



## OPEN How landscape element characterization affects aesthetic preferences and visual attention in urban wetland park recreation spaces

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The landscape quality of recreation space in urban wetland parks directly affects the public's recreational experience and well-being. Given that the public's landscape experience and visual evaluation of recreation spaces are closely related, it is important to understand the public's visual evaluation of the landscape and the factors affecting it for the optimization and enhancement of recreation spaces. The present study focuses on Wulong River Wetland Park in Fuzhou City, Fujian Province, China. The study integrates eye-tracking, scenic beauty estimation and landscape element characterization, and systematically explores the influence mechanism of landscape features on visual evaluation through correlation analysis and multiple linear stepwise regression analysis. The results demonstrated that: (1) Eye-tracking and landscape element characteristics were significantly correlated, in which eight elements such as deciduous plants, colored-leaf plants, and greening rate influenced the visual attractiveness; (2) The scenic beauty estimation was mainly affected by greening rate, openness of view, and plant growth status. In future research, a combination of landscape element characteristics and landscape visual evaluation is recommended as a means of improving the landscape quality of urban wetland park recreation space.

**Keywords** Eye-tracking, Landscape visual assessment, Characteristic of landscape elements, Recreation space, Urban wetland park

Urban wetland parks refer to comprehensive parks located within cities or their suburbs that are centered on wetland ecosystems, equipped with essential recreational and management facilities, and that integrate ecological conservation with public services<sup>1,2</sup>. Compared with ordinary urban green spaces, urban wetland parks are characterized by the “blue–green coupling” of elements, and they play critical roles in stormwater retention, pollution abatement, and biodiversity maintenance<sup>3,4</sup>. They therefore hold strategic importance for urban livability, public health, and disaster risk reduction<sup>5</sup>. In recent years, the construction and optimization of such blue–green spaces have increasingly been regarded as essential to improving sustainable local decision-making<sup>6,7</sup>; Systematic evaluation can help allocate scarce natural-space resources more effectively and enhance recreational experiences and residents' well-being<sup>8,9</sup>. Among human sensory modalities, vision accounts for the majority of environmental information acquisition—often reported at around 80%<sup>7</sup>. Accordingly, visual landscape quality occupies a central place in public-space assessment and is widely recognized for its importance to restoration, nature conservation, and planning/management<sup>10</sup>.

Early studies on visual landscape quality relied primarily on subjective perception and qualitative approaches: on the one hand, experts were invited to evaluate ecological and scenic beauty<sup>11,12</sup>; questionnaires were used to collect public preference data grounded in sensory experience<sup>13,14</sup>. With methodological advances, the introduction of machine learning, computer vision, and street-view/remote-sensing data has made large-scale, automated assessment of landscape quality feasible<sup>15,16</sup>. Nevertheless, gaps remain between objective and subjective perspectives: the mechanisms by which people understand and form landscape preferences are still

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not fully clear<sup>17</sup>, and mismatches in knowledge and terminology between experts and the public can complicate the interpretation of structure and elements<sup>18,19</sup>. Moreover, while much existing work contrasts “artificial” versus “natural” settings, differences in the internal composition of elements within blue–green spaces can also systematically shape preferences. Greater attention should therefore be paid to the mechanisms linking “elemental composition” with visitor preferences to strengthen the practical guidance for park development<sup>20</sup>.

In recent years, eye-tracking has been widely applied in landscape-visual studies<sup>21</sup>. By recording fixation points, dwell time, saccade trajectories, and pupil dynamics, eye-tracking reveals how visual information is extracted and how selective attention operates. It is widely viewed as a key bridge connecting objective landscape attributes with subjective visual preference<sup>22–24</sup>, and it helps identify the objects and compositional cues within a scene that most attract attention<sup>24</sup>. Prior research shows that, in urban streets and parks, openness, landscape heterogeneity, and the proportion/complexity of natural versus artificial elements systematically alter fixation patterns and are accompanied by differences in preference<sup>21</sup>; In traditional village public spaces, eye-tracking indicators capture the visual-behavior characteristics of the “user–place” relationship and suggest optimization strategies<sup>25</sup>; In forest (urban) parks, structural attributes such as design intensity and openness strongly influence visual behavior and preference, with peak preference often occurring around moderate levels—indicating threshold or nonlinear effects<sup>26</sup>—mountain landscapes, perceived naturalness and the visibility of artificial features are key determinants of preference<sup>27</sup>. However, context-specific evidence remains scarce for wetland parks where composite elements such as “blue–green–beach–boardwalk” coexist.

In coastal Fujian Province, urban wetland corridors are largely shaped by river systems and have gradually become important recreational spaces for city residents. Wulong River Wetland Park is the first wetland in Fuzhou City to be opened to the public in the form of an urban park, forming a linear riverfront corridor approximately 5.87 km in length and covering about 243 ha. After two decades of ecological restoration, the park now integrates flood control, habitat provision, science education, and leisure functions within a narrow riparian belt that is closely connected to the surrounding communities. However, empirical studies that explicitly link the micro-scale composition of recreational spaces in such wetland parks with visitors’ visual behavior and aesthetic evaluations remain limited, resulting in a lack of guiding principles for further optimization of landscape configuration. Consequently, for Wulong River Wetland Park and similar urban wetland corridors in Fujian, there is a practical need for evidence that directly reflects how visitors perceive, observe, and evaluate specific recreation spaces, so as to support fine-grained design optimization.

Against this backdrop, the present study focuses on urban wetland parks and conducts an empirical investigation using a “single-stimulus-set, three-source data linkage” approach. We employ pixel-level image segmentation and manual interpretation to construct 20 operational indicators of landscape elements across three categories—spatial, natural, and artificial—use four classes of eye-tracking metrics to characterize attentional mechanisms, and obtain subjective aesthetic preference via Scenic Beauty Estimation (SBE). Based on these data, we use correlation analysis and multivariate regression (including incremental  $R^2$ , variance decomposition, and path tests) to address the following questions: (1) What are the characteristics of landscape elements, scenic-beauty evaluation, and eye-tracking metrics across different recreational spaces within urban wetland parks? (2) How are the characteristics of different landscape elements related to scenic-beauty evaluation and eye-tracking outcomes? (3) Which specific landscape-element characteristics exert significant effects on scenic-beauty evaluation and eye-tracking indicators?

## Materials and methods

### Study area

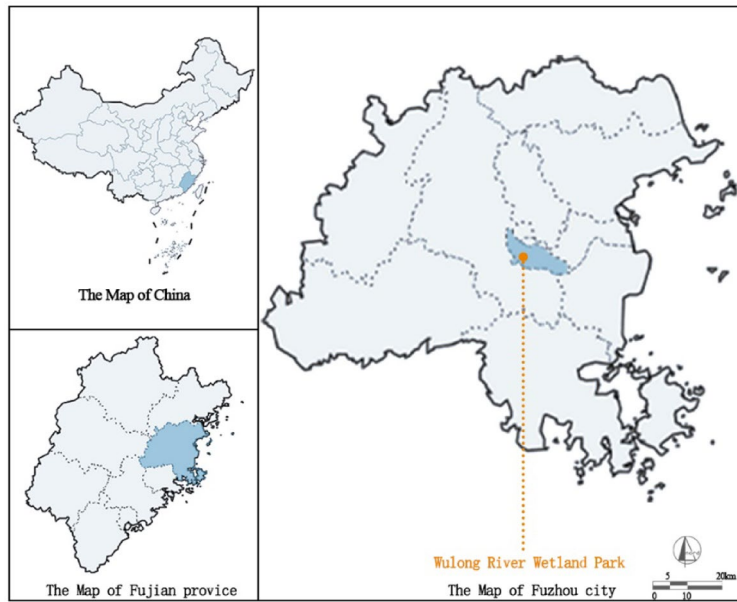
Located on the southeast coast of China, Fuzhou City is the capital of Fujian Province, with geographic coordinates ranging from 25°15′ to 26°39′ N latitude and 118°08′ to 120°31′ E longitude. With the accelerating urbanization process, Fuzhou City faces many challenges in improving the quality of ecological environment and improving the living environment of residents.

Wulong River Wetland Park is the focus of this paper (Fig. 1). As the first wetland to be opened as a park in Fuzhou City, the park is located in the Wulong River basin, a tributary of the Min River, and is part of a strip-type riverbank corridor with a length of about 5.87 km and a total area of about 243 hectares. The park is composed of five distinct sections: wetland ecological restoration and reconstruction area, wetland biodiversity science popularization area, reed-bed ecotourism area, native wetland protection area, and embankment city tree garden. Since its opening in 2003, the park has been responsible for restoring the wetland ecology of Fuzhou City, raising public awareness of wetland protection and popularizing wetland science knowledge. Although it suffered some damage in the early days, the ecological function has been gradually restored through effective measures. In the future, a balance should be struck between ecological protection and public interest, and the public should be guided to enjoy natural beauty and leisure and tourism activities while protecting the ecological environment. To systematically clarify the methodological framework of this study, a four-stage technical route featuring “Theory-Data-Analysis-Application” was developed (Fig. 2).

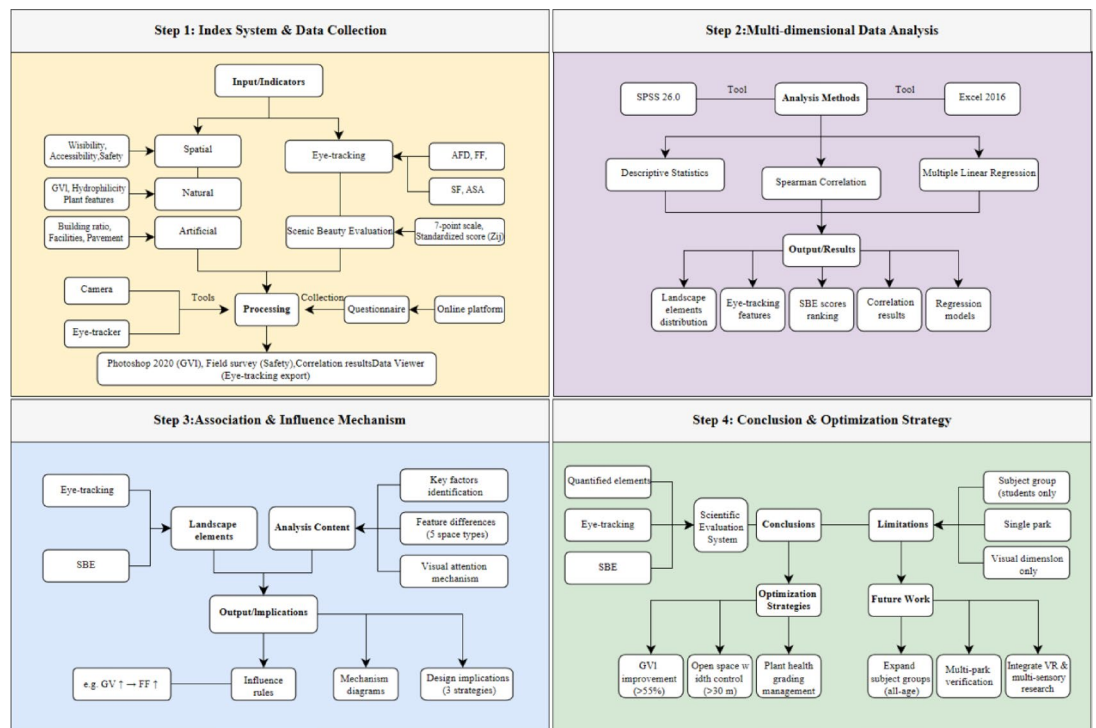
### Sample site selection

Photographic studies have been demonstrated to effectively avoid the influence of external disturbances, including climate, temperature, and light, and exhibit a high degree of concordance with field assessment results. Research has demonstrated that seasonality manifests not only in alterations to natural landscape components but also in the behaviors of visitors<sup>28</sup>, and it is relevant to conduct the experiments in spring when the number of visitors is high. The photographs were captured using a Canon EOS 80D DSLR camera during the period of March to April of 2024, under conditions of clear sky or slight cloud cover.

Combined with the field research and the specific spatial needs of recreation activities in the park, the recreation space types of Wulong River Wetland Park are divided into five types: distribution recreation space



**Fig. 1.** Study area and sample plot selection. Map data from OpenStreetMap (<https://www.openstreetmap.org/>). Modify it using QGIS version 3.42.2 (<https://qgis.org/>). Modify using the Creative Commons Attribution (CC BY) license agreement.

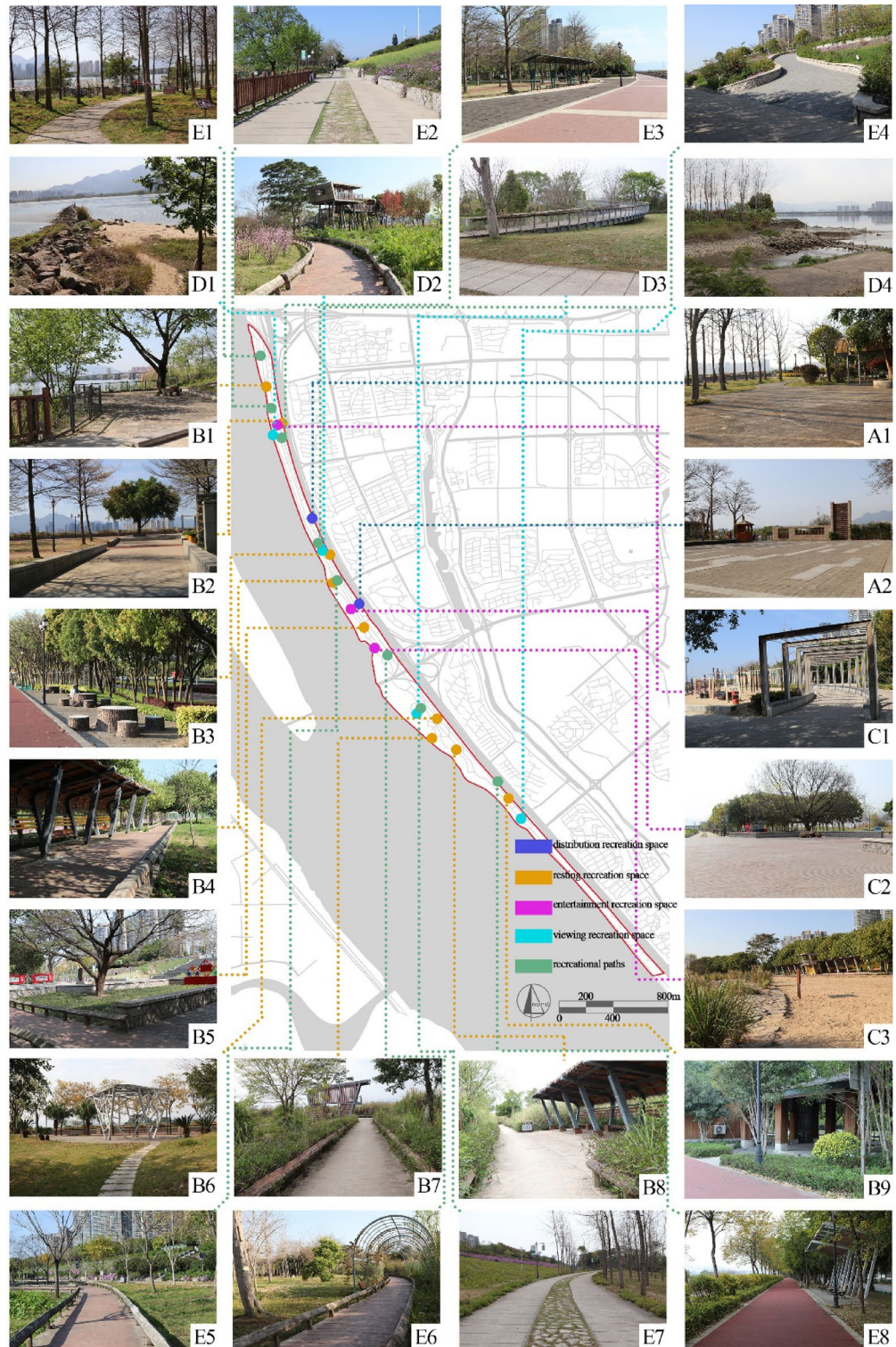


**Fig. 2.** Improve workflow of the study.

(A1-A2), resting recreation space (B1-B9), entertainment recreation space (C1-C3), viewing recreation space (D1-D4), and recreational paths (E1-E8). A total of 264 photos were taken, and 26 ornamental and representative recreation spaces were selected by the experts of the Department of Landscape Architecture (Fig. 3).

### Landscape element characterization data collection

To scientifically quantify the characteristics of landscape elements in the recreational spaces of urban wetland parks, a total of 20 indicators were selected from three dimensions—spatial element characteristics, natural



**Fig. 3.** Experimental material. Map data from OpenStreetMap (<https://www.openstreetmap.org/>). Modify it using QGIS version 3.42.2(<https://qgis.org/>). Modify using the Creative Commons Attribution (CC BY) license agreement.

element characteristics, and artificial element characteristics—with reference to relevant previous studies, consultations with experts and scholars, and integration of the landscape element features of the park’s internal recreational spaces (Table 1). According to Kaplan’s Environmental Preference Theory, the “accessibility” and “visual legibility” of the environment are core dimensions that influence human spatial cognition and preference. The role of spatial safety lies in eliminating psychological anxiety caused by environmental uncertainty and

Types	No.	Characterization of landscape elements	Evaluation description	Quantitative method
Characterization of spatial elements	V1	Openness of view	Percentage of sky within visual range	Image processing
	V2	Spatial accessibility	Ease of getting to the shooting spot	Segmentation analysis
	V3	Spatial safety	Level of safety of recreation space within visual range	On-site investigation
Characterization of natural elements	V4	Greening rate	Percentage of green plants within visual range	Image processing
	V5	Hydrophilicity	Is the river visible within visual range	Determine whether there is or is not
	V6	Living type composition	Distribution of trees, shrubs and grasses in the botanical landscape at the immediate landscape	Segmentation analysis
	V7	Plant color richness	Number of colors such as leaf color, flower color, branch color, ornamental grass spike color, etc. of plants within visual range	Demographics
	V8	Flowering plant	Nearby view with or without flowering plants	Demographics
	V9	Colored-leaf plants	Nearby view with or without colored foliage plants	Demographics
	V10	Deciduous plant	Plants with or without deciduous state in the close-up view	Demographics
	V11	Plant growth status	Visualize the condition of decaying, dead plants in plant landscapes within	Determine Whether there is or is not
	V12	Beach rate	Percentage of beaches within visual range	Image processing
	Characterization of artificial elements	V13	Peripheral buildings rate	Percentage of floor space in the park perimeter within visual range
V14		Number of favorable landscapes	Number of active landscape elements such as scenic rocks, pavilions, wooden walkways, open space facilities, etc. within visual range	Demographics
V15		Number of negative landscapes	Number of negative landscape elements such as public toilets, electric utilities, trash cans, etc. within visual range	Demographics
V16		Garden paths and spatial patterns	Morphology of the park roads and node spaces within visual range	Segmentation analysis
V17		Artificial materials rate	Percentage of man-made materials within visual range, including vignettes and pathways	Image processing
V18		Pavement materials	Material of road surfacing within visual range	Segmentation analysis
V19		Recreational facilities	Number of open space facilities within visual range	Demographics
V20		Recreational activity type richness	Number of types of open space activities within visual range	On-site investigation

**Table 1.** Quantification the characteristics of landscape elements.

providing a basic sense of psychological security for recreational users<sup>29</sup>. Spatial accessibility enables planners to accurately identify mismatches between park supply and residents' demand, avoiding the limitations of "empirical" design<sup>30</sup>. Visual openness directly determines recreational users' subjective experience of the landscape and serves as a key link connecting the physical environment and human psychological perception<sup>31</sup>. Thus, three indicators—"Visual Openness (V1)", "Spatial Accessibility (V2)", and "Spatial Safety (V3)"—were selected.

Guided by the Biophilia Hypothesis, which states that humans have an innate affinity for and preference toward natural environments, the Green View Index connects objective green spaces with subjective human experiences, quantifying "visible greenery" and providing empirical evidence for the health value of green vision<sup>32</sup>. Natural scenes containing water bodies (e.g., "green-aquatic" or "aquatic-green" combinations) have significantly higher preference scores than pure green scenes<sup>33</sup>. Color-leaved plants significantly improve the scenic beauty of plant communities through "color contrast", "hue dominance", and "visual impact", breaking the monotony of traditional single-tone green landscapes<sup>34</sup>. The combination of plants with different life forms (e.g., trees, shrubs, and herbs) shapes the visual hierarchy and structural stability of plant communities, influencing life form composition and enhancing the visual texture of the landscape<sup>35</sup>. The number of flowering plants and deciduous plants can add color highlights and visual focal points to the landscape, improving its vividness and attractiveness<sup>36</sup>. Plant growth status determines the healthiness of individual plant appearance and the visual integrity of plant communities, with healthy growth enhancing the landscape's vitality and aesthetic quality<sup>37</sup>. The Sand Ratio (V12) enriches the landscape's visual hierarchy and experiential scenarios by controlling the area proportion of sand beaches in the landscape<sup>38</sup>. Thus, eight indicators—"Green View Index (V4)", "Hydrophilicity (V5)", "Life Form Composition (V6)", "Plant Color Richness (V7)", "Number of Flowering Plants (V8)", "Number of Color-Leaved Plants (V9)", "Number of Deciduous Plants (V10)", "Plant Growth Status (V11)", and "Sand Ratio (V12)"—were selected.

In the artificial element system, the Surrounding Building Ratio controls the height, density, and style proportion of buildings around the park, regulating visual coordination between the park landscape and the surrounding built environment<sup>39</sup>. The number of positive landscapes and negative landscapes can change the overall visual quality of the park, enhancing or weakening users' landscape experience and memory association<sup>40</sup>. Garden paths and spatial patterns can guide recreational users' visual movement and spatial exploration paths<sup>41</sup>. The Artificial Material Ratio affects the landscape's ecological perception and practicality<sup>42</sup>. Different pavement materials influence the landscape's visual temperature perception and microclimate comfort, while

adjusting the visual coordination between paved areas and the surrounding landscape<sup>43</sup>. Recreational facilities meet the visual needs for functional identification<sup>44</sup>, and the Richness of Activity Types reflects the landscape's adaptability to different activities<sup>45</sup>. Thus, eight indicators—"Surrounding Building Ratio (V13)", "Number of Positive Landscapes (V14)", "Number of Negative Landscapes (V15)", "Garden paths and spatial patterns (V16)", "Artificial Material Ratio (V17)", "Pavement Material (V18)", "Recreational Facilities (V19)", and "Richness of Activity Types (V20)"—were selected.

### Eye-tracking data collection

In terms of relevant research experience, it can be posited that a sample size of 30 or more subjects constitutes a medium-sized sample<sup>46</sup>. Moreover, college students can be considered a feasible and universal subject group<sup>47</sup>. In this experiment, it is reasonable to invite 60 college students as volunteers to participate. They were informed of the purpose of the experiment and received appropriate training to ensure the usability of the obtained data. 7 people were excluded from the study because their eyes could not be calibrated during the experiment, 4 people had an eye movement sampling sample rate of less than 70%, and 3 people had extreme data because the questionnaire was filled out in a short period of time. The final sample consisted of 46 participants aged 18 to 25, including 17 males and 29 females.

To comprehend the subjects' eye movements while observing the recreation space in the park, eye movement data was collected using the Eyelink 1000plus eye tracker (produced by SR Research, Canada). Experiments used a 27-inch IPS monitor (resolution: 2560 × 1440 pixels; refresh rate: 60 Hz). Participants were seated 60 cm away from the screen. The pupil + corneal reflex tracking mode was employed, with a sampling frequency of 1000 Hz and a nine-point calibration mode. A five-point validation was conducted post-calibration, with recalibration required for excessive errors. Eye movement events were classified using SR Research's default algorithms: fixations were defined as durations ≥ 80 ms and displacement ≤ 0.5°. The device was connected by two computers: one for the subject to identify pupil and eye movements, and the other for the experimenter to adjust settings and record eye movement data. During the experiment, the subject was instructed to position themselves in a seated posture directly in front of the screen, with their chin supported by the tower-shaped frame in front of the eye tracker. The right eye data of the subject was recorded while they viewed the photograph with both eyes. Images were presented in a fully randomized order using E-Prime 3.0 software, with each participant receiving an independent sequence to avoid order effects. Each image was displayed for 5 s, followed by a 1-second blank screen interval to eliminate visual persistence. A total of 26 images were presented per participant.

The selection of indicators was based on the suitability of the research objectives and experimental conditions. Priority was given to core parameters that could stably reflect overall visual behavior. A total of four eye-tracking indicators were therefore selected for this study (Table 2): Average fixation duration, Fixation frequency, Saccade frequency, average saccade amplitude<sup>48–50</sup>.

### Scenic beauty estimation data collection

Relevant studies have confirmed that the results of the two evaluation methods used in scenic beauty estimation, namely online questionnaires and indoor slide shows, tend to be consistent and both have high reliability<sup>51,52</sup>. Consequently, this study utilized a web platform to compile and distribute the questionnaire, thereby facilitating the evaluation process for subjects. The questionnaire is divided into two sections: the first comprises subject demographic information, including name, gender, and academic major; the second part involves the estimation of scenic beauty for various sample photos of recreation spaces using a 7-point scale (1–7). SBE evaluations adopted a non-overlapping sample design with eye-tracking to avoid priming effects. A total of 120 college students aged 18–25 were recruited via an online survey platform. Invalid responses were excluded, resulting in a final valid sample size—sufficient to reduce individual bias in landscape SBE assessments. This scale ranges from "very dislike" to "very like" and is used to assess the subjects' preferences for the presented spaces. Higher values on the scale indicate a greater degree of preference. However, it is important to note that the results of the questionnaire are susceptible to the influence of individual characteristics within the sample and the subjective judgment criteria of the respondents. The 26 images used for SBE evaluation are identical to those in the eye-tracking experiment: all are watermark-free images uniformly cropped to 1920 × 1080 pixels and adjusted to a brightness of 500 cd/m<sup>2</sup> using Photoshop. Additionally, the corresponding labels of each image are fully consistent across both experiments, ensuring a one-to-one correspondence between images and data. To ensure the reliability and validity of the results, the evaluated values must be standardized. The specific formula employed for this purpose is as follows:

Eye-tracking metrics	Abbreviation	Meaning
Average fixation duration (ms)	AFD	The average time the subject spent looking at each fixation point. The more effort the subject put into recognizing the picture, the longer the average time they spent looking at the fixation point.
Fixation frequency (count/s)	FF	The ratio of the number of fixations to the duration of fixations is an indicator of the degree of attention paid to the evaluation area. A high fixation frequency indicates that the subject feels that the picture is important or is relatively interesting.
Saccade frequency (count/s)	SF	The number of saccades per unit time can reflect the search behavior of the subject. During the information search process, a high saccade frequency indicates that the subject's search is extensive and the features of the images they are observing are not distinctive.
Average saccade amplitude (°)	ASA	Reflects the extent of information obtained. The smaller the average saccade amplitude, the more distinct the picture features and the more directly the subject can reach the target area.

**Table 2.** The meanings of eye-tracking metrics.

$$\begin{aligned} Z_{ij} &= (R_{ij} - \bar{R}_i) / s_j \\ \bar{Z}_i &= \sum_{j=1}^{N_i} Z_{ij} / N_i \end{aligned}$$

$Z_{ij}$ —The standardized score value of the  $j$ th subject for the  $i$ th photo;  $R_{ij}$ —The rating value of the  $j$ th subject for the  $i$ th photo;  $\bar{R}_i$ —The mean of all rating values for the  $i$ th subject;  $s_j$ —Standard deviation of all rating values for the  $j$ th subject;  $\bar{Z}_i$ —The mean of the standardized scores of all subjects for the  $i$ th photo;  $N_i$ —Total number of people who rated photo  $i$ .

### Statistical analysis

Multiple linear regression is a classic quantitative method for exploring the influence mechanism of independent variables on the dependent variable. It has the advantages of intuitive model interpretation and high interpretability of coefficients, and can clearly identify key influencing factors and their directions of effect<sup>29</sup>. The sample eye-tracking data collected through the Data Viewer software was exported and the eye-tracking metrics and heat map were compiled. The results of the collected scenic beauty estimation questionnaires were exported to a web platform and compiled using EXCEL 2016. After preliminary compilation, all data were processed in SPSS 26.0, and the processing methods mainly included general descriptive statistical analysis, correlation analysis, and multiple linear stepwise regression analysis.

## Results

### Characterization of landscape elements in recreation space

Figure 4 presents the results of quantifying the characteristics of landscape elements in different recreation space plots.

Among the spatial element characteristics, it is evident that B3, B5, and B9 sample plots exhibit low view openness (V1). Spatial accessibility (V2) demonstrates significant fluctuations, while spatial safety (V3) is predominantly high.

Among the natural element characteristics, greening rate (V4) is moderate; hydrophilicity (V5) is mostly of medium-low value, and most sample plots cannot see the river surface; living type composition (V6) scores high; plant color richness (V7) is balanced, and is higher in sample plots E5, B3, and B4; the gap of flowering plants (V8) is significant, and is higher in sample plots E7, E2, and E5; and the distribution of colored-leaf plants (V9) and deciduous plants (V10) is dispersed, with a higher number of A1, B3, and E8 sample sites; plant growth status (V11) was generally better, and beach rate (V12) was generally low.

Among the artificial elements characteristics, the peripheral buildings rate (V13) is higher in C1 and D4; the distribution of the number of positive landscapes (V14) and the number of negative landscapes (V15) is more evenly distributed, and only C3 has more positive landscapes; the ratio of straight and zigzag garden paths and spatial patterns (V16) is close to that of straight and zigzag garden paths; the manmade materials rate (V17) is higher in A2, C1, and E7; and pavement materials (V18) is mostly a single type. In the manmade materials rate (V17), A2, C1 and E7 are higher; pavement materials (V18) are predominantly of a single type, with only D3 and E3 exhibiting more than two types. The variation in the number of recreational facilities (V19) among different sites is substantial, with B2, B3 and B5 being higher; and the recreational activity type richness (V20) had a small difference in score between plots.

As can be seen from the analysis in Fig. 5, decentralized recreation spaces have higher values for openness of view (V1), number of negative landscapes (V15), and manmade materials rate (V17); resting recreation spaces have prominent natural element characteristics, as reflected in the high values for greening rate (V4), living type composition (V6), plant color richness (V7), and plant growth status (V11) are higher; entertainment recreation spaces are more characterized by artificial elements. The peripheral buildings rate (V13), number of favorable landscapes (V14), recreational facilities (V19), and recreational activity type richness (V20) are all higher than those of other types, and there is a higher beach rate (V12); scenic recreation spaces are characterized by hydrophilicity (V5) and paving material (V18) are distinct; recreational paths are richer in terms of spatial accessibility (V2), spatial safety (V3), flowering plants (V8), colored-leaf plants (V9), deciduous plants (V10), garden paths and spatial patterns (V16), and are especially prominent in flowering plants (V8) and deciduous plants (V10).

### Recreation space analysis using eye tracking

#### Visual heat map analysis

Figure 6 shows the visual heat map of the 26 sample areas created by visualizing and superimposing the gaze positions of 46 subjects. In the distribution recreation spaces, visual attention was predominantly directed towards artificial elements characteristics. Visual attention in the resting recreation space is scattered, focusing more on recreation facilities, colorful vegetation and the end of the road. Subjects in the entertainment recreation space pay more attention to the visual center and are easily attracted to artificial elements. Viewing recreation space has a wide range of attention areas and is influenced by many types of landscape elements. The visual focus of recreational paths was similar, and some sample sites were attracted by signage and structures, but the end of the path received the most attention.

#### Analysis of the eye tracking indicators

Fluctuations in AFD between sample plots are quite obvious. Spaces with rich visual information, such as E8, E1, and A1, cause longer fixations. Both FF and SF show small changes, and the changes in FF and SF data are almost consistent across sample plots. There are fluctuations in ASA, but it remains relatively stable overall, as shown in Fig. 7.

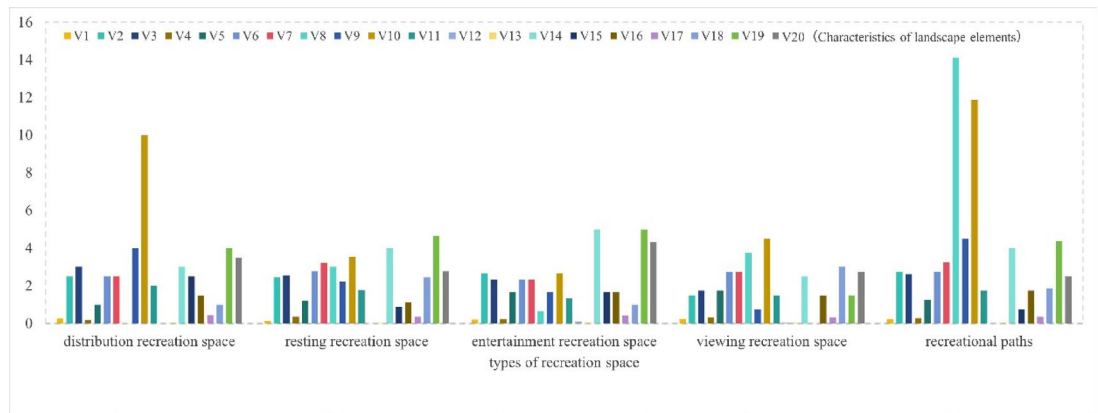


**Fig. 4.** Characteristics of landscape elements in different recreation space samples.

As can be seen in Fig. 8, a discernible variation in the eye-tracking indicators is evident among distinct categories of recreation spaces. AFD is ranked as follows: recreational paths > distribution recreation space > viewing recreation space > resting recreation space > entertainment recreation space. FF is ranked as follows: resting recreation space > recreational paths > entertainment recreation space > viewing recreation space > distribution recreation space. SF is ranked as follows: viewing recreation space > resting recreation space > recreational paths > entertainment recreation space > distribution recreation space; ASA is ranked as follows: viewing recreation space > resting recreation space > recreational paths > entertainment recreation space > distribution recreation space.

**Analysis of scenic beauty estimation of recreation spaces**

The scores of the 26 sample plots, in descending order, are as follows: D2 > E8 > B1 > B6 > B4 > E5 > E1 > B3 > E6 > E2 > D3 > A1 > B9 > C3 > B5 > E3 > B2 > E4 > D1 > B7 > C1 > B8 > D4 > C2 > E7 > A2. The sample plot that received the highest score was plot D2 in the viewing recreation space, with a score of 1.422. Conversely, plot A2 in the distribution recreation space had the lowest score, at -0.928. Furthermore, the mean scenic beauty estimations for different types of recreation spaces are: viewing recreation space > resting recreation space > recreational paths > entertainment recreation space > distribution recreation space (Fig. 9).



**Fig. 5.** Characteristics of landscape elements of different types of recreation space.

## Analysis of the influence of the characteristics of landscape elements on eye-tracking and scenic beauty estimation

### Correlation analysis

Table 3 show that different characteristics of landscape elements have a significant impact on eye-tracking indicators. AFD was significantly positively correlated with colored-leaf plants ( $p < 0.05$ ) and deciduous plants ( $p < 0.01$ ). FF was significantly positively correlated with greening rate ( $p < 0.01$ ), living type composition ( $p < 0.01$ ), and plant color richness ( $p < 0.01$ ). In contrast, artificial materials ( $p < 0.01$ ) were significantly negatively correlated with FF. SF was significantly positively correlated with plant growth status ( $p < 0.05$ ) and pavement materials ( $p < 0.05$ ), while it was significantly negatively correlated with artificial materials ( $p < 0.05$ ). In addition, ASA was significantly negatively correlated with the number of negative landscapes ( $p < 0.01$ ).

Table 4 show that there is a significant relationship between scenic beauty evaluation and multiple characteristics of landscape elements. Among the characteristics of natural elements, the greening rate ( $p < 0.01$ ), living type composition ( $p < 0.05$ ), plant color richness ( $p < 0.01$ ), and plant growth status ( $p < 0.01$ ) are significantly and positively correlated with scenic beauty evaluation. In terms of the characteristics of artificial elements, the number of favorable landscapes ( $p < 0.05$ ) was also significantly positively correlated with the scenic beauty estimation, while the manmade materials rate ( $p < 0.01$ ) was significantly negatively correlated with the scenic beauty estimation.

### Construction and analysis of multiple linear regression model

The objective of this study was to explore the influence of the characteristics of landscape elements on eye-tracking and scenic beauty estimation. The characteristics of landscape elements were used as independent variables (The variance inflation factor (VIF) values for all independent variables are less than 10), multiple linear stepwise regression analysis was performed with eye-tracking indicators and scenic beauty estimation as dependent variables (Table 5).

Specifically, deciduous plants ( $t = 7.406$ ,  $p < 0.01$ ) and colored-leaf plants ( $t = 2.140$ ,  $p < 0.05$ ) were found to significantly prolong AFD, with a model explanatory power of 78.0%. The greening rate ( $t = 4.109$ ,  $p < 0.01$ ) was also found to significantly increase FF, with a model explanatory power of 38.8%. Furthermore, pavement materials ( $t = 3.338$ ,  $p < 0.01$ ) and colored-leaf plants ( $t = 2.545$ ,  $p < 0.05$ ) were found to significantly increase SF, with a model explanatory power of 44.6%. Conversely, the number of negative landscapes ( $t = -4.043$ ,  $p < 0.01$ ), openness of view ( $t = -4.007$ ,  $p < 0.01$ ), and the life form composition ( $t = -2.219$ ,  $p < 0.05$ ) exhibited a significant decreasing effect on ASA, with a model explanatory power of 50.8%. The scenic beauty estimation was predominantly influenced by greening rate ( $t = 9.879$ ,  $p < 0.01$ ), openness of view ( $t = 4.029$ ,  $p < 0.01$ ), and plant growth status ( $t = 2.183$ ,  $p < 0.05$ ), with a model explanatory power of 85.6%.

Given the current sample size (26 observations paired with 20 candidate predictors), the ratio of observations to predictors is relatively low (approximately 1.3:1), which may lead to potential overfitting and unstable exact coefficient values in stepwise OLS regression. Therefore, effect sizes (e.g., standardized  $\beta$  coefficients) and their directions (positive or negative associations) are more robust to sampling fluctuations and model assumptions, as they reflect the inherent strength and direction of relationships between variables rather than random noise introduced by small-sample constraints. These robust indicators should thus be prioritized when interpreting the model results, while exact coefficient values should be interpreted with caution.

## Discussion

This study adopts a three-source interactive paradigm of “landscape element composition–eye tracking–SBE” to systematically examine the relationship among “elements–attention–preference” within the composite blue-green setting of urban wetland parks. The results reveal stable differences in fixation structures and aesthetic evaluations across various recreation spaces. We further demonstrate that elements such as deciduous/colored foliage, vegetation abundance, visual openness, pavement texture, the proportion of artificial materials, and negative landscape features are consistently and interpretably associated with AFD, FF, SF, ASA, and SBE.

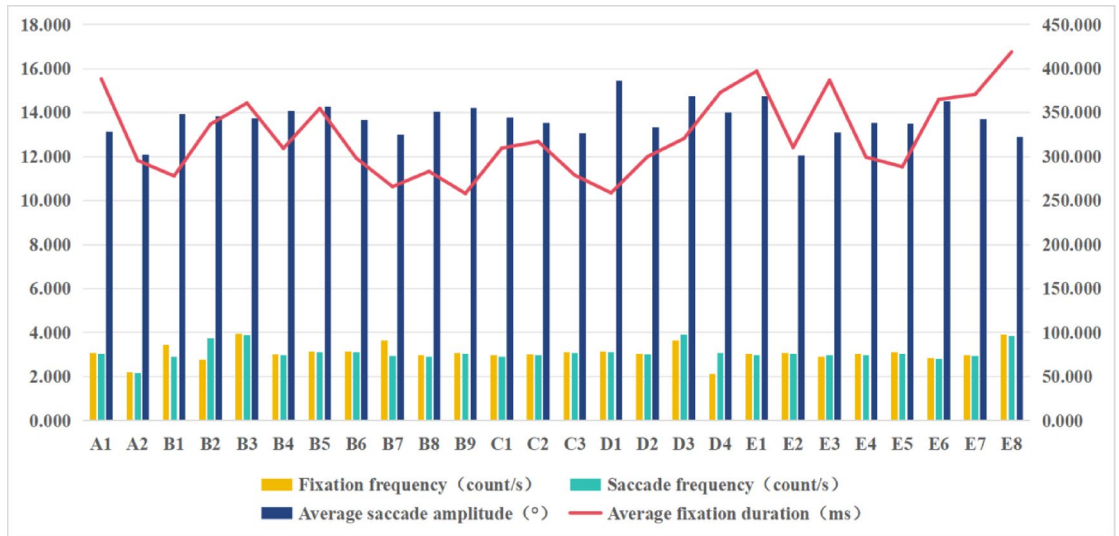


**Fig. 6.** Visual heat map of recreation space.

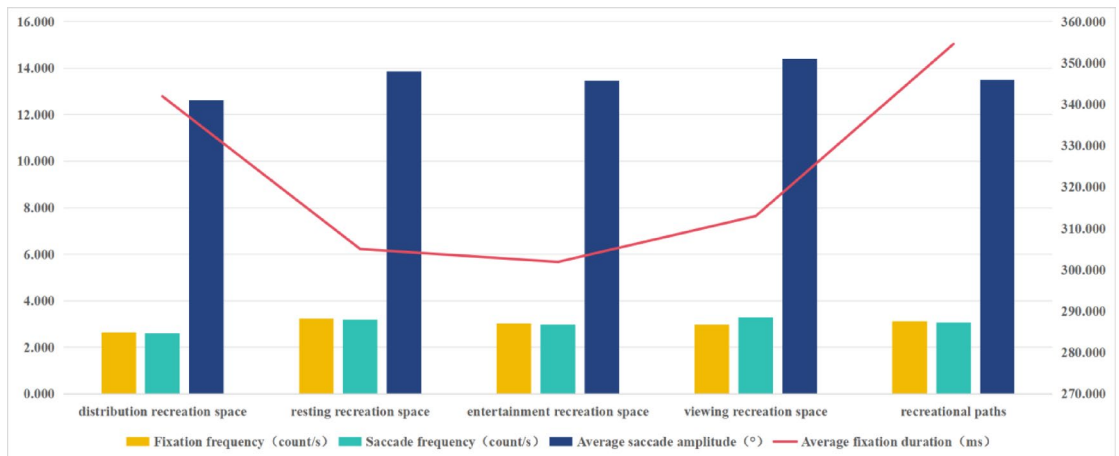
Compared with previous research that has largely emphasized the “natural–artificial” dichotomy or single blue/green dimensions, this study refines methodological control by ensuring stimulus consistency and pixel-scale quantification. This allows for clearer identification of marginal effects at the element level and more precise mapping of attention pathways. At the same time, we align our findings with international theories and evidence regarding saliency–fixation consistency, complexity/coherence–preference, and prospect–refuge, thereby providing operational indicator anchors for future mechanism testing and design translation in larger samples and multi-context scenarios.

**The relationship between the characteristics of landscape elements and eye-tracking**

Eye-tracking results show that under free-viewing conditions, fixation hotspots tend to cluster around the compositional center and highly salient cues (e.g., vanishing points of paths, directional signage, high-contrast

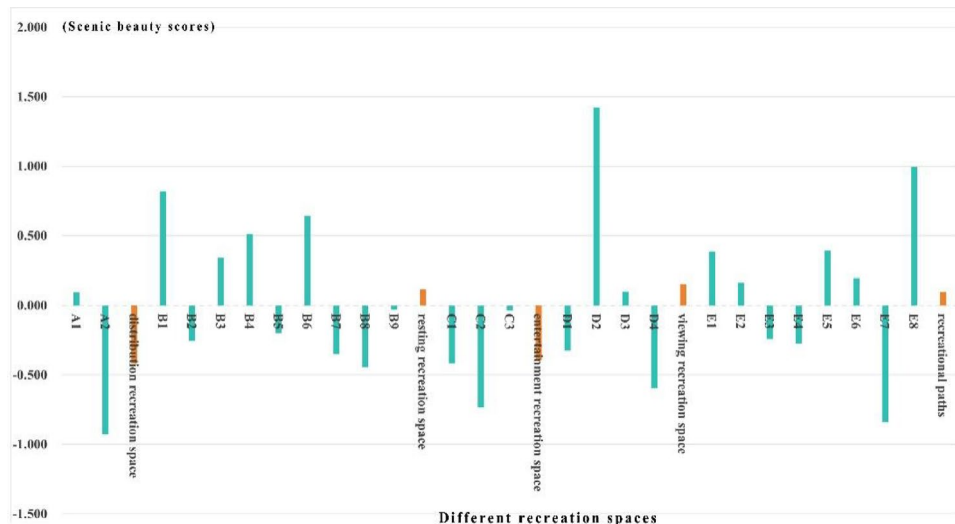


**Fig. 7.** Eye-tracking indicators for different recreation space samples. A dual-axis setting is used in the figure to display the characteristics of data in different magnitudes. The left axis corresponds to FF, SF, and ASA, while the right axis corresponds to AFD.



**Fig. 8.** Eye-tracking indicators for different types of recreation space. A dual-axis setting is used in the figure to display the characteristics of data in different magnitudes. The left axis corresponds to FF, SF, and ASA, while the right axis corresponds to AFD.

vegetation, and open water surfaces). This pattern is consistent with research on saliency–fixation map congruence, suggesting that visual saliency and compositional organization jointly drive early attentional allocation<sup>53</sup>. At the element–indicator level, deciduous/colored foliage and vegetation abundance were respectively associated with longer average fixation duration (AFD) and denser fixation frequency (FF), indicating that seasonal color and structural naturalness enhance local processing and sampling. In contrast, pavement texture and chromatic contrast increased saccade frequency (SF), reflecting more active search behaviors. Conversely, a high proportion of artificial materials and negative landscapes were linked to lower FF/SF or reduced average saccade amplitude (ASA), implying that excessive hardscape or distracting features restrict exploratory viewing and panoramic scanning. These directional relationships are consistent with eye-tracking evidence from urban green and waterfront studies, aligning with findings that natural elements more readily capture gaze, while small artificial anchors may still attract brief attention<sup>21,54,55</sup>. Mechanistically, the combination of visual openness and foreground framing fits well within the prospect–refuge framework: broad vistas coupled with moderate enclosure promote both initial fixation efficiency and sustained attention, providing process-level support for the dual cues of “safety–explorability”<sup>56</sup>.



**Fig. 9.** Scenic beauty estimation of different recreation space samples and types.

### Relationship between the characteristics of landscape elements and scenic beauty Estimation

Overall scenic beauty estimation (SBE) was positively associated with higher vegetation abundance, healthy plant growth, and clear visual openness. However, excessive natural density or poorly managed boundaries could lead to perceptions of “crowding–clutter,” thereby diminishing preference—consistent with classical findings on balancing complexity and coherence<sup>57,58</sup>. A joint reading of SBE and eye-tracking indicators shows that seasonal color and material contrast tend to enhance preference through increasing local processing and search load (AFD, SF), while visual openness and directional coherence were associated with larger saccade amplitude and fewer ineffective regressions (ASA and readability), which in turn supported higher overall evaluation. This pattern strongly converges with eye-tracking–preference findings in waterfront parks, particularly concerning the dominance of water–green proportion, openness, and tree presence in shaping preference<sup>21,59</sup>. It should be emphasized that our proposed “element–attention–preference” pathways are inferred from associations and group differences; the causal mechanisms and mediation strengths require formal testing with larger samples and multi-context designs using hierarchical regression or structural equation modeling<sup>60</sup>.

### Implications for Wulong river and Fujian wetland corridors

Within Wulong River Wetland Park, the five types of recreation space show distinct element–attention–preference patterns. Distribution spaces, which mainly serve as circulation nodes and plazas, have higher openness, a larger proportion of hardscape and more negative landscapes, and therefore record the lowest SBE scores. In contrast, viewing spaces that combine direct river views with structured vegetation and simple paving obtain the highest SBE values, while resting spaces with high greening rates and diverse, well-grown plants also receive above-average evaluations. Recreational paths occupy an intermediate position: flowering and deciduous plants attract attention and improve preference, but segments with a high proportion of artificial materials tend to score lower than more vegetated paths. These contrasts suggest that in a long and narrow riparian park like Wulong River Wetland Park, aesthetic experience depends more on the fine configuration of vegetation, water visibility and hardscape along the river edge than on large-scale landform. Under the climatic and urban conditions of coastal Fujian, design priority should therefore be given to strengthening hydrophilic viewing nodes and vegetated path segments with layered, seasonal planting, while retrofitting distribution spaces to reduce negative landscapes and visually dominant hard surfaces. For similar river-based urban wetland parks in Fujian, the Wulong case indicates that modest adjustments to element composition at key nodes can significantly improve visual experience without major changes to overall spatial structure.

### Impact on the design of recreation space

In terms of design translation, our findings support the principles of “prioritizing readability, maintaining moderate heterogeneity, and constraining hardscape.” At key nodes and along linear boardwalks, introducing water-facing openings and rhythmic lateral view corridors can enhance long-distance vistas and reduce low-level obstructions, thereby improving initial fixation efficiency and widening saccade amplitude. Ensuring sufficient vegetation abundance and healthy growth, while organizing layered “tree–shrub–grass” structures and incorporating seasonal/colored foliage in the near view, can extend local fixations and increase preference—though excessive density should be avoided to prevent visual clutter. For hardscape and facilities, a “necessary but restrained” approach is advised: texture/chromatic contrasts may serve as limited visual anchors to stimulate search, while overall artificial proportion and negative features should be controlled to preserve naturalness and aesthetic quality. These strategies align with eye-tracking patterns observed in free-viewing/walking paradigms

		AFD	FF	SF	ASA
Openness of view	r	0.194	-0.278	-0.057	-0.335
	p	0.343	0.169	0.783	0.094
Spatial accessibility	r	0.263	-0.015	-0.013	-0.178
	p	0.194	0.943	0.951	0.384
Spatial safety	r	0.043	-0.315	-0.213	-0.039
	p	0.833	0.117	0.296	0.848
Green rate	r	-0.212	0.721**	0.335	0.082
	p	0.298	0.000	0.094	0.692
Hydrophilicity	r	-0.221	0.119	-0.059	-0.081
	p	0.278	0.564	0.774	0.695
Living type composition	r	-0.200	0.711**	0.383	-0.222
	p	0.327	0.000	0.053	0.275
Plant color richness	r	-0.043	0.637**	0.247	-0.110
	p	0.835	0.000	0.223	0.592
Flowering plant	r	0.114	-0.221	-0.239	-0.126
	p	0.579	0.279	0.240	0.539
Colored-leaf plants	r	0.413*	0.133	0.322	-0.370
	p	0.036	0.518	0.108	0.063
Deciduous plant	r	0.889**	-0.205	0.135	0.045
	p	0.000	0.314	0.512	0.827
Plant growth status	r	0.067	0.328	0.406*	-0.222
	p	0.746	0.102	0.040	0.275
Beach rate	r	-0.338	0.063	0.043	0.076
	p	0.091	0.760	0.837	0.713
Peripheral buildings rate	r	0.109	-0.318	0.031	-0.104
	p	0.595	0.113	0.880	0.614
Number of favorable landscapes	r	0.126	0.189	0.208	-0.351
	p	0.541	0.356	0.308	0.078
Number of negative landscapes	r	0.133	-0.010	0.009	-0.540**
	p	0.516	0.961	0.966	0.004
Garden paths and spatial patterns	r	0.226	-0.093	-0.051	-0.041
	p	0.266	0.653	0.803	0.842
Artificial materials rate	r	0.076	-0.597**	-0.443*	-0.188
	p	0.711	0.001	0.023	0.357
Pavement materials	r	0.272	-0.058	0.438*	0.167
	p	0.178	0.780	0.025	0.414
Recreational facilities	r	0.348	0.065	0.167	-0.337
	p	0.081	0.754	0.416	0.092
Recreational activity type richness	r	-0.066	-0.127	-0.130	-0.148
	p	0.749	0.535	0.526	0.470

**Table 3.** Correlative results of eye-tracking metrics and characteristics of landscape elements. \* $p < 0.05$ , \*\* $p < 0.01$ .

and converge with empirical evidence from waterfront parks, while also resonating with the structural logic of “openness–accessibility–boundary” emphasized in blue–green infrastructure design for multiple benefits<sup>54,59,61</sup>.

### Limitations and future research

We acknowledge that this study, conducted under static same-stimulus and small-sample controlled conditions, identifies indicative mechanisms but still requires validation of ecological validity and population heterogeneity. Future research should employ VR/mobile eye-tracking and multi-season, multi-site field paradigms, combined with physiological and emotional measures, to examine the strength of “attention–restoration–preference” linkages. Methodologically, we recommend following minimal reporting standards for eye-tracking research, including detailed documentation of equipment, calibration, event detection, and AOI settings, to enhance reproducibility and cross-study comparability. Moreover, integration of semantic segmentation/saliency modeling with empirical eye-tracking can strengthen the robustness of pixel-level element quantification<sup>62</sup>.

Characteristic of landscape elements	Scenic beauty estimation	
	<i>r</i>	<i>p</i>
Openness of view	0.169	0.409
Spatial accessibility	0.072	0.726
Spatial safety	0.000	1.000
Green rate	0.857**	0.000
Hydrophilicity	0.005	0.979
Living type composition	0.456*	0.019
Plant color richness	0.838**	0.000
Flowering plant	0.082	0.689
Colored-leaf plants	0.151	0.462
Deciduous plant	0.019	0.926
Plant growth status	0.611**	0.001
Beach rate	-0.208	0.309
Peripheral buildings rate	-0.216	0.289
Number of favorable landscapes	0.448*	0.022
Number of negative landscapes	-0.331	0.099
Garden paths and spatial patterns	0.185	0.365
Manmade materials rate	-0.675**	0.000
Pavement materials	0.257	0.206
Recreational facilities	0.159	0.439
Recreational activity type richness	-0.165	0.420

**Table 4.** Correlation between scenic beauty Estimation and characteristics of landscape elements. \* $p < 0.05$ , \*\* $p < 0.01$ .

Dependent variable	Independent variable	Unstandardized coefficients (B)		Standardized coefficient	t	Significance	R <sup>2</sup>	Adjusted R <sup>2</sup>	F
		B	Standard error	Beta					
Average fixation duration	Constant	281.973	6.129	-	46.010	0.000	0.798	0.780	45.343**
	Deciduous plants	5.340	0.721	0.773	7.406	0.000			
	Colored-leaf plants	2.336	1.092	0.223	2.140	0.043			
Fixation frequency	Constant	2.379	0.184	-	12.908	0.000	0.413	0.388	16.882**
	Greening rate	2.360	0.574	0.643	4.109	0.000			
Saccade frequency	Constant	2.751	0.095	-	29.008	0.000	0.490	0.446	11.046**
	Pavement materials	0.123	0.037	0.508	3.338	0.003			
	Colored-leaf plants	0.033	0.013	0.387	2.545	0.018			
Average saccade amplitude	Constant	16.548	0.785	-	21.087	0.000	0.567	0.508	9.615**
	Number of negative landscapes	-0.405	0.100	-0.578	-4.043	0.001			
	Openness of view	-5.363	1.339	-0.586	-4.007	0.001			
	Living type composition	-0.529	0.238	-0.325	-2.219	0.037			
Scenic beauty estimation	Constant	-2.103	0.206	-	-10.192	0.000	0.873	0.856	50.460**
	Greening rate	4.361	0.441	0.845	9.879	0.000			
	Openness of view	2.150	0.534	0.315	4.029	0.001			
	Plant growth status	0.222	0.102	0.183	2.183	0.040			

**Table 5.** Results of Stepwise regression analysis.

## Conclusion

This study departs from the theory of landscape visual assessment and uses eye-tracking technology to analyze the visual perception and influencing factors of different recreation space types in urban wetland parks. The eye movements of people differ in response to the characteristics of landscape elements, and are mostly influenced by the characteristics of plants, which produce different visual feedback. People tend to pay more attention to plant landscaping with rich colors, high greening rate, and obvious seasonal changes, while spaces lacking maintenance and with messy plant landscapes are not valued. Among the artificial element characteristics, attention should be paid to reducing the proportion of artificial materials in the space, appropriately increasing

the combination of pavement materials, and reducing the number of negative landscapes. The results of the scenic beauty estimation of the characteristics of landscape elements are similar to the results of the eye-tracking, reflecting a relatively unified subjective and objective evaluation by the viewer. This proves that the quantitative method of characteristic of landscape elements can be combined with scenic beauty estimation and eye movement estimation to conduct landscape visual evaluation research<sup>16</sup>. Compared with qualitative evaluation, the quantitative analysis of characteristic of landscape elements is more objective and can reflect the characteristic of landscape elements that affect the results of landscape visual evaluation. The application of landscape visual assessment to the design of recreation spaces in urban wetland parks deepens the understanding of people's visual assessment in recreation spaces, helps clarify the interaction between people and the environment, and provides an empirical basis for landscape planning and design.

### Data availability

The datasets used and/or analyzed during the current study available from the corresponding author (Fan Liu: 13850268926@163.com) on reasonable request.

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## Author contributions

M.W. Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing-original draft, Writing – review & editing. H.T. Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – review & editing. J.C. Conceptualization, Data curation, Formal analysis, Investigation, Software, Writing-original draft. F.L. Conceptualization, Formal analysis, Methodology, Data curation, Supervision, Validation, Writing – review & editing. M.L. Data curation, Validation, Writing – review & editing. X.Y. Data curation Investigation, Validation. S.L. Data curation Investigation, Validation. J.D. Conceptualization, Method-

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### Declarations

#### Competing interests

The authors declare no competing interests.

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