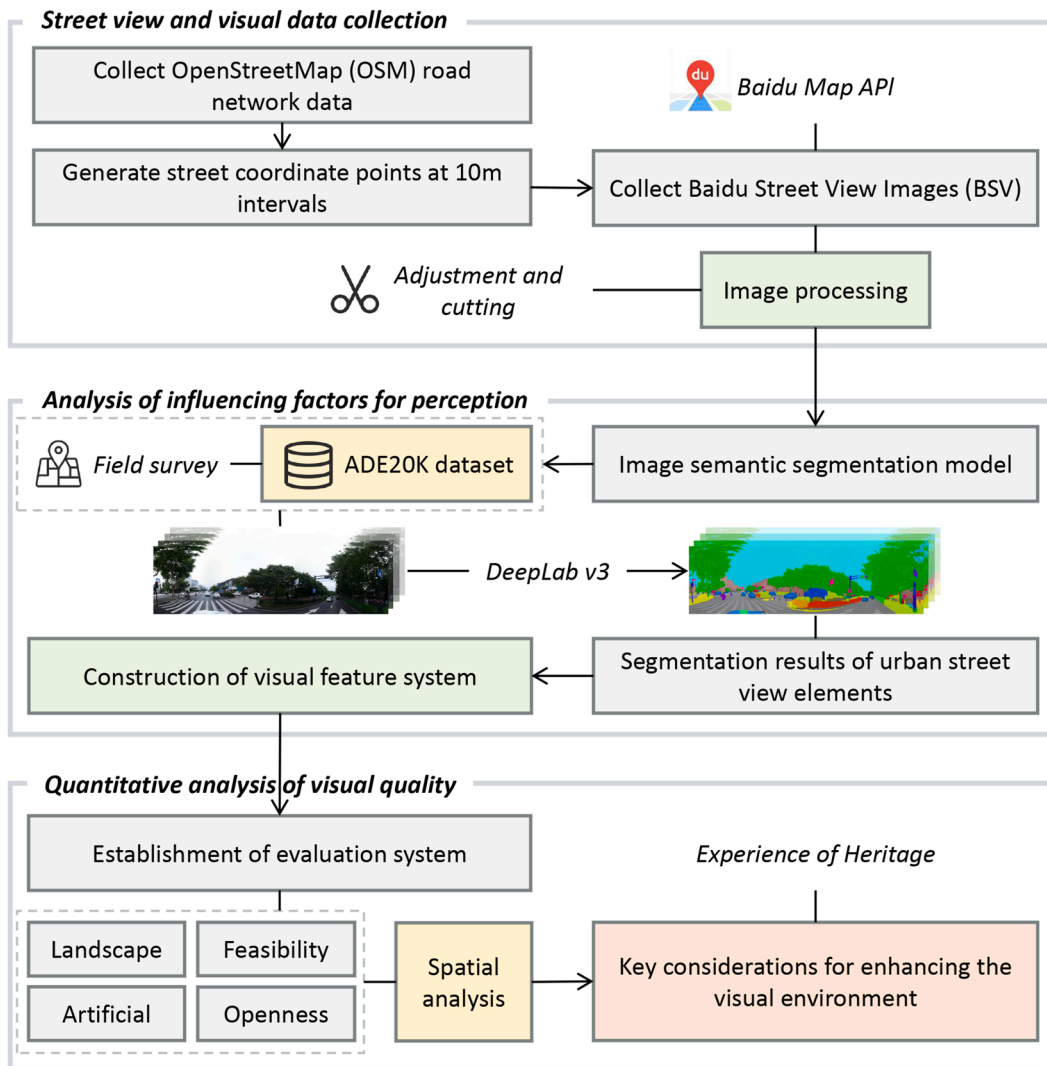


Fig. 1 Research framework.

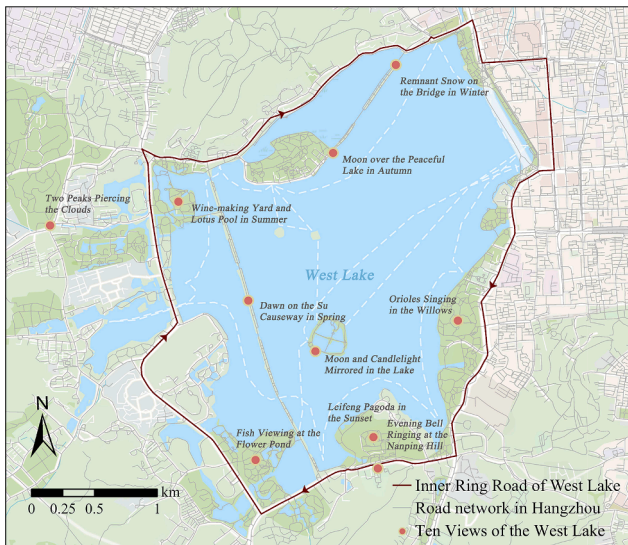
During the Southern Song Dynasty, nobles and intellectuals frequently convened here, with carriages and horses stationed, making this area rich in resources, the palaces and residences were magnificent. A historical map illustrated the location, name, source, and status of West Lake, together with surrounding transportation, economy, architectures, and other urban landscapes. One might envision the wealth of West Lake during that period (Fig. 3).

West Lake is home to numerous heritage resources, with the “Ten Scenes of West Lake” being the most iconic and renowned. They have been transmitted since the Southern Song Dynasty, boasting a history of 700 years. They are *Dawn on the Su Causeway in Spring*, *Wine-making Yard and Lotus Pool in Summer*, *Moon over the Peaceful Lake in Autumn*, *Remnant Snow on the Bridge in Winter*, *Leifeng Pagoda in the Sunset*, *Orioles Singing in the Willows*, *Fish Viewing at the Flower Pond*, *Moon and Candlelight Mirrored in the Lake*, *Evening Bell Ringing at the Nanping Hill*, *Two Peaks Piercing the Clouds*. They embody an idealized representation of the West Lake landscape, reflecting human refinement and interpretation. The “Ten Scenes of West Lake” possess distinct features but are

cohesively interwoven into the overall ambiance and spatial composition of West Lake, creating a refined and harmonious pattern. They are illustrated in the *Ten Scenes of West Lake* by Lan Shen, the Qing Dynasty’s artist. As demonstrated below (Fig. 4).

The “Ten Scenes of West Lake” exemplifies a logical integration of natural components, including mountains, water, and vegetation, resulting in an exquisite environmental art design. This also presents the criteria for our research subject—Inner Ring Road, and the development of West Lake beautiful areas: whether the existing planning constitutes a rational integration of various aspects, and serves as a cohesive network to enhance the visitor experience.

The majority of heritage sites surrounding West Lake are predominantly located near these ten landscapes. West Lake development materials released by the Hangzhou Municipal Government indicate that there are 68 significant areas of interest in the picturesque area surrounding West Lake (Fig. 5). All of these heritage sites are situated within the 1000 m buffer zone of the Inner Ring Road, ensuring accessibility.



**Fig. 2** Inner Ring Road of West Lake and major heritage sites. Source: Standard Map Service System of China, revised by the authors.

### 2.3. Street view images

Regarding the acquisition and preparation of street view images, we obtained the road network data for the Inner Ring Road in the West Lake scenic area via an open street map. We identified the precise paths of the Inner Ring Road based on public government documents. The street view imagery was primarily sourced from Baidu Street View (BSV). BSV is a mapping service website that offers visual information of streets in over 600 cities across China (Yue et al., 2022). Research using BSV is becoming more and more common, especially in the field of urban planning,

due to its ability to provide large-scale and multi-perspective visual information about the city. The research directions and applications of BSV include urban environmental assessment and monitoring (Han et al., 2023; Liang et al., 2024; Wang et al., 2024), urban planning and design (Qin et al., 2024; Wu et al., 2024), socio-economic research (Xu et al., 2023; Zhang et al., 2022), as well as transportation and safety (Pan et al., 2024; Ren et al., 2024), among others. Deep learning (Tao et al., 2022), image processing (Qin et al., 2024), and spatial analysis (Zhang et al., 2024) are commonly used technical approaches. The BSV was obtained by the Street View Vehicle, which is equipped with a GPS and a fisheye lens. The GPS records the vehicle's geographic location while traversing the street, and the fisheye lens captures 360° street view photographs. The primary advantage of Street View images compared to other data is that they are obtained from a camera affixed to a vehicle traversing the street, thereby aligning more closely with the perspective of an individual navigating the Inner Ring Road in West Lake, as opposed to images of sidewalks or streets that are not accessible to other vehicles.

We used BSV photos as a surrogate for the street view environment. Nevertheless, the seasonal variability of plants may result in an inaccurate assessment of street greenness if the date of the image is not taken into account. The Baidu Street View metadata API offers data regarding the latitude, longitude, and date of the captured photographs. The findings indicate that the majority of the BSV photos utilized in this study were captured during the summer months and were updated approximately in June 2020, aligning with the actual utilization of the study region. Based on the dimensions of the study area, we established sampling locations uniformly at 10m intervals. Ultimately, we acquired a total of 1276 genuine panoramic photos.



**Fig. 3** Map of West Lake. Source: Lin'an Prefectural Gazetteer of southern Song Dynasty.



Fig. 4 Ten Scenes of West Lake by lan Shen, Qing Dynasty.

Moreover, the inherent properties of panoramic photographs lead to image distortion (Li et al., 2018), with pronounced distortion at the top and bottom of the image (Tsai and Chang, 2013), rendering it inappropriate for subsequent metric calculations. The distortion at the center of

the image is minimal. It has been shown that cutting the central section of a panoramic image can be utilized to assess the visual closure of roadway walkability (Yin and Wang, 2016). The less warped the cropped segment is, the more closely it resembles the human visual field (Ki and Lee, 2021). Consequently, this study employed the same methodology to crop and utilize the segment of the panoramic image that aligns with the pedestrian’s perspective and exhibits minimal distortion (Fig. 6).

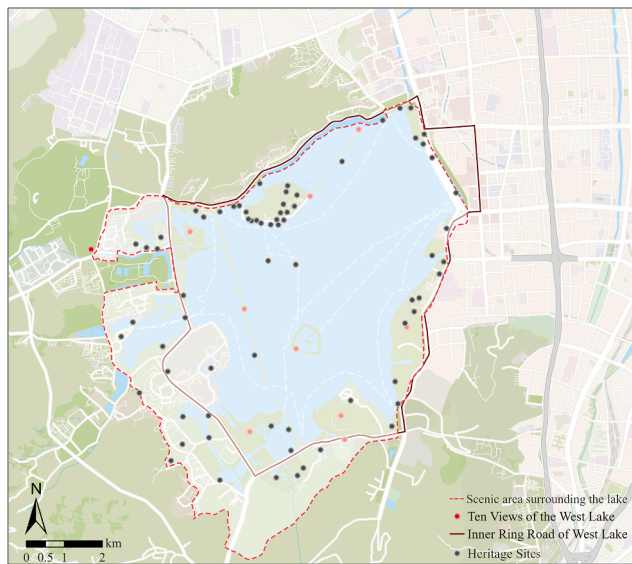


Fig. 5 Distribution of significant heritage sites in the scenic area surrounding West Lake.

### 2.4. Semantic segmentation

Identifying and delineating landscape components in a photograph is essential for accurately assessing the visual quality of a roadway. Semantic segmentation is a sophisticated technique for classifying photos into various elements (e.g., structures, sky, vegetation, automobiles) at the pixel level. We chose the DeepLab v3 model for our research. It has been applied to a variety of scenarios, proving its segmentation accuracy and efficiency. Such as road extraction (Mahmud et al., 2021; Sussi et al., 2024), cityscape analysis (Li et al., 2024; Zhou et al., 2024), traffic conditions (Pan et al., 2024) and so on.

The choice of dataset has a significant impact on the results of model identification. The dataset used in this study is ADE20K, which exhibits robust generalization capabilities and is recognized for its precision and efficacy, particularly in street scene segmentation. It was released by the Massachusetts Institute of Technology (MIT) and

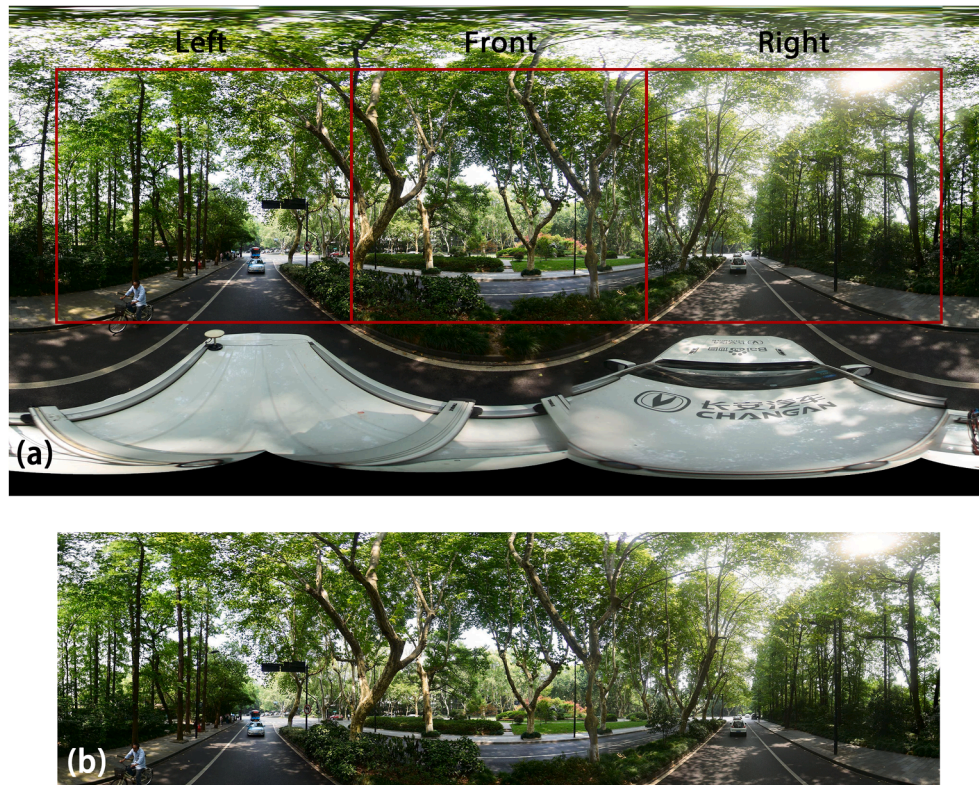


Fig. 6 Processing of cropping of distortion in the street view image.

contains over 20000 finely annotated images covering a wide range of indoor and outdoor scenes. It is currently one of the most comprehensive datasets for scene parsing and semantic segmentation (Zhou et al., 2017, 2019). Relevant studies have demonstrated its excellent semantic segmentation capabilities in multiple domains (Liu et al., 2023, 2024; Zhang et al., 2023), especially in quality assessment for urban planning (Yuan et al., 2023) and complex environment recognition (Sediqi and Lee, 2021). The pre-experimental results indicate that the picture segmentation trained on this dataset is more detailed and can precisely delineate the features around the Inner Ring Road in West Lake. This method produces annotated photos that can precisely quantify the area percentage of each landscape component, facilitating an objective evaluation of the streets' visual quality.

## 2.5. Evaluation indicator system

The development of an indicator system is crucial for assessing the spatial visual quality of streets. In recent years, the development of the street spatial visual evaluation index system has evolved from a unidimensional framework to a multidisciplinary, comprehensive evaluation system, with research emphasizing the categorization of index dimensions, innovation in technical methodologies, and the amalgamation of subjective and objective data. Diversified expansion has been achieved in the indicator dimension, encompassing objective indicators like visual preference (Huang et al., 2023), an aesthetic dimension characterized by composite indicators such as

landscape hierarchy (Harvey et al., 2015), and functional aspects including visual similarity (Verma et al., 2024) and traffic sign infrastructure recognition (Campbell et al., 2019). From a technological perspective, artificial intelligence technology substantially enhances the intelligent building of systems (Xu et al., 2021), exemplified as street scene information extraction with convolutional neural networks (Zijing and Hao, 2024). The collecting and application of objective data depend on satellite remote sensing (Chen et al., 2022), network street view photos (Zhang et al., 2025), drone technology (Jinji and Yuanqin, 2020), and other methods for extraction. Subjective data, conversely, are mostly acquired through questionnaires (Han et al., 2022), human-computer interactions (Yao et al., 2019), and several other techniques to ascertain users' preferences.

The establishment of an evaluation index system should be closely related to the selected research area. And it is necessary to organize and summarize the indicators that have been extensively validated to enhance the applicability of the system in other scenarios. This study focuses on the internal roadways of the lakeside. The selection of evaluation indicators and the computation of visual parameters should prioritize cultural experiences and heritage resources, accurately portraying the actual environment encountered by users in street spaces. The index system we ultimately developed can be classified into four categories: Landscape, Openness, Artificial, and Feasibility.

- (1) Landscape significantly influences driving behavior in tourist destinations. The visibility of greenery and the

diversity of plant populations might influence the perception and evaluation of heritage items (Xu and Niu, 2024). The proportion of the lake within the field of vision is also significant, as it is a key landscape element that effectively represents West Lake.

- (2) The sky's openness and confinement are also significant. An expansive vision enhances the perception of freedom, but a constricted vista highlights essential elements.
- (3) The transitional space between streets and buildings serves as an extension and penetration from the streets into the constructed environment, typically featuring street furniture such as store signs, light poles, rest facilities, and other structures. Their location is related to the advancement of commerce, tourism, and various sectors, playing a crucial role in improving the functionality and image of the scenic area, while showcasing the diversity of the visual aesthetics of the street.
- (4) Feasibility is a crucial quantitative metric for an internal thoroughfare featuring scenic attractions. The street's intricacy will influence driving velocity and visual perception, so it must be incorporated into the assessment criteria.

These four categories can be further divided into Green View Index (GVI), Greenery Diversity Index (GDI), Blue View Index (BVI), Sky View Index (SVI), Spatial Enclosure Index (SEI), Building View Index (BuVI), Service Facility Index (SFI), Road Walkability Index (RWI), and Road Traffic Index (RTI) (Table 1).

### 3. Results

#### 3.1. Semantic segmentation results

The image segmentation results yielded a diverse array of visual elements, including trees, sky, roads, buildings, cars, and grass. We conducted parameter calculations and present the top 10 most significant elements in proportion as an example (Table 2). The findings indicate that:

- (1) There exists a notable disparity in the proportionate coverage within the field of view. Trees, sky, roads, and buildings dominate the field of view, comprising over 80 % of the visual composition, which forms the foundation of the visual landscape of the Inner Ring Road. However, this can also result in excessive tree cover which will obscure viewing while creating shade space.
- (2) The proportion of trees and sky in the field of view demonstrates the highest standard deviation among these elements, signifying their variability and dynamism, which contribute to a broader range of visual perceptions. But are these elements of the same proportions for a long time, or is there a sharp change of rhythm to reduce people's visual fatigue. This requires more in-depth research.
- (3) In addition, there are some interesting findings. The maximum value of "water" is only 0.139251, which indicates that it is not the main landscape element of the Inner Ring Road of West Lake. This result is

contrary to the planning purpose of the road itself. The poor performance of "sidewalk" may also indicate that there are fewer pedestrian-friendly paths within the area, but this still needs to be further confirmed.

#### 3.2. Visual quality analysis of street space

The segmentation results are derived from the previously established visual evaluation index system. Visual element data is aggregated at each sampling point. The results of the extraction and calculation of visual elements are presented, with a color gradient from green to red representing low to high values.

The spatial distribution of each landscape index in West Lake exhibits notable regional disparities and internal correlations. In the Landscape dimension, (1) the Green View Index is predominantly elevated, with the western mountains and northern regions constituting the primary visual elements due to their dense arboreal and grassland coverage (Fig. 7). Conversely, the index approaches zero in the northeast, attributed to the prevalence of commercial complexes. This is the devouring of the ecological space of the heritage area by the continuous expansion of urban capital. Dense commercial complexes are a one-way exploitation of the economic value of the land, seriously jeopardizing the ecosystem service value of this area.

(2) The Greenery Diversity Index mirrors the Green View Index but exhibits more significant fluctuation, particularly in the western region of the city, where the abundance of plant species in natural areas is notably remarkable, significantly alleviating visual fatigue (Fig. 8).

(3) The Blue View Index exhibits inadequate water visibility, with only the southern section of the water area meeting the criterion, highlighting the deficiencies of the lakefront road's hydrophilic qualities (Fig. 9). This is an implicit deprivation of public space rights in the heritage area. Visual accessibility deficiencies of water-friendly spaces should be enhanced by rationalizing the assessment of view corridors and removing visual barrier structures.

In the Openness dimension, (1) the Sky View Index and Green View Index exhibit a negative correlation, with the dense tree canopy creating a natural shading system that improves spatial comfort while exacerbating the site's enclosure (Fig. 10). However, excessive and continuous enclosed spaces can fatigue people and enhance the sense of oppression. Too many trees can also lead to increased homogenization of the area.

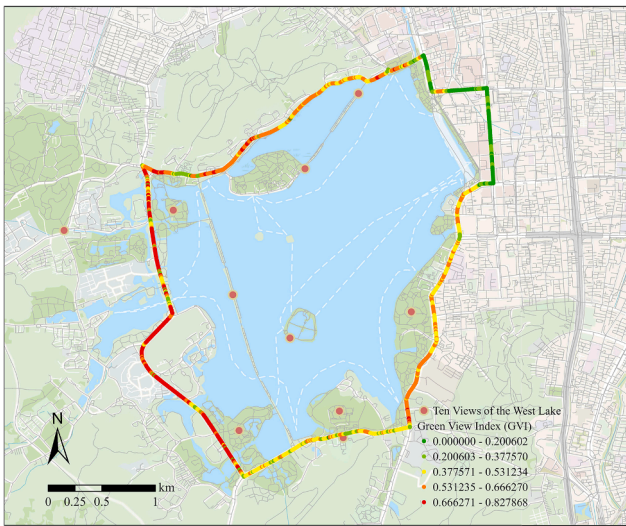
(2) The Spatial Enclosure Index reveals a complex pattern: the northeastern commercial district and the northern segment of the tunnel beneath the lake exhibit the highest building density (Fig. 11). Dense buildings and lack of greenery may lead to an increased heat island effect and a sense of spatial oppression. This completely artificial environment may reduce people's willingness to explore. At the same time, the western landscaped area generates a semi-open space by establishing a visual corridor through the arrangement of trees and shrubs. This maintains a degree of privacy while avoiding complete closure. It is worth extending to other areas.

**Table 1** The West Lake Inner Ring Road landscape visual evaluation index system.

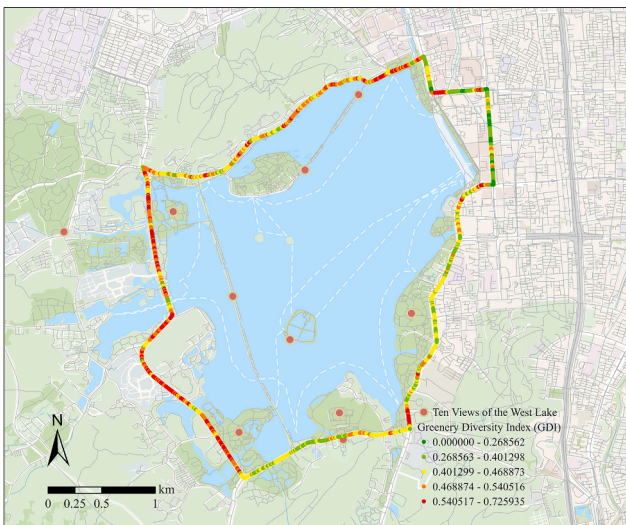
Dimension	Item	Description
Landscape (Liu et al., 2021; Zhang et al., 2023; Zhang et al., 2025)	Green view index (GVI)	Sum of the area proportions of all visible greenery components (e.g., tree, plant, grass, flower, and palm). $GVI_n = \sum_{i=1}^K G_{i,n}$ , where $K$ denotes the total number of greenery components considered, and $G_{i,n}$ represents the area proportion of the $i$ th greenery component in the $n$ th street image.
	Greenery diversity index (GDI)	Shannon diversity index based on the area proportions of all visible greenery components (e.g., tree, plant, grass, flower, and palm). $GDI_n = - \sum_{i=1}^K G_{i,n} \ln G_{i,n}$ , where $K$ denotes the total number of greenery component considered, and $G_{i,n}$ represents the area proportion of the $i$ th greenery component in the $n$ th street image.
	Blue view index (BVI)	Area proportion of water in a view. $BVI_n = B_n$ , where $B_n$ represents the proportion of water pixels in the $n$ th street image.
Openness (Jiang et al., 2022; Rui and Cheng, 2023)	Sky view index (SVI)	Area proportion of sky in a view. $SVI_n = V_n$ where $V_n$ represents the proportion of sky pixels in the $n$ th street image.
	Spatial enclosure index (SEI)	Sum of the area proportions of all enclosure components (e.g., building, plant, fence, skyscraper). $SEI_n = \sum_{i=1}^K E_{i,n}$ , where $K$ denotes the number of enclosure components considered, and $E_{i,n}$ represents the area proportion of the $i$ th enclosure component in the $n$ th street image.
Artificial (Zhang et al., 2025; Zhang et al., 2025)	Building view index (BuVI)	Sum of the area proportions of all visible building types (e.g., building, hovel, skyscraper). $BuVI_n = \sum_{i=1}^K Bu_{i,n}$ , where $K$ denotes the number of building types considered and $Bu_{i,n}$ represents the area proportion of the $i$ th building type in the $n$ th street image.
	Service facility index (SFI)	Sum of the area proportions of all visible service facilities for use and decoration (e.g., bench, streetlight, signboard, canopy, sculpture). $SFI_n = \sum_{i=1}^K F_{i,n}$ , where $K$ denotes the number of service facility types considered, and $F_{i,n}$ represents the area proportion of the $i$ th service facility type in the $n$ th street image.
Feasibility (Rui and Cheng, 2023; Wang and Xiu, 2023; Zhang et al., 2025)	Road walkability index (RWI)	Ratio of the surface area of the walkway (e.g., sidewalk, path, runway) to that of the driveway (road), as observed in street view images. $RWI_n = \frac{\sum_{i=1}^K W_{i,n}}{D_n}$ , where $K$ denotes the number of walkway types considered, and $W_{i,n}$ and $D_n$ represent the area proportion of the $i$ th walkway type and driveway in the $n$ th street image.
	Road traffic index (RTI)	Ratio of the pavement area (e.g., sidewalk, path, runway, road) of the street to the total area of all streets examined in the study. $RTI_n = \frac{\sum_{i=1}^K R_{i,n}}{\sum_{i=1}^K R_{i,total}}$ , where $K$ denotes the number of pavement types considered, and $R_{i,n}$ and $R_{i,total}$ represent the area proportion of the $i$ th pavement type in the $n$ th street image and all street images analyzed around West Lake.

**Table 2** Semantic segmentation results of landscape elements in the Inner Ring Road of West Lake.

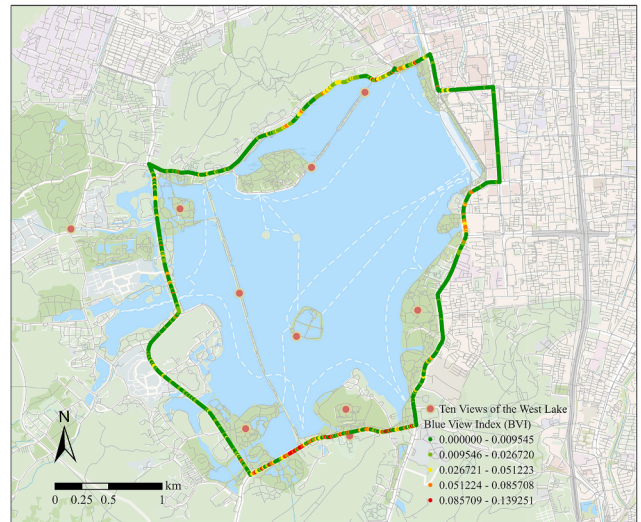
Category	Range	Mean	SD
Tree	(0, 0.731895)	0.460347871	0.176396407
Sky	(0, 0.561155)	0.216035744	0.13621677
Road	(0.037158, 0.235775)	0.122911276	0.039404043
Building	(0, 0.341409)	0.041557688	0.061249296
Plant	(0, 0.169712)	0.034973339	0.029682525
Sidewalk	(0.000373, 0.094281)	0.030612516	0.017596507
Car	(0, 0.126916)	0.018970081	0.019152615
Water	(0, 0.139251)	0.013280591	0.023220688
Wall	(0, 0.443295)	0.012625094	0.030436503
Grass	(0, 0.08916)	0.007571149	0.009787797



**Fig. 7** The green view index around West Lake.



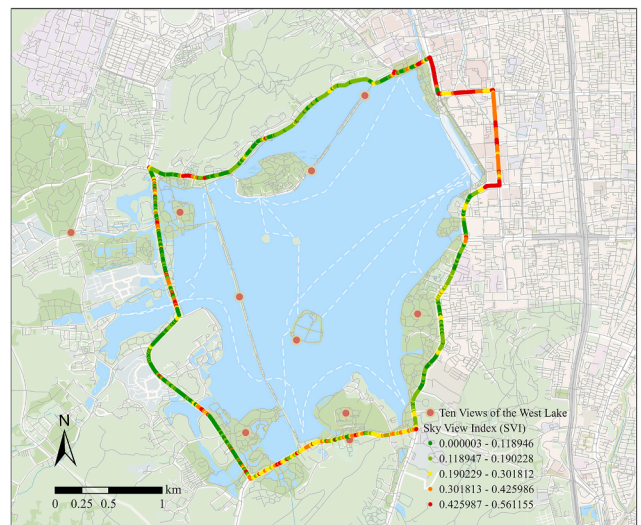
**Fig. 8** The greenery diversity index around West Lake.



**Fig. 9** The blue view index around West Lake.

In the Artificial dimension, (1) the Building View Index is focused on the northeastern business zone, the eastern residential sector, and the northern cultural complex, in stark contrast to the zero-value natural landscape in the southern and western regions (Fig. 12). It reflects an over-centralization of the area’s urban functions. This may lead to increased separation or even fragmentation of the West Lake area, increasing the pressure for cross-regional exchanges.

(2) The Service Facility Index is fragmented, exhibiting a concentration in the northeastern region, whilst the remainder is relatively balanced (Fig. 13). Excessive centralized distribution can lead to resource waste and overcrowding in public spaces. Even if the indicators are evenly distributed, there may still be a problem of a single type of service facility. Subsequently, detailed statistics and analysis should be conducted on facility categories to enhance people’s accessibility and user experience.



**Fig. 10** The sky view index around West Lake.

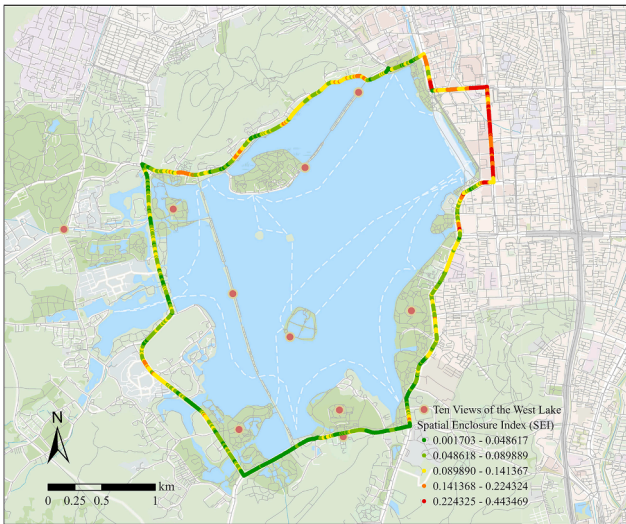


Fig. 11 The spatial enclosure index around West Lake.

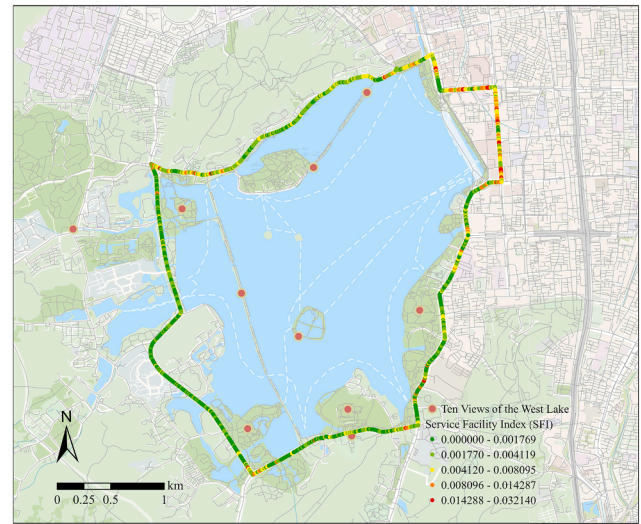


Fig. 13 The service facility index around West Lake.

In the Feasibility dimension, (1) the Road Walkability Index indicates that the southwestern region of West Lake has superior pedestrian pathways (Fig. 14). However, the overall situation is still dominated by vehicular roads, which can lead to fragmentation of the overall pedestrian network.

(2) The Road Traffic Index indicates that the eastern section of West Lake possesses the most efficient transportation infrastructure (Fig. 15). An over-reliance on motorized lanes can sacrifice slow-moving space while improving accessibility and has the potential for traffic congestion. In contrast, the western section is less robust. Overall, the north-east is heavily influenced by urbanization and therefore has a more developed road transport system. The areas closer to the interior have a single mode of travel. This weakens regional connectivity. In the future, the road system should be improved in a rational and graded manner to build a pedestrian network throughout

the region, and thus implement dynamic management of streets.

### 3.3. Characteristics of extreme value

By examining the extreme values of each indicator, one may ascertain the distribution of these extreme indicators and thereafter analyze and modify them to suit the specific context (Fig. 16).

The spatial distribution of each landscape index in the West Lake area exhibited multi-dimensional differentiation (Fig. 17).

The dominance of natural landscapes is primarily located in the western region, where dense forests and significant spatial closure mark the area with the highest Green View Index. This area is an example of ecological conservation with reduced human intervention, and reasonable conservation measures should continue to be

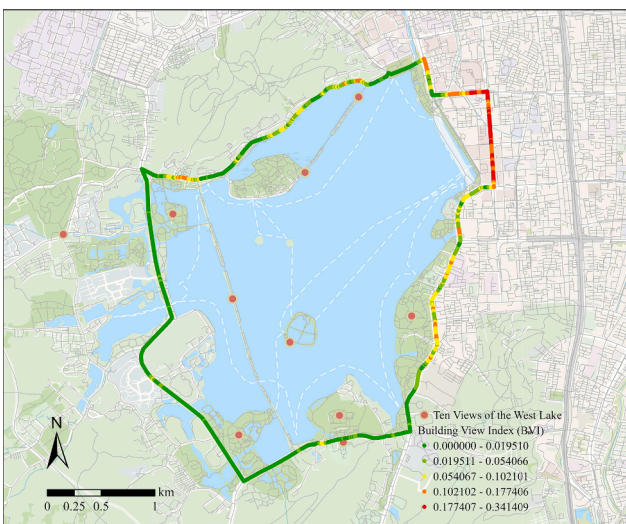


Fig. 12 The building view index around West Lake.

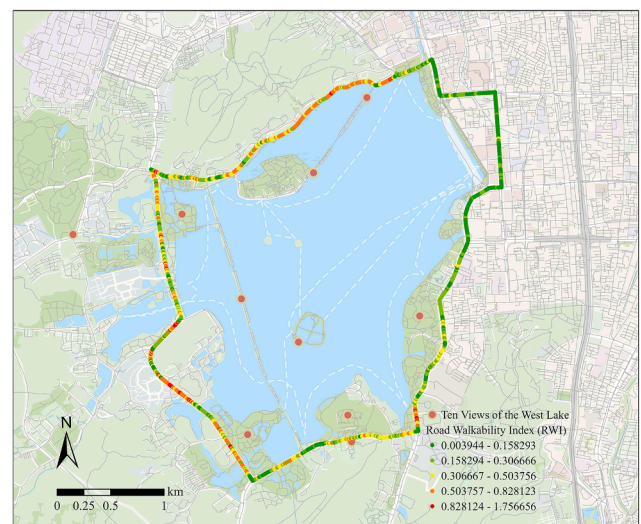


Fig. 14 The road walkability index around West Lake.

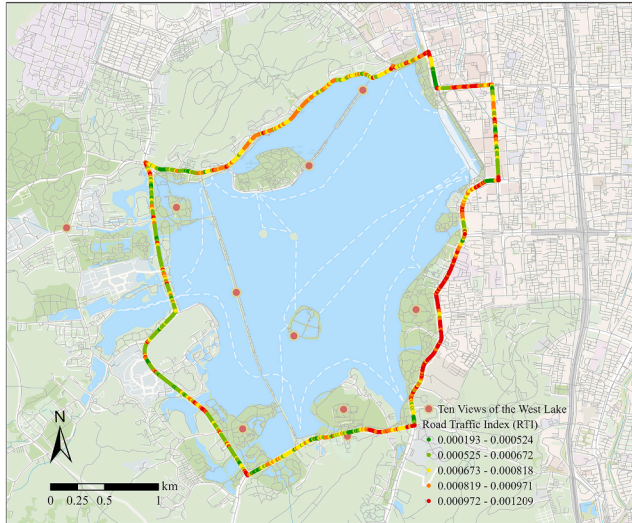


Fig. 15 The road traffic index around West Lake.

imposed in the future to maintain natural features. In the northeastern region, the Greenery Diversity Index reaches its maximum value, attributed to the prevalence of artificialized environments featuring street trees and flower beds, which enhance diversity but contribute to visual fatigue. Street view image also show that overly dense artificial landscaping can diminish the natural attributes of the entire area. While the southern peak area boasts the highest Blue View Index, the visibility of the lake is limited by both vegetation density and design constraints, indicating a deficiency in water-friendly experiences. This exposes the imbalance between functionality and aesthetics in modern landscape design.

The artificial areas show considerable contradictions. The Sky View Index in the northeast shows the highest value, attributable to the density of buildings, which highlights the significant shading effect of the tree canopy in the natural area. This is also related to the ratio between building height and street width. In order to create a good rhythm of spatial enclosure, this indicator should be subsequently measured rationally. Conversely, the extreme value of the Spatial Enclosure Index is observed in the continuous tunnel traversing the northeast, where the enclosed space disrupts multi-dimensional landscape perception and alters the temporal and spatial rhythms of landscape experience through variations in speed. These spatial indicators reveal one of the problems with heritage area design: in the pursuit of function and efficiency, we are unconsciously dissolving the continuity of landscape perception.

The arrangement of buildings and facilities enhances the functional characteristics of the space. The northeastern commercial area exhibits the highest Building View Index and Road Traffic Index, underscoring its urban interface characteristics. However, the high population density and complex traffic patterns contribute to congestion, especially on holidays. Therefore, it is necessary to implement reasonable diversions and guidelines in this area. A three-dimensional transportation system is also one of the

potential solutions. In contrast, the southern region leverages the Leifeng Pagoda heritage group to achieve a peak in the Service Facility Index, facilitating connectivity between the mountain forest and urban space via transportation facilities. It can be used as a paradigm for the promotion of urban service functions in heritage areas.

The Road Walkability Index is highest in forested areas, indicating a significant level of walking activity in natural environments. However, the highest values of the Service Facility Index are not in this area, so there may be infrastructure deficiencies. The convergence of various transportation modes in the Northeast increases the Road Traffic Index value while diminishing the recreational quality of the landscape. Therefore, appropriate improvements to the traffic mixing dilemma are necessary. This can be improved by increasing the natural proportion of this area, or by enhancing cross-regional linkages.

The indicators collectively illustrate the composite contradiction arising from the interaction between artificial intervention and natural succession in the West Lake scenic area, adhering to the pattern of "West lake, East city".

The minimum values for the nine indicators are presented (Fig. 18). The selection of the minimum value is significant due to the unique conditions of the site (the tunnel beneath the lake), which results in a more significant number of landscape points exhibiting a zero value for a specific indicator (Fig. 19). This selection focuses on more typical scenarios for narration.

The tunnel's presence notably influenced the assessment of the roadway's spatial quality. The minimum values of the Green View Index, Greenery Diversity Index, and Sky View Index were found in the tunnel beneath the lake. Extended tunnel travel durations resulted in a fragmented landscape experience. This is one of the current problems within the area. This section exacerbates the conflict between artificial facilities and nature conservation. Subsequently, reasonable consideration should be given to re-routing the route, or improving the decorative design of the side walls inside the tunnel on top of the original to reduce the sense of severance.

Additional indicators are similarly defined. The lowest Blue View Index is found in the commercial area. This is also a common problem throughout the area. The lowest values of the Spatial Enclosure Index and Building View Index are situated in the forested landscape to the west, both of which are closely linked to the site's composition. The proximity of the Service Facility Index indicates a reduced level of artificiality in the forested landscape. They reflect the ecological advantages of the area, but insufficient service facilities can also affect people's experience, leading to a homogenization of landscape functions. The lowest Road Walkability Index remains in the north-east, characterized by a high density of carriageways and a limited number of accessible transport systems for pedestrians, resulting in walking space being squeezed to a critical mass. This area also with a low Road Traffic Index, which are mainly characterized by carriageways only. Narrow lanes and high traffic can create a vicious cycle. Therefore, the reorganization and redistribution of traffic space is urgent and necessary. For example, building an intelligent transportation system, installing traffic flow-

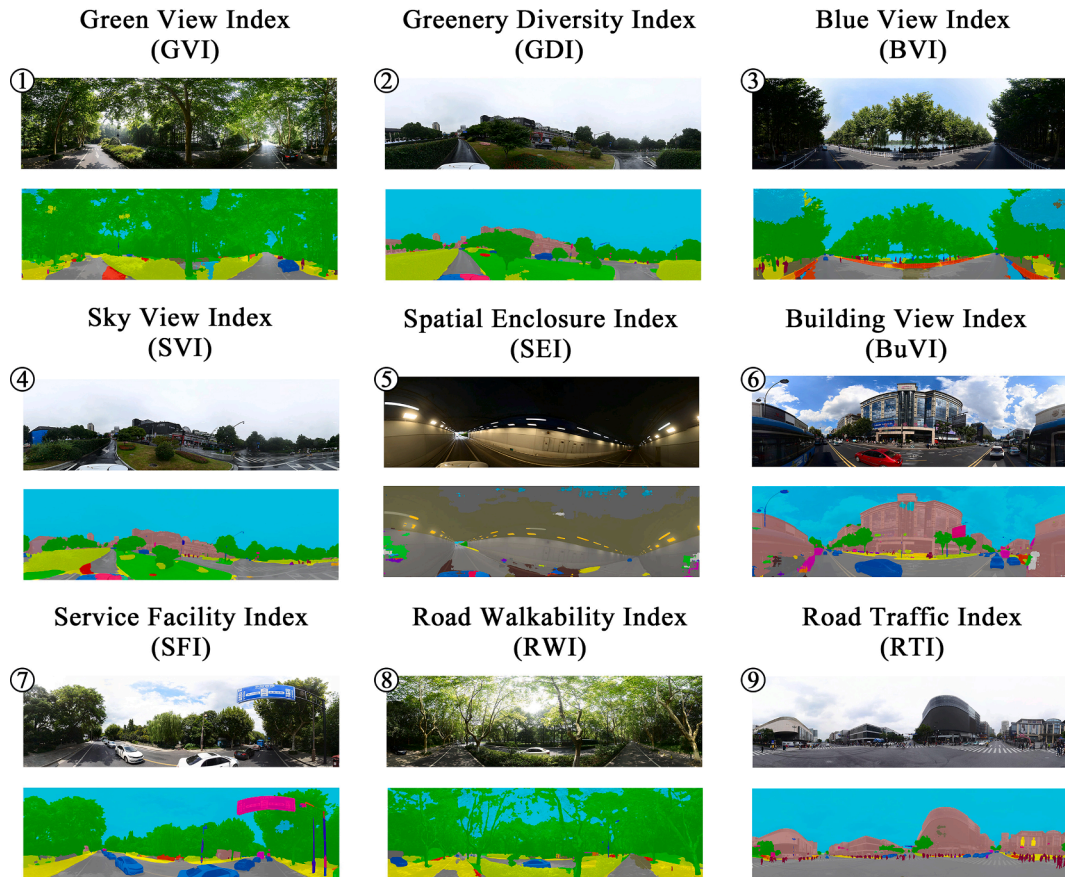


Fig. 16 The highest values of spatial quality indicators for scenic spots surrounding West Lake.

aware signals, or implementing different vehicle control measures on weekdays and holidays. These measures may protect the ecological substrate of the area while enhancing the service functions, and ultimately reshape the right-of-way allocation for pedestrians and vehicles in the Northeast District.

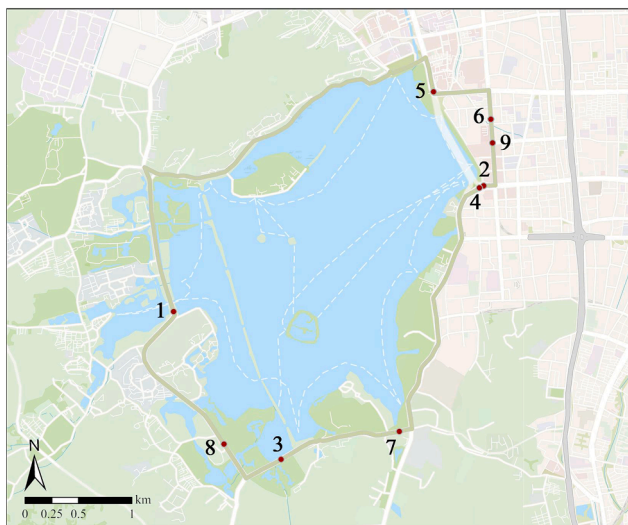


Fig. 17 The spatial distribution of the highest value of the indicator.

### 3.4. Classification of feature scenarios

This study utilized k-means cluster analysis, informed by the assessment framework’s results, to identify five distinct scenes in the scenic spots surrounding West Lake, each characterized by unique assessment indicator values. We employed the SPSS data analysis tool to examine the indicator values across 1276 study sites, identifying five significant categories (Table 3).

As far as the concrete is concerned, Cluster 1 has a high Green View Index, Greenery Diversity Index, and a low level of artificiality. The lower Spatial Enclosure Index indicates that people can see more of the sky, and the Road Walkability Index belongs to a relatively average group, but with more complex traffic patterns. Therefore, Cluster 1 is a traffic-oriented scenario with better greenery.

Clusters 2 and 3 exhibit similarities in possessing a favorable Green View Index alongside a high Greenery Diversity Index. Cluster 2 highlights the overall impact of greenery, while Cluster 3 focuses more on the travel experience in conjunction with the environment, as indicated by its high Road Traffic Index. Both are classifications of pathways in natural environments conducive to transit.

Cluster 4 exhibits a balanced Spatial Enclosure Index and Building View Index; however, it demonstrates a lower Green View Index and other natural indicators in comparison to the preceding groups. Simultaneously, it exhibits minimal visibility of water surfaces, categorizing it as the

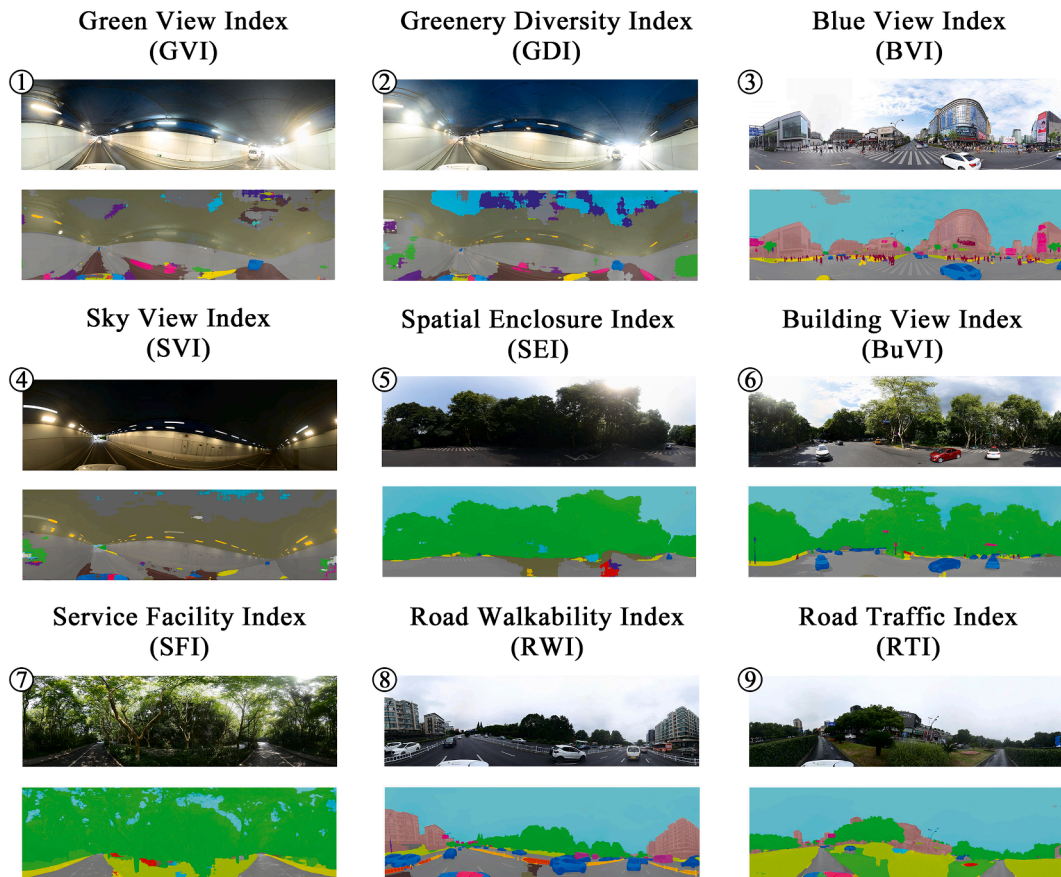


Fig. 18 The lowest values of spatial quality indicators for scenic spots surrounding West Lake.

group with the most unfavorable overall ecological environment. This scene is characterized by numerous artificial structures and associated service facilities, representing the most abundant type of scene and being particularly suited for offering supplementary services at tourist attractions.

Cluster 5 is characterized by specificity and a lower quantity. The primary focus is on traversing roads situated within tunnels, leading to the highest Spatial Enclosure Index and minimal values in other metrics.

The figure illustrates the spatial distribution of five clusters of scenes identified through k-means cluster analysis (Fig. 21).

By visualizing the distribution of different categories of spaces, we can discover that the West Lake scenic area is approximately categorized into an artificial scenic location in the northeast and a natural scenic location in the southwest. This facilitates subsequent overall management and planning. (1) Cluster 1 is distributed across the northeast, south, and west of the site. However, the distribution is very scattered and occurs mainly as an articulated part of different zones. (2) Cluster 2 is predominantly situated in the western forest scenic area, noted for its high green visibility and enclosure. It presents a good continuity in general and the few interrupted landscape rhythms avoid its negative effects. It is the main embodiment of the natural attributes of the West Lake area. (3) Cluster 3 represents the continuous landscape characterized by the highest quantity and longest duration distance, serving as the predominant scene in the West Lake scenic area. It is mainly located in the north, east and south. Continuous road traffic connects the whole area. However, this is accompanied by a negative visual experience that remains unchanged for a long period of time. Appropriate changes in planting and spatial enclosure may be an effective

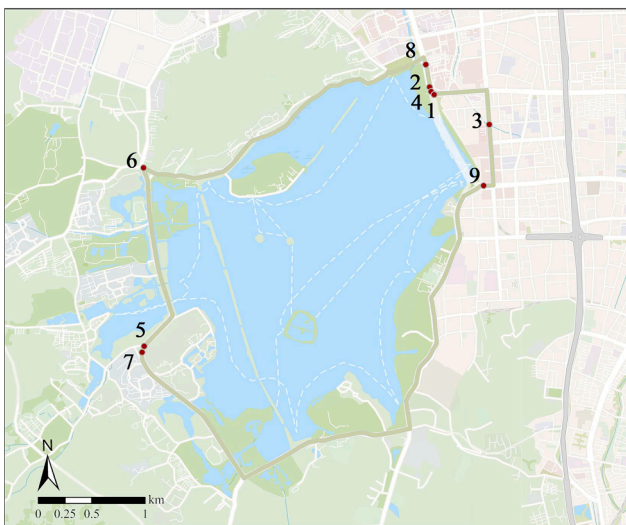


Fig. 19 The spatial distribution of the lowest value of the indicator.

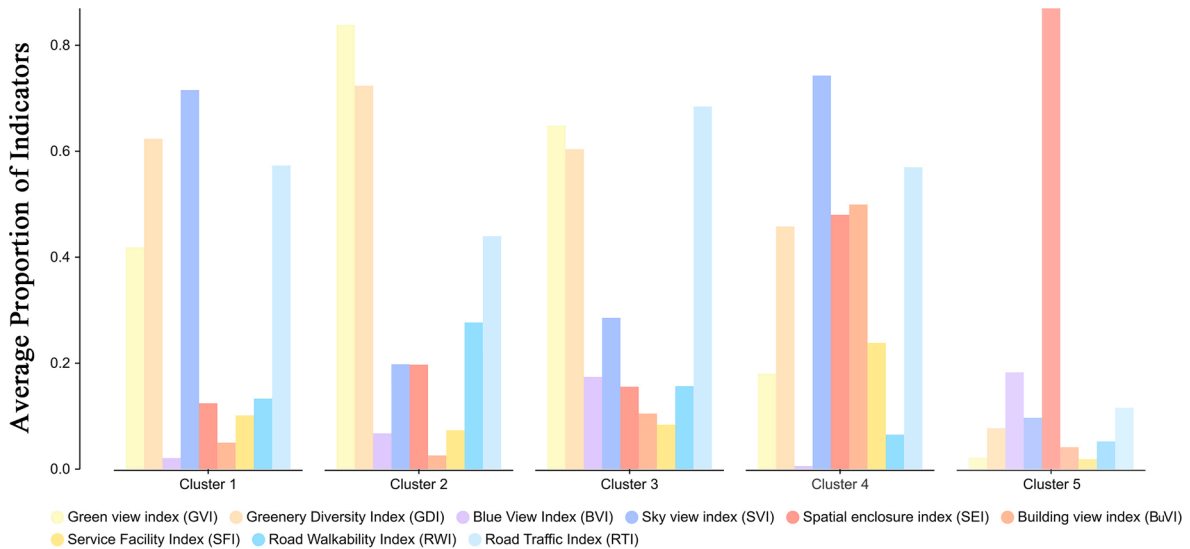


Fig. 20 Indicators for different clusters of scenic spots surrounding West Lake.

solution. (4) Cluster 4, characterized by the most pronounced artificial attributes, is situated in the northeast and exhibits continuity and coherence. This spatial type dominates this stretch of road. The overly dense distribution has caused the formation of an intensive character of the area, making it cut off from the traditional naturalization of the heritage area. (5) Cluster 5 is characterized by the tunnel section located beneath the lake. It is an important traffic transfer point for the heritage area, with a steady and sustained peak traffic flow, and has an important role to play in relieving traffic pressure in the northeast. But whether it should be classified as a scenic route is a question that should be pondered. More rational roadway choices can avoid long hours of tunnel driving. At the same time, separating daily commuters from tourists would be more effective in reducing traffic congestion.

## 4. Discussion

### 4.1. Interpretation of main findings

#### 4.1.1. Why is the visibility of water important?

Water plays multiple roles in landscape design. It is an essential component of ecosystems, supporting biodiversity and providing habitats (Rahmat et al., 2023). It also

regulates temperature and humidity, creating a pleasant environment for visitors. Different forms of water can significantly enhance visual appeal (Azzam Hamodat and Ahmed Yousif Alomary, 2014; Whalley, 1988), by combining dynamic and static elements, a rich landscape hierarchy can be created (Gawde and Sharma, 2023). Water can also serve as a focal point in the landscape, attracting visitors’ attention and guiding their movement in conjunction with infrastructure (Jin and Miao, 2024).

In traditional Chinese culture, water often represents the longing for a better life and reverence for nature (Ma, 2014). For example, water in classical Chinese gardens symbolizes elegance and charm (Chen et al., 2023). Therefore, the water in West Lake is not only a provider of ecological services, but also an anchor for history and culture (Gao, 2020).

However, our research found that the water visibility in the West Lake heritage area is very low, which to a certain extent subverts people’s traditional understanding. Existing research showed that in West Lake, people are more concerned with spaces dominated by natural elements such as water (Y. Chen et al., 2023). But due to the unreasonable planting density and route selection of vegetation, people can only see very little water on the Inner Ring Road. Only by reasonably presenting the blue space can a good image of West Lake as a heritage area be created. This study is a preliminary investigation of these elements, and more precise research methods are needed in the future to provide methods and ideas for water resource management and design.

#### 4.1.2. How to deal with the homogenization problem?

Although West Lake has unique attractions such as the “Ten Scenes of West Lake,” visual evaluation results showed that the scenic area still suffers from a long-standing problem of repetitive landscape elements.

Homogenization is a common issue in regional development, leading to poor destination imagery and reduced competitiveness (Tolvanen et al., 2020). It stems from a lack of innovative design, failing to fully leverage and highlight local characteristics (Ruiz-Ballesteros and Cáceres-Feria,

Table 3 Number of different clusters.

Cluster	Number
1	200
2	394
3	513
4	164
5	5
<b>Valid</b>	<b>1276</b>

The bar charts illustrate the variations in specific metrics across clusters (Fig. 20).



Fig. 21 Distribution of different categories of spaces in the scenic area surrounding West Lake.

2016). This manifests in the replication of template-based success stories, an overemphasis on form at the expense of visitor needs, and the uneven distribution of resources within tourist attractions (Andari et al., 2022). Additionally, the balancing of interests between local governments and developers can also impact a region's uniqueness (Hu, 2015). This often results in the sacrifice of cultural and ecological values in pursuit of economic benefits.

Re-examining the cultural resources of the West Lake heritage area is a key measure to solve this problem. As we described in the main text, West Lake has rich heritage resources, which can be used to customize personalized tourist routes and enhance the visitor experience through the construction of smart scenic spots. The road network should be used reasonably to link various heritage sites, and a series of landscapes with small regional characteristics should be created based on the historical "Ten Scenes of West Lake." The design of repetitive elements should be avoided to form complementary advantages and enhance overall competitiveness (Yang et al., 2019).

#### 4.1.3. How should tunnels be treated reasonably?

Tunnels are mainly designed in heritage areas to facilitate transportation. However, there are also many disadvantages, mainly in terms of environmental impact, visitor experience, operation and maintenance, etc.

In terms of the ecological environment, tunnels alter the flow paths of surface water and groundwater (Ye et al., 2012), thereby affecting vegetation growth and animal habitats. In terms of visitor experience, monotonous environments and insufficient lighting can easily cause visual fatigue and discomfort (Liu et al., 2023; Song et al., 2024).

Implementing appropriate landscape beautification to ensure that tunnel entrances and exits harmonize with the surrounding landscape is an effective measure (Ming et al., 2021). For example, designing lighting systems reasonably to adjust brightness and color temperature to simulate natural light environments. And installing transitional lighting at entrances to help people adapt to changes in light intensity (Jiao et al., 2021). Furthermore, incorporating appropriate local-themed murals, sculptures, and vegetation to create visual variety can effectively enhance the cultural significance of this gray space (Liang et al., 2024).

In future, artificial intelligence technology should also be used for tunnel safety management, such as using computer vision and image processing technology for detection and decision-making optimization (Liu et al., 2024), as well as improving data support with multi-sensor and information fusion (Yang et al., 2024), ultimately enhancing the overall visual experience of heritage areas.

#### 4.2. Design strategies for the streets of the West Lake heritage area

In digital era, experience and observation are critical components of spatial understanding. They contribute to the conservation and practice of heritage sites. This study proposes a methodological system that constitutes a fundamental work. The landscape design approach offers a human-centered perspective for assessing street landscape perception, facilitating the formulation of more comprehensive and detailed design strategies. It encompasses the subsequent points:

#### 4.2.1. Enhance the visibility of West Lake

As a region where the water system constitutes the primary landscape, the visual analysis of the overall street reveals that a substantial expanse of vegetation obstructs the water system. This contradicts the cultural essence of the scenic area. Attention must be paid to the appropriate height and crown width of roadside street trees and plant groupings, along with the planting density in the subsequent enhancement.

#### 4.2.2. Better integration of heritage resources

This study currently analyzes the overall visual space of the West Lake ring road; however, further research is required to assess the visual quality of specific heritage sites. This involves identifying the characteristics of various elements and establishing a distinct environment through the management of plant species, spatial shading, and other factors. This will enable users to perceive the distinctions among the spaces of the “Ten Scenes of West Lake.”

#### 4.2.3. Constructing dynamic changes

From the perspective of overall spatial changes in the streets surrounding the lake, indicators such as the Green View Index and Blue View Index have remained constant over an extended period. This stagnation has significantly negatively affected users’ travel experiences, leading to fatigue while driving and a diminished visual experience. The interplay of open and closed spaces can be achieved by aligning vegetation with the adjacent built environment. Alternatively, themed streets may be categorized based on various heritage resource-rich areas to enhance the overall experience while preserving their fundamental characteristics.

This method can be utilized in future environmental management for the pre-planning and subsequent renewal of streets, enabling a statistical analysis of the overall landscape quality. Furthermore, by implementing regular image acquisition and analysis, the management body can achieve dynamic monitoring of the quality of the street visual landscape. This facilitates a practical, long-term evaluation of the efficacy of street protection and sustainable development.

## 5. Conclusion

As a transportation infrastructure, the street is a complex and critical element of heritage area planning. It needs to meet the needs of modern cities while preserving the integrity and historic value of the heritage. This includes a number of dimensions such as transportation, accessibility, public space and economic vitality. The visual quality of a heritage area is fundamental in creating attractiveness. It is also the key to an integrated tourism system. Through rational route selection and management, the advantages and characteristics of the heritage will be maximized. In this way, the sustainable development of the region can be truly realized.

## 5.1. Key findings of the study

In this study, we chose the Inner Ring Road of the West Lake heritage area as our research object. We acquired 1276 clear and complete street view images of West Lake using python. Based on ADE20K as the training dataset, we completed the semantic segmentation using DeepLab v3 deep learning model. They have been validated by a large number of studies, so the results of the experiments are very significant. We also established a system for evaluating visual experience that contains 9 indicators and 4 dimensions, which were also selected based on a large number of previous studies. The study found the following important patterns:

- (1) “Tree” and “sky”, with a range of (0, 0.731895) and (0, 0.561155) in the total street view images, are the two elements with the greatest range of variation and the highest number of simultaneous occurrences. While the percentage range of “water” is only (0, 0.139251).
- (2) The high greenness of the natural areas in the west contrasts with the artificial attributes in the northeast, exposing the erosion of the ecology by urbanization. The Blue View Index deficit across the area also attests to the loss of the dominance of waterfront spaces.
- (3) The Green view index, Diversity of plant groups and Spatial enclosure index showed that the forest conservation effect of the heritage area was significant, and their highest values were 0.827867535, 0.725935158 and 0.443469039, respectively. However, they also weakened the Blue View Index, whose highest value was only 0.139250731, revealing the contradiction between ecological conservation and landscape accessibility.
- (4) The presence of the tunnels at West Lake results in natural indicators converging to 0. The fragmented landscape experience reveals the disruption of the continuity of the experience of the heritage area by the linear project.

## 5.2. Limitations and future research opportunities

This study applied image segmentation techniques to resource-rich landscapes characterized by distinct features; however, it presents several limitations and offers insights for future research, including the following:

- (1) The integration of quantitative and qualitative research is essential: While quantitative methods effectively assess and manage the visual quality of landscapes on both sides of the street, current image segmentation algorithms remain limited to intuitively combining and matching elements. The calculated results fail to capture the observer’s deeper emotional responses and attentiveness to the space, thus inadequately revealing its underlying cultural value.

- (2) Considerations of dynamic perspectives: The existing research primarily focuses on static street view images from the dataset perspective. In practice, street usage is characterized by dynamism and continuity. Drivers and pedestrians undergo intricate alterations in vision, behavior, and perception within a dynamic environment. Consequently, future studies should consider the inclusion of field experiments.
- (3) Utilization of heritage resources: Historical texts and images serve as primary mediums for conveying local cultural connotations. Currently, full utilization has not been comprehensively achieved. Future research should focus on the recognition and segmentation of ancient landscape paintings through the training of large-scale image datasets, integrating this with textual analysis using digital humanities tools to enhance the study's fidelity to the site's original historical context.

This study illustrates the effectiveness of the approach using the case of the Inner Ring Road of West Lake in Hangzhou; however, we acknowledge the limitations inherent in a single case study. West Lake has unique social, cultural, and natural features. Therefore, the applicability of this research result to other regions with different socio-cultural backgrounds and physical environments may be limited. Future research should cover a wider range of heritage areas with different geographical and developmental backgrounds to enhance the generalizability of research findings. Based on this, the approach's versatility will be validated, and comparisons will be conducted to demonstrate the impact of various landscape types on visual quality indicators. We expect these findings to offer important insights into street planning and management strategies for landscape settings in designated heritage areas.

### Ethics statement

The authors declare that their Institutional Ethics Committee confirmed that no ethical review was required for this study.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgments

This work was supported by the National Social Science Art Program of China (Grant No. 21BJ130), Tsinghua University's independent research project, Humanities Special Project (Grant No. 2023THZWC24), Tsinghua University's Student Research Training (Grant No. 2521T0532). And thanks to the editors and reviewers for improving the quality of this article.

### References

- Ali, S., Xu, H., Ahmed, W., Ahmad, N., Solangi, Y.A., 2020. Metro design and heritage sustainability: conflict analysis using attitude based on options in the graph model. *Environ. Dev. Sustain.* 22, 3839–3860.
- Andari, R., I, W.G.S., I, G.R., Sukawati, T.G.R., 2022. The strength of local Wisdom values as a differentiation strategy in creating sustainable tourism competitiveness. *WEB* 19, 4088–4104.
- Azzam Hamodat, A., Ahmed Yousif Alomary, 2014. Water in landscape design, its effect on the Placemaking. (*AREJ*) 22, 97–117.
- Bak, S., Min, C.-K., Roh, T.-S., 2019. Impacts of UNESCO-listed tangible and intangible heritages on tourism. *J. Trav. Tourism Market.* 36, 917–927.
- Boukrouh, N., Bouchair, A., 2024. Urban walkability assessment, a double examination by physical environment and users' perceptions: the Case of Jijel City in Algeria. *J Build Rehabil* 9, 92.
- Campbell, A., Both, A., Sun, Q., 2019. Detecting and mapping traffic signs from Google Street View images using deep learning and GIS. *Comput. Environ. Urban Syst.* 77, 101350.
- Chen, B., Feng, Q., Niu, B., Yan, F., Gao, B., Yang, J., Gong, J., Liu, J., 2022. Multi-modal fusion of satellite and street-view images for urban village classification based on a dual-branch deep neural network. *Int. J. Appl. Earth Obs. Geoinf.* 109, 102794.
- Chen, X., Yin, Y., Jiang, M., Lin, H., 2023. Deep analysis of the homogenization phenomenon of the ancient water towns in Jiangnan: a dual perspective on landscape patterns and tourism destination images. *Sustainability* 15, 12595.
- Chen, Y., Ma, Q., Xu, L., Shi, Y., Lu, Z., Wu, Y., Feng, M., 2023. Spatial sight analysis of Hangzhou Xiaoyingzhou based on tourists' landscape preference. *Frontiers of Architectural Research* 12, 1157–1170.
- Ding, W., Wei, Q., Jin, J., Nie, J., Zhang, F., Zhou, X., Ma, Y., 2023. Research on public space micro-renewal strategy of historical and cultural blocks in Sanhe ancient town under perception quantification. *Sustainability* 15, 2790.
- Dong, W., Dai, D., Shen, P., Zhang, R., Liu, M., 2024. How public urban space enhance restoration benefits through combined multisensory effects: a systematic review. *Land* 13, 2018.
- Gao, B., 2020. The effect of memory construction of cultural landmarks on urban development. In: *Proceedings of the 2nd International Conference on Architecture: Heritage, Traditions and Innovations (AHTI 2020)*. Atlantis Press, Moscow, Russia.
- Gawde, R., Sharma, S., 2023. Water element as an aesthetic aspect of landscape design. *IJRASET* 11, 636–638.
- Gopal, K., Shin, E.J., 2019. The impacts of rail transit on the lives and travel experiences of women in the developing world: evidence from the Delhi Metro. *Cities* 88, 66–75.
- Guriță, D., Scortescu, F.I., 2023. Religious tourism and sustainable development of the economy in the context of globalization in the Northeast area of Romania. *Sustainability* 15, 12128.
- Han, X., Wang, L., Seo, S.H., He, J., Jung, T., 2022. Measuring perceived psychological stress in urban built environments using google street view and deep learning. *Front. Public Health* 10, 891736.
- Han, X., Yu, Y., Liu, L., Li, Ming, Wang, L., Zhang, T., Tang, F., Shen, Y., Li, Mingshuai, Yu, S., Peng, H., Zhang, J., Wang, F., Ji, X., Zhang, X., Hou, M., 2023. Exploration of street space architectural color measurement based on street view big data and deep learning—a case study of Jiefang North Road Street in Tianjin. *PLoS One* 18, e0289305.
- Han, Y., Zhong, T., Yeh, A.G.O., Zhong, X., Chen, M., Lü, G., 2023. Mapping seasonal changes of street greenery using multi-temporal street-view images. *Sustain. Cities Soc.* 92, 104498.

- Harvey, C., Aultman-Hall, L., Hurley, S.E., Troy, A., 2015. Effects of skeletal streetscape design on perceived safety. *Land. Urban Plan. Spec. Iss.: Critic. Approach. Land. Visualiz.* 142, 18–28.
- He, Y., Chen, K., Han, X., 2024. Residential urban heritage space identification, delimitation, and potential assessment model based on space syntax. *J. Chinese Archit. Urbanism* 6, 1732.
- Huang, J., Liang, J., Yang, M., Li, Y., 2023. Visual preference analysis and planning responses based on street view images: a case study of Gulangyu island, China. *Land* 12, 129.
- Hussein, A.S., Hapsari, R., 2021. Heritage experiential quality and behavioural intention: lessons from Indonesian heritage hotel consumers. *J. Herit. Tourism* 16, 317–336.
- Hu, X., 2015. Game analysis between local government and developers in the exploitation of tourism scenic spots. *ME* 06 223–227.
- Jang, S.-Y., Kim, S.-A., 2023. Content curation for spatial experience of architectural heritage. *J. Comput. Cult. Herit.* 15 (69), 1–14.
- Jiang, H., Dong, L., Qiu, B., 2022. How are macro-scale and micro-scale built environments associated with running activity? The application of Strava data and deep learning in inner London. *ISPRS Int. J. Geoinf.* 11, 504.
- Jiao, F., Du, Z., Chen, G., Zheng, H., Tang, Z., Wang, S., 2021. Entrance zone length of extra-long undersea tunnels based on vision adaptation. *Tunn. Undergr. Space Technol.* 113, 103970.
- Jin, W., Miao, W., 2024. How the ecological structure affects the aesthetic atmosphere of the landscape: evaluation of the landscape Beauty of Xingqing Palace Park in Xi'an. *PLoS One* 19, e0302855.
- Jin, Z., Qin, X., Chen, L., Jin, M., Li, F., 2015. Using dual isotopes to evaluate sources and transformations of nitrate in the West Lake watershed, Eastern China. *J. Contam. Hydrol.* 177–178, 64–75.
- Jinji, Z., Yuanqin, W., 2020. Research on stereo image synthesis based on Oblique Photography of UAV. In: Kountchev, R., Patnaik, S., Shi, J., Favorskaya, M.N. (Eds.), *Advances in 3D Image and Graphics Representation, Analysis, Computing and Information Technology*. Springer, Singapore, pp. 287–295.
- Jones, Z.M., Ponzini, D., 2021. Cultural mega-events in heritage-rich cities. *Cidades. Comunidades e Territórios*.
- Ki, D., Lee, S., 2021. Analyzing the effects of Green View Index of neighborhood streets on walking time using Google Street View and deep learning. *Landsc. Urban Plann.* 205, 103920.
- Lai, P., Ou, D., Zheng, H., 2024. Exploring Acoustic-Visual perception and satisfaction in urban Parks: based on behavioral analysis. *Ecol. Indic.* 162, 112022.
- Lee, K., Wylie, B., Williams, N.S.G., Johnson, K.A., Sargent, L.D., Williams, K.J.H., 2024. "It's a little soap opera of its own": Fascinating green roofs offer complexity, movement, sensory engagement, and vast vistas. *Landsc. Urban Plann.* 242, 104925.
- Lei, Y., Zhou, H., Xue, L., Yuan, L., Liu, Y., Wang, M., Wang, C., 2024. Evaluating and comparing human perceptions of streets in two megacities by integrating street-view images, deep learning, and space syntax. *Buildings* 14, 1847.
- Liang, B., Li, Z., Xu, M., Xiao, J., Long, H., 2024. Study on the design parameters of landscape elements of urban tunnel body segments in China based on biomass perception. *Appl. Sci.* 14, 6100.
- Li, M., Yeh, A.G.O., Xue, F., 2024. CIM-WV: a 2D semantic segmentation dataset of rich window view contents in high-rise, high-density Hong Kong based on photorealistic city information models. *Urban. Inf.* 3, 12.
- Li, S., Ma, S., Tong, D., Jia, Z., Li, P., Long, Y., 2022. Associations between the quality of street space and the attributes of the built environment using large volumes of street view pictures. *Environ. Plan. B Urban Anal. City Sci.* 49, 1197–1211.
- Li, X., Ratti, C., Seiferling, I., 2018. Quantifying the shade provision of street trees in urban landscape: a case study in Boston, USA, using Google Street View. *Landsc. Urban Plann.* 169, 81–91.
- Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., Zhang, W., 2015. Assessing street-level urban greenery using Google Street View and a modified green view index. *Urban For. Urban Green.* 14, 675–685.
- Liang, C., Jiang, H., Yang, S., Tian, P., Ma, X., Tang, Z., Wang, H., Wang, W., 2024. Characterizing street trees in three metropolises of central China by using Street View data: from individual trees to landscape mapping. *Ecol. Inform.* 80, 102480.
- Liang, S., Zou, Z., 2023. Eine kontrastive Untersuchung über das Raumerleben anhand von Berichten im chinesischen und deutschen Reisemagazin. *Interkulturelles Forum der deutsch-chinesischen Kommunikation* 3, 243–266.
- Liu, J., Kang, J., Luo, T., Behm, H., Coppack, T., 2013. Spatio-temporal variability of soundscapes in a multiple functional urban area. *Landsc. Urban Plann.* 115, 1–9.
- Liu, L., Song, Z., Li, X., 2024. Artificial intelligence in tunnel construction: a comprehensive review of hotspots and frontier topics. *Geohazard Mechanics* 2, 1–12.
- Liu, Q., Tang, X., Li, K., 2022. Do historic landscape images predict tourists' spatio-temporal behavior at heritage sites? A case study of West Lake in Hangzhou, China. *Land* 11, 1643.
- Liu, Y., Ge, P., Liu, Q., Fan, S., Wang, Y., 2024. An empirical study on multi-domain robust semantic segmentation. *Int. J. Comput. Vis.* 132, 4289–4304.
- Liu, Ye, Xiao, T., Liu, Yuqi, Yao, Y., Wang, R., 2021. Natural outdoor environments and subjective well-being in Guangzhou, China: comparing different measures of access. *Urban For. Urban Green.* 59, 127027.
- Liu, Z., Zhang, Y., Guo, X., 2023. Boosting semantic segmentation via feature enhancement. *J. Vis. Commun. Image Represent.* 92, 103796.
- Liu, Z.H., Yu, D., Zhou, T., Wang, X., Xu, W., 2023. Review on tunnel interior landscape and driving safety research. In: 23rd COTA International Conference of Transportation Professionals, CICTP 2023. American Society of Civil Engineers, Beijing, China, pp. 421–427.
- Lu, J., Luo, X., Zhang, P., 2019. Rights–values–interests: the conflict between world cultural heritage and community: a case study of the West Lake cultural landscape heritage in China. *Sustainability* 11, 4560.
- Ma, X., Ma, C., Wu, C., Xi, Y., Yang, R., Peng, N., Zhang, C., Ren, F., 2021. Measuring human perceptions of streetscapes to better inform urban renewal: a perspective of scene semantic parsing. *Cities* 110, 103086.
- Ma, B., 2014. The comparison in the development of garden waterscape in the East and West Country. *Appl. Mech. Mater.* 584–586, 691–694.
- Ma, Y., Bhatt, N.R., Wu, Q., Pokharel, M., 2025. Urban rail transit in heritage – rich cities: exploring the unique project risks. *Eng. Construct. Architect. Manag.*
- Mahmud, M.N., Osman, M.K., Ismail, A.P., Ahmad, F., Ahmad, K.A., Ibrahim, A., 2021. Road image segmentation using unmanned aerial vehicle images and DeepLab V3+ semantic segmentation model. In: 2021 11th IEEE International Conference on Control System, Computing and Engineering (ICCSCE). IEEE, Penang, Malaysia, Pp. 176–181.
- Ming, L., Zhiqiang, L., Rongrong, Q., 2021. Discussion on landscape and greening technology of highway structural tunnel entrance. *E3S Web Conf.* 261, 03035.
- Mouratidis, K., 2021. Urban planning and quality of life: a review of pathways linking the built environment to subjective well-being. *Cities* 115, 103229.
- Nofal, E., Stevens, R., Coomans, T., Vande Moere, A., 2018. Communicating the spatiotemporal transformation of architectural heritage via an in-situ projection mapping installation. *Digit. Appl. Archaeol. Cultur. Heritage* 11, e00083.
- Pan, S., Liu, Z., Yan, H., Chen, N., Zhao, X., Li, S., Witlox, F., 2024. Automatic identification of bottlenecks for ambulance passage

- on urban streets: a deep learning-based approach. *Adv. Eng. Inform.* 62, 102931.
- Park, K., Ewing, R., Sabouri, S., Larsen, J., 2019. Street life and the built environment in an auto-oriented US region. *Cities* 88, 243–251.
- Qin, X., Yang, D., Wangari, V.W., 2024. Quantitative characterization and evaluation of highway greening landscape spatial quality based on deep learning. *Environ. Impact Assess. Rev.* 107, 107559.
- Rahmat, A.F., El Archi, Y., Putra, M.A., Benbba, B., Mominov, S., Liudmila, P., Issakov, Y., Kabil, M., Dávid, L.D., 2023. Pivotal issues of water-based tourism in worldwide literature. *Water* 15, 2886.
- Ren, M., Zhang, X., Zhi, X., Wei, Y., Feng, Z., 2024. An annotated street view image dataset for automated road damage detection. *Sci. Data* 11, 407.
- Ruiz-Ballesteros, E., Cáceres-Feria, R., 2016. Community-building and amenity migration in community-based tourism development. An approach from southwest Spain. *Tour. Manag.* 54, 513–523.
- Rui, Q., Cheng, H., 2023. Quantifying the spatial quality of urban streets with open street view images: a case study of the main urban area of Fuzhou. *Ecol. Indic.* 156, 111204.
- Sediqi, K.M., Lee, H.J., 2021. A novel upsampling and context convolution for image semantic segmentation. *Sensors* 21, 2170.
- Smirnov, E., Kudinov, S., 2021. Using a genetic algorithm for planning interesting tourist routes in the city on the basis of open street map data. In: 2021 IEEE Congress on Evolutionary Computation (CEC), Kraków, Poland, pp. 264–271.
- Snyder, A.B., 2022. The designed and the ad hoc: dynamic remakings of street space in New York City. *Architect. Minn.* 23.
- Song, Y., Zhu, H., Shen, Y., Feng, S., 2024. Green tunnel lighting environment: a systematic review on energy saving, visual comfort and low carbon. *Tunn. Undergr. Space Technol.* 144, 105535.
- Su, L., Ismail, N.H., 2024. Application of intangible cultural heritage elements in the interactive space. *Inter. J. Edu. Human.* 13, 88–91.
- Su, Q., Xiao, J., Yu, X., Chen, iang, 2020. Research on evaluation model of road congestion of tourist attraction based on spatial syntax and neural network method – A case of Gulangyu Island, Xiamen, China. *arXiv.2003.13406*.
- Sussi, S., Husni, E., Siburian, A., Yusuf, R., Budi Harto, A., Suwardhi, D., 2024. Effect of dataset distribution on automatic road extraction in very high-resolution orthophoto using DeepLab V3+. *IJ-AI* 13, 1650.
- Tao, Y., Wang, Y., Wang, X., Tian, G., Zhang, S., 2022. Measuring the correlation between human activity density and streetscape perceptions: an analysis based on Baidu street view images in Zhengzhou, China. *Land* 11, 400.
- Tolvanen, A., Kangas, K., Tarvainen, O., Huhta, E., Jäkäläniemi, A., Kytä, M., Nikula, A., Nivala, V., Tuulentie, S., Tyräinen, L., 2020. The relationship between people's activities and values with the protection level and biodiversity. *Tour. Manag.* 81, 104141.
- Tsai, V.J.D., Chang, C.-T., 2013. Three-dimensional positioning from Google street view panoramas. *IET Image Process.* 7, 229–239.
- Verma, D., Mumm, O., Carlow, V.M., 2024. Assessing visual similarity of neighbourhoods with street view images and deep learning techniques. *J. Urban Des.* 30 (4), 520–531. <https://doi.org/10.1080/13574809.2024.2357804>.
- Wang, L., Hou, C., Zhang, Y., He, J., 2024. Measuring solar radiation and spatio-temporal distribution in different street network direction through solar trajectories and street view images. *Int. J. Appl. Earth Obs. Geoinf.* 132, 104058.
- Wang, X., Wu, H., Gorenflo, L.J., Wu, C., 2023. Exploring 1800 years of ecosystem services from West Lake, Hangzhou, China. *Stud. Hist. Gard. Des. Landsc.* 43, 279–297.
- Wang, X., Yang, M., Li, W., Yuan, L., Ren, Q., Xie, Q., Liu, R., 2025. Natural movement: measuring optimal pathway configuration of museum layout and pedestrian accessibility through visibility graph analysis and intelligent agent simulation. *Front. Archit. Res.* 14 (5), 1228–1248.
- Wang, Y., Xiu, C., 2023. Spatial quality evaluation of historical blocks based on street view image data: a case study of the Fangcheng district. *Buildings* 13, 1612.
- Wang, Z.Z., Chen, C., 2017. Fuzzy comprehensive Bayesian network-based safety risk assessment for metro construction projects. *Tunn. Undergr. Space Technol.* 70, 330–342.
- Wen, D., Liu, M., Yu, Z., 2022. Quantifying ecological landscape quality of urban street by open street view images: a case study of Xiamen island, China. *Remote Sens.* 14, 3360.
- Whalley, J.M., 1988. Water in the landscape. *Landsc. Urban Plann.* 16, 145–162.
- Wu, Y., Liu, Q., Hang, T., Yang, Y., Wang, Y., Cao, L., 2024. Integrating restorative perception into urban street planning: a framework using street view images, deep learning, and space syntax. *Cities* 147, 104791.
- Xu, F., Jin, A., Chen, X., Li, G., 2021. New data, integrated methods and multiple applications: a review of urban studies based on street view images. In: 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, Brussels, Belgium, Pp. 6532–6535.
- Xu, J., Liu, Yaolin, Liu, Yanfang, An, R., Tong, Z., 2023. Integrating street view images and deep learning to explore the association between human perceptions of the built environment and cardiovascular disease in older adults. *Soc. Sci. Med.* 338, 116304.
- Xu, S., Liu, Y., Qian, Y., Wang, Q., 2017. The significance of the West Lake pattern and its heuristic implications for creating China's heritage tourism economics. *Tour. Manag.* 58, 286–292.
- Xu, W., Zhao, J., 2023. Investigating visual aesthetic fatigue in urban green spaces. *Int. J. Environ. Res.* 17, 27.
- Xu, X., Niu, L., 2024. Analysis of influencing factors of green view index based on street view segmentation. *Int. Arch. Photogram. Rem. Sens. Spatial Inf. Sci.* XLVIII-4–2024, 517–524.
- Yang, C., Dong, J., Hao, J., 2019. Cooperation Contracts between Small and Major Scenic Spots in Peak Seasons. *Sage Open* 9.
- Yang, X., Yu, S., Wang, J., Chen, H., Huang, Y., Luo, Z., Fu, L., 2024. Application of a digital twin for highway tunnels based on multi-sensor and information fusion. *Front. Physiol.* 1335494.
- Yao, Y., Liang, Z., Yuan, Z., Liu, P., Bie, Y., Zhang, J., Wang, R., Wang, J., Guan, Q., 2019. A human-machine adversarial scoring framework for urban perception assessment using street-view images. *Int. J. Geogr. Inf. Sci.* 33, 2363–2384.
- Ye, F., He, C., Wang, S., Zhang, J., 2012. Landscape design of mountain highway tunnel portals in China. *Tunn. Undergr. Space Technol.* 29, 52–68.
- Yin, L., Wang, Z., 2016. Measuring visual enclosure for street walkability: using machine learning algorithms and Google Street View imagery. *Appl. Geogr.* 76, 147–153.
- Yuan, Y., Wang, R., Niu, T., Liu, Y., 2023. Using street view images and a geographical detector to understand how street-level built environment is associated with urban poverty: a case study in Guangzhou. *Appl. Geogr.* 156, 102980.
- Yue, H., Xie, H., Liu, L., Chen, J., 2022. Detecting people on the street and the streetscape physical environment from Baidu street view images and their effects on community-level street crime in a Chinese city. *ISPRS Int. J. Geoinf.* 11, 151.
- Zhang, A., Zhai, S., Liu, X., Song, G., Feng, Y., 2022. Investigating the association between streetscapes and mental health in Zhanjiang, China: using Baidu street view images and deep learning. *IJERPH* 19, 16634.

- Zhang, C., Xu, F., Wu, C., Xu, C., 2023. Rethinking 1D convolution for lightweight semantic segmentation. *Front. Neurobot.* 17, 1119231.
- Zhang, F., Wu, L., Zhu, D., Liu, Y., 2019. Social sensing from street-level imagery: a case study in learning spatio-temporal urban mobility patterns. *ISPRS J. Photo. Remote Sens.* 153, 48–58.
- Zhang, R., Taylor, K., 2020. Cultural landscape meanings. The case of West Lake, Hangzhou, China. *Landsc. Res.* 45, 164–178.
- Zhang, T., Wang, L., Hu, Y., Zhang, W., Liu, Y., 2024. Measuring urban green space exposure based on street view images and machine learning. *Forests* 15, 655.
- Zhang, W., Chen, J., Tian, Y., 2025. Street quality measurement and accessibility analysis based on streetscape data: the case of Mingcheng district in Xi'an city. *Appl. Sci.* 15, 583.
- Zhang, X., Lin, E.S., Tan, P.Y., Qi, J., Waykool, R., 2023. Assessment of visual landscape quality of urban green spaces using image-based metrics derived from perceived sensory dimensions. *Environ. Impact Assess. Rev.* 102, 107200.
- Zhang, Y., Xiong, X., Yang, S., Zhang, Q., Chi, M., Wen, X., Zhang, X., Wang, J., 2025. Enhancing the visual environment of urban coastal roads through deep learning analysis of street-view images: a perspective of aesthetic and distinctiveness. *PLoS One* 20, e0317585.
- Zhou, B., Zhao, H., Puig, X., Fidler, S., Barriuso, A., Torralba, A., 2017. Scene parsing through ADE20K dataset. In: 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR). IEEE, Honolulu, HI, pp. 5122–5130.
- Zhou, B., Zhao, H., Puig, X., Xiao, T., Fidler, S., Barriuso, A., Torralba, A., 2019. Semantic understanding of scenes through the ADE20K dataset. *Int. J. Comput. Vis.* 127, 302–321.
- Zhou, H., Wang, J., Widener, M., Wilson, K., 2024. Examining the relationship between active transport and exposure to streetscape diversity during travel: a study using GPS data and street view imagery. *Comput. Environ. Urban Syst.* 110, 102105.
- Zhu, Y., 2025. Contested sacred space: state power, spatial politics, and heritage tourism. *Tour. Geogr.* 1–25.
- Zijing, C., Hao, Y., 2024. Research on street view information extraction method based on convolutional neural network. In: 2024 IEEE 6th International Conference on Power, Intelligent Computing and Systems (ICPICS), pp. 525–530.