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Visual Quality Assessment of Rural Landscapes Based on Eye-Tracking Analysis and Subjective Perception

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Abstract

Traditional visual quality assessments of rural landscapes rely on subjective methods. This study integrates eye-tracking technology with subjective perception evaluation to construct a visual quality assessment model for rural landscapes, aiming to reveal the intrinsic relationship between objective visual behavior and subjective perception, with the aim of providing scientific guidance for rural landscape planning to promote sustainable rural development. Using landscape photographs from nine rural sampling sites in Guangzhou, eye-tracking experiments were conducted to collect participants' eye movement data, combined with online questionnaires to obtain scenic beauty ratings and landscape characteristic factor evaluations. The findings reveal the following: (1) Eye-tracking experiments and subjective evaluation results showed high consistency, with samples having higher scenic beauty ratings demonstrating more prominent performance in core eye movement indicators such as total fixation duration and count, and total saccade duration, and typically possessing higher landscape characteristic factor values. (2) Urban–suburban-integrated rural landscapes exhibited poorer visual quality, characteristic-preservation rural landscapes elicited more in-depth and sustained visual exploration, and clustered-improvement rural landscapes possessed higher scenic beauty ratings and landscape characteristic factor values. (3) Total saccade duration was the key eye movement indicator for predicting scenic beauty ratings. (4) Multiple landscape characteristic factors significantly influence eye movement behavior.

Keywords: rural landscape; landscape visual quality assessment; eye-tracking technology; subjective perception

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1. Introduction

The strategic focus of China's rural development centers on promoting high-quality economic growth in rural areas, systematically preserving and promoting outstanding local culture, and comprehensively improving the rural ecological environment to advance sustainable rural development [1]. As a core component and foundational project of building a Beautiful China, the construction of beautiful villages has gained increasing prominence. In recent years, the Chinese government has issued a series of policy documents, systematically promoting processes such as rural ecological restoration and human settlement improvement, achieving remarkable results. However, the current

issues of unbalanced and inadequate development are most pronounced in rural areas, manifesting as shortcomings in infrastructure, public services, industrial development, and environmental quality [2]. Simultaneously, with the evolution of the "primary social contradiction", the people's aspirations for a high-quality life have grown, making the beautification of the rural environment critically important. Against this backdrop, the report of the 20th National Congress of the Communist Party of China explicitly proposed to "coordinate rural infrastructure and public service layout, and build livable, workable, and harmonious beautiful villages", charting the course for rural development. This policy, rooted in a people-centered development philosophy, prioritizes farmers' aspirations for a better life as its starting point and ultimate goal. It emphasizes coordinating rural infrastructure, industrial development, and the ecological environment, with ecological conservation at the forefront [3]. Alongside improving material conditions, it attaches great importance to preserving local cultural heritage.

In response to the global trends of "living heritage", "holistic preservation", and "digitalization" [4] in cultural heritage conservation, domestic and international research converges on core concepts and technical methodologies. The continuity of cultural memory and its sustainable transmission and technologies, like geographical information systems (GIS) and virtual reality (VR) for visualization and interactive experience concerns, as a research focus is expanded from individual elements to holistic cultural landscapes [5]. However, differences in social development stages, cultural contexts, and policy objectives lead to different starting points and emphases. Chinese research is closely integrated into the national strategy of rural revitalization, emphasizing the pivotal role of cultural heritage in enhancing endogenous rural development and shaping civilized rural customs [6]. In contrast, international research adopts a more diverse focus, addressing topics such as sustainable heritage conservation [7] and the preservation of post-industrial heritage [8]. This divergence, in practice, occurring within a shared trend, provides valuable opportunities for mutual exchange and learning.

Guided by the report of the 20th National Congress of the Communist Party of China, Guangdong Province's "Decision of the CPC Guangdong Provincial Committee on Deepening the Ecological Construction of Green and Beautiful Guangdong" emphasizes the need to implement integrated urban–rural greening initiatives and build a high-quality ecological environment characterized by cohesive "green beauty" [9]. This directive provides clear guidance for advancing rural greening and beautification efforts, promoting sustainable economic development in rural areas. However, current rural greening practices commonly suffer from problems such as landscape homogenization, ecological and visual effect disharmony, and lack of regional characteristics [10]. Against this backdrop, the scientific validity and applicability of rural landscape visual quality assessment directly relate to rural construction's effectiveness and sustainability. A rigorous system for assessing landscape visual quality enables more precise optimization and distinctive enhancement of rural environments. Such a system supports the growth of rural tourism and strengthens the broader goals of the rural revitalization strategy.

Currently, various landscape visual quality assessment methods have been developed domestically and internationally. Early research predominantly employed methods combining scenic beauty estimation (SBE) with GIS technology [11], semantic differential (SD) methods [12], and others to construct evaluation systems. Later stages gradually introduced computational models to enhance evaluation accuracy and objectivity, such as employing eye-level visual-field image-recognition technology [13], VR panoramic technology, and optimized visibility analysis algorithms [14]. With the development of research technology, researchers began utilizing neurophysiological instruments such as

eye-tracking, electroencephalography, and magnetic resonance imaging to directly monitor visual attention allocation and brain cognitive processing.

Among these, eye-tracking technology, by recording observers' "observation patterns", establishes a key connection between objective landscape scene measurements and subjective population perception, providing an ideal bridge for integrating objective and subjective evaluation methods [15]. Currently, this technology has been widely applied in multiple fields, including landscape perception [16], built environment assessment [17,18] restorative environment evaluation [19], and emotional experience prediction [20]. These studies typically combine subjective perceptual judgments with objective eye-tracking data, effectively bridging the gap between subjective perception and objective indicators, significantly enhancing the scientific validity and explanatory power of evaluation results, and providing important evidence for landscape protection and design management. However, existing research on the relationship between eye movement behavioral characteristics and subjective perception of landscape characteristic factors remains insufficient.

Landscape characteristics, as core elements constituting visual quality, have become a research focus regarding their influence on public perception [21]. In-depth exploration of tourists' visual attention mechanisms toward landscape characteristics [22] is an important pathway for promoting landscape design from "empirical judgment" toward "scientific evidence-based practice". In terms of assessment targets, most landscape visual-quality studies have focused on wetland parks [23], forest parks [24], historical districts [25], and historical cultural cities [26], while rural landscapes have received comparatively limited attention. Existing rural research concentrates on road-corridor characteristics [27] and public spaces [28,29], leaving a gap in comprehensive, systematic visual-quality evaluations across different categories of rural settlements and landscape types.

Research on rural landscapes exhibits differing emphases domestically and internationally. Overseas studies began earlier, and focus primarily on biodiversity, ecosystem services, management and policy research, land use, and people's perceptions, and preferences toward rural landscapes [30]. In contrast, research in rural landscapes emphasizes localized approaches, concentrating primarily on the identification and evaluation of rural landscape characteristics [31], rural landscape patterns [32], and the conservation and planning of rural landscapes [33]. Chinese evaluations of rural landscapes mainly focus on four dimensions: comprehensive, ecological, aesthetic, and landscape features. However, visual quality assessments of rural landscapes remain limited, with methods predominantly relying on single subjective evaluations and rarely integrating advanced equipment such as eye-tracking technology.

This addresses the following two questions using eye-tracking technology and subjective evaluation: (1) Do the results of eye-tracking experiments align with subjective perception evaluations? (2) What is the quantitative relationship between eye-tracking behavior characteristics and subjective perception? Eye-tracking technology is used to objectively record participants' visual behavior (fixation points and durations), and these data are integrated with subjective evaluations to explore the relationship between subjective perception of landscapes and eye-tracking patterns. This approach overcomes the limitations of separating subjective questionnaires from objective metrics, providing a quantifiable and verifiable empirical pathway for evaluating landscape visual quality.

Building on this, this study proposes a rural landscape visual evaluation framework that integrates eye-tracking metrics with subjective perception while reflecting regional characteristics. This framework aids in identifying key visual elements that shape rural landscape experiences, advancing the integration and deepening of rural landscape evaluation theory and providing a scientific basis and practical support for the planning, design, and sustainable development of rural landscapes.

2. Materials and Methods

2.1. Study Area Overview

This study refers to the "Guangdong Province Village Classification Method", selecting three types of village in the Guangzhou area with significant differentiation in development strategies, namely clustered improvement, urban–suburban integration, and characteristic preservation [34], for study. Urban–suburban-integration villages must meet all three of the following criteria: (1) They are adjacent to municipal or county centers within urban development boundaries. (2) Their residential patterns tend toward urbanization, and they can assume urban functions. (3) They are capable of sharing urban facilities and services, possessing potential for urban transformation. Clustered-improvement villages require only one of the following: (1) They already have a large scale with concentrated residential areas. (2) They are located outside urban boundaries but possess favorable location, transportation, facilities, and industrial foundations, with radiating influence and development potential. (3) They demonstrate prospects for agglomeration development across various factors. Characteristic-preservation villages need to meet one of the following criteria: (1) They are designated at the provincial level or higher as historical and cultural villages, or traditional villages. (2) They are designated at the provincial level or below, or those not designated but possessing a historical, cultural, or natural landscape value worthy of protection. (3) They contain abundant cultural relics and historic sites, clusters of traditional architecture, or unique intangible cultural heritage.

The sample selection proceeded as follows: First, candidate villages were identified based on Guangzhou's official village classification list. Second, field research was conducted to assess their landscape characteristics and confirm whether they met the criteria for their respective categories. Finally, three representative villages were selected from each of the three categories (Appendix A Table A1), resulting in a total of nine sample villages in the Guangzhou region (Figure 1).

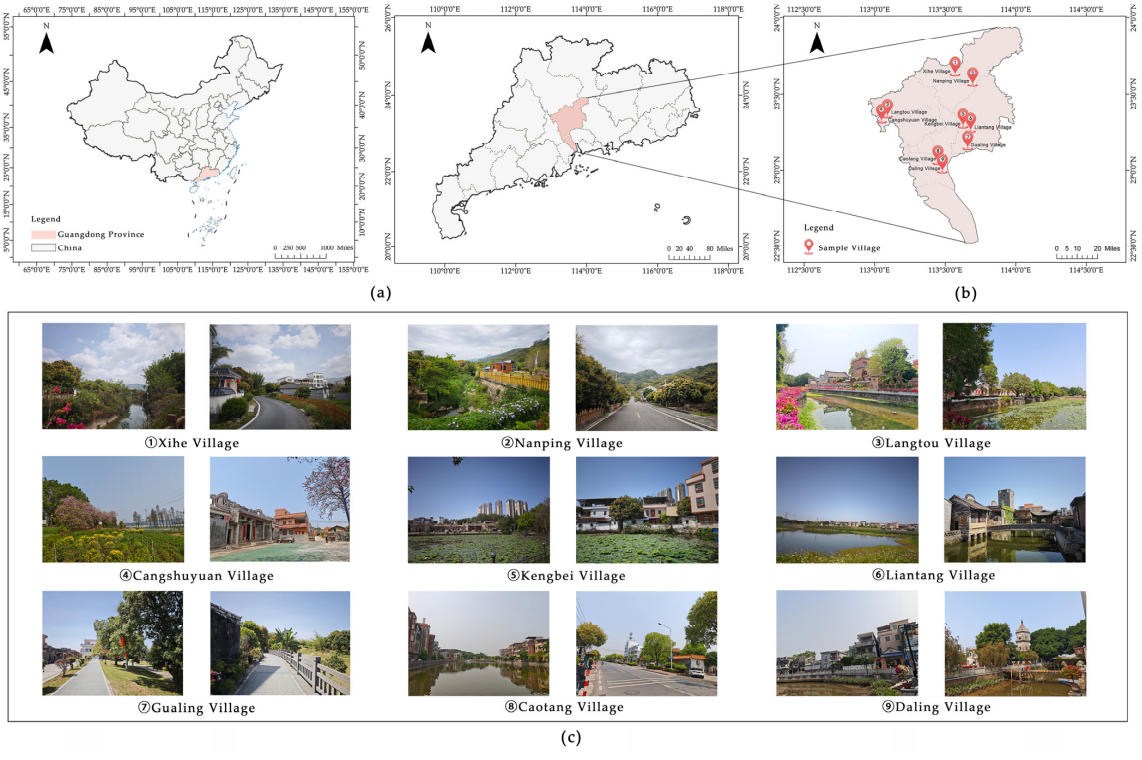


Figure 1. Distribution map of sample villages: (**a**) China, Guangdong Province; (**b**) distribution map of the nine sample villages; and (**c**) photographs of the current state of the nine sample villages.

2.2. Participant Selection

The participants in this study's eye-tracking experiment were university students. Research shows that university students and the general public do not differ significantly in their landscape evaluations. Students' assessments can therefore serve as a proxy for broader population views, and they tend to approach aesthetic judgment with fewer utilitarian considerations [35]. Their relative uniformity in age, cultural background, and education also helps limit potential bias from these variables in the evaluation results. Additionally, reviewing recent Chinese and international literature in the eye-tracking landscape evaluation field reveals that university students are the main group for conducting eye-tracking experiments, accounting for nearly 90% of experiments with 20–60 participants, demonstrating high sample feasibility and representativeness [36]. Therefore, we recruited 30 university students through online recruitment for this experiment. Table 1 shows the composition of the sample had a male-to-female ratio of 1:2; a landscape-architecture-to-non-specialist-background ratio of 1:2; an educational-level (vocational college/undergraduate/graduate and above) ratio of 13:7:10; a frequency-of-rural-landscape-exposure (frequent/infrequent) ratio of 11:4; and an age range of 18–25 years. All participants had no history of neurological or psychiatric disorders, with perfect or corrected vision of 1.0 or above, with no color blindness, ptosis, or other issues. This provided a good sample for eye movement data collection.

Table 1. Participant information.

Category		Number	Percentage
Sex	Male	10	33.3%
	Female	20	66.6%
Major	Landscape architecture	10	33.3%
	Non-landscape architecture	20	66.6%
Education level	Associate degree	13	43.3%
	Bachelor's degree	7	23.3%
	Graduate degree or above	10	33.3%
Frequent exposure to rural landscapes	Yes	22	73.3%
	No	8	26.6%

2.3. Image Acquisition

Extensive research demonstrates that using photographs as media for landscape quality assessment shows no significant difference from on-site evaluation [37]. Therefore, this visual quality assessment experiment employed landscape photographs combined with questionnaires and PPT presentations. This study conducted systematic field surveys in nine sample villages, including Caotang, Kengbei, and Xihe Villages, comprehensively recording rural internal and surrounding landscape information through on-site photography and landscape documentation. The camera was a Canon EOS RP. To ensure that sample photographs authentically reflect rural scenery, shooting times were selected between 9:00 and 11:00 and between 14:00 and 16:00, avoiding strong light and backlighting situations. Weather was clear with high visibility during shooting, ensuring high color fidelity in photographs. Shooting angles employed horizontal perspective, simulating the authentic angle of human eye observation. All photographs were taken by the same person, with a 3:4 ratio, to ensure consistent shooting technique, maintaining a uniform shooting height of 1.5 m. Shooting content covered the overall village landscape, ensuring complete presentation of main landscape elements, initially capturing 1002 effective landscape photographs.

For sample selection, this study first identified 200 representative rural landscape photographs. Five landscape architecture experts then conducted a collective review and selected 6 images from each of the nine villages—54 photographs in total—to serve as the evaluation samples.

2.4. Eye-Tracking Experiment

2.4.1. Experimental Equipment and Venue Selection

This study employed an eye-tracking device manufactured by Pupil Labs (Pupil Neon, Berlin, Germany) to conduct eye-tracking experiments, with an eye movement sampling frequency of 200 Hz. The experimental venue was selected as a quiet, comfortable indoor laboratory with an area of 15 m^2. Experimental equipment included one 14-inch (1920 × 1080P) laptop computer and one 120-inch (4:3, 1080P) projector.

2.4.2. Eye Movement Indicator Selection

This study selected five core eye movement indicators: total fixation count, total fixation duration, total saccade duration, total blink count, and pupil diameter enlargement count [38] (Table 2). Eye-tracking hotspot analysis can support identification of important landscape elements and regions [39]. Therefore, to more intuitively present spatial distribution characteristics of visual attention, this study also analyzed and mapped participants' eye movement heat maps as auxiliary analytical tools.

Table 2. Selected eye movement indicators and their meanings.

Eye Movement Indicator	Definition and Significance
Total fixation count	Refers to the total number of times participants' gaze stays within the stimulus area during the experiment. The higher the fixation count, the richer the landscape information and the stronger the attraction, eliciting more sustained attention and exploration from participants [40].
Total fixation duration	Refers to the total duration of participants' gaze staying within the stimulus area during the experiment. Longer fixation duration indicates richer landscape information and stronger attraction, eliciting more sustained attention and exploration from participants [41].
Total saccade duration	Refers to the total time spent on rapid eye movements between two fixation points during the experiment. Longer saccade duration indicates that participants engage in broader spatial scanning when exploring the landscape, reflecting higher cognitive involvement and interest level, thus demonstrating higher attractiveness [42].
Pupil diameter enlargement count	Refers to the total number of times the pupil diameter changes during the experiment, directly reflecting the degree of interest in viewing. The more frequent the pupil diameter enlargement, the more it indicates heightened psychological attention and stronger emotional response [43].
Total blink count	Refers to the total number of blinks during the experiment. Generally, the more relaxed observers are when viewing, the more likely they are to blink [44].

2.5. Subjective Questionnaire Evaluation

2.5.1. Landscape Characteristic Factor Selection

Rural landscapes are complex systems composed of various natural and cultural elements. To deeply understand and analyze rural landscapes to a greater extent, they must be decomposed into smaller, more researchable components. In research exploring the visual quality of rural landscapes, many studies decompose landscape characteristic factors into aspects of vegetation [45], water bodies [46], buildings [47], roads [48], farmland [49], and overall landscape perception (color and element richness [50,51], and sanitation conditions [52] as evaluation indicators). Therefore, based on Guangzhou rural landscape characteristics and the literature indicator summaries, this study finally determined 13 evaluation indicators and their criteria (Table A2).

To assess the validity and reliability of the 13 landscape feature factors selected for this study, standard tests were conducted. The reliability analysis showed an overall Cronbach's alpha coefficient of 0.687 (above 0.6), indicating acceptable internal consistency. Regarding validity, the Kaiser–Meyer–Olkin Measure of Sampling Adequacy (KMO) value was 0.809 (above 0.8), and Bartlett's test of sphericity was significant ($p < 0.01$). These results indicate that the sample is highly suitable for factor analysis and possesses good construct validity. Overall, the 13 landscape feature factors selected exhibit sound reliability and validity.

2.5.2. Questionnaire

This study created an online questionnaire on the Wenjuanxing platform using the 54 rural landscape photographs from the eye-tracking experiment. Questionnaire content included three parts: participant's basic information, photograph scenic beauty evaluation, and landscape characteristic factor evaluation. Scenic beauty evaluation employed the internationally standard 5-point Likert scale, with higher values indicating higher aesthetic quality of the rural landscape sample photograph. Landscape characteristic factor evaluation was conducted according to the pre-established scoring table.

2.6. Experimental Procedure

The experimental procedure was divided into three stages: preparation, experimental, and conclusion (Figure 2).

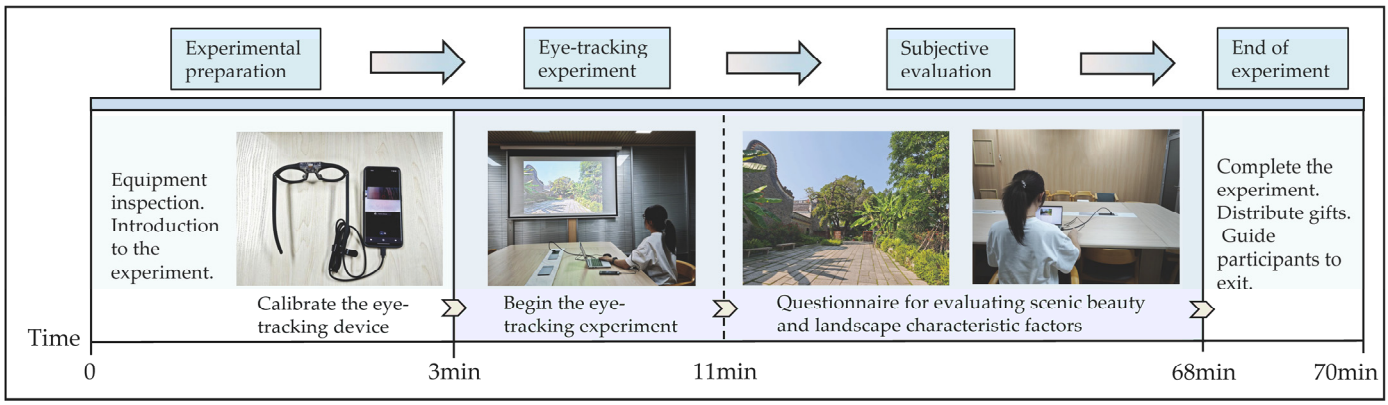


Figure 2. Experimental protocol flowchart.

(1) Preparation stage: This stage included checking and calibrating the eye-tracking device, laptop computer, and other experimental equipment; guiding participants to be seated; and explaining the complete experimental procedure and precautions clearly and concisely.

(2) Experimental stage: This stage included two components, eye movement data collection and subjective questionnaire evaluation. First, after wearing the eye-tracking device, participants viewed 2 warm-up images presented by the projector, and then viewed 54 experimental images played in random order, with each image displayed for 8 s, separated by 2 s blank screens to eliminate visual aftereffects. After completing the eye movement task, participants were guided to the laptop computer to complete the scenic beauty and landscape characteristic factor evaluation questionnaire for the samples.

(3) Conclusion stage: After participants completed all experiments, they were thanked and given small gifts, and then they were guided to leave.

2.7. Data Analysis Methods

Excel and IBM SPSS Statistics (version 27.0) software were used to statistically analyze eye movement and questionnaire survey data. First, the mean values of five eye movement data items from 30 participants for 54 sample photographs were calculated in Excel, and data from the Wenjuanxing platform were exported to Excel for statistical analysis. Subsequently, a one-way analysis of variance (ANOVA), correlation analysis, and multiple stepwise regression analysis were performed in SPSS for scenic beauty with eye movement indicators, scenic beauty with landscape characteristic factors, and eye movement indicators with landscape characteristic factors.

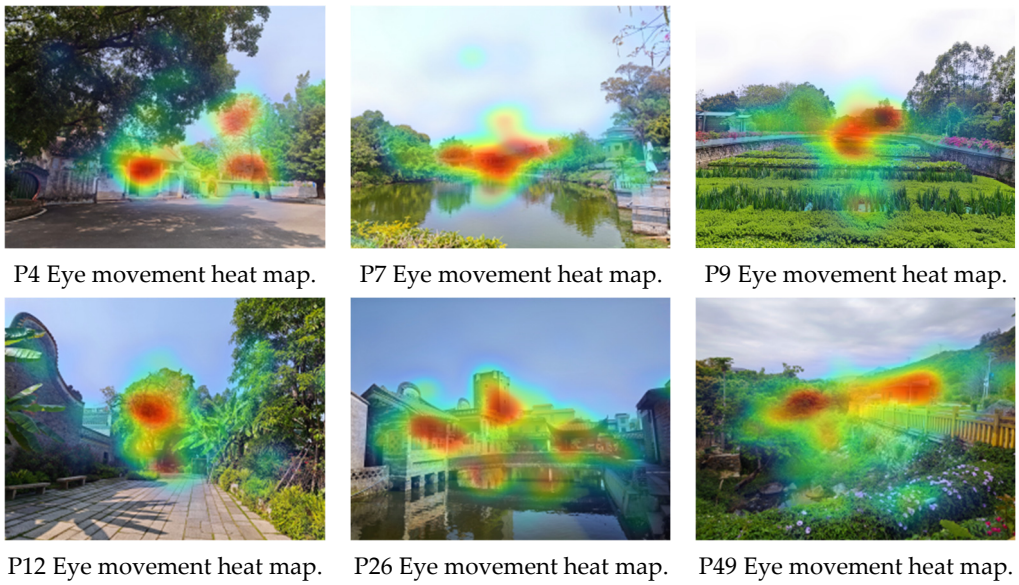
3. Experimental Results and Analysis

3.1. Eye Movement Data Analysis

3.1.1. Analysis of Eye Movement Indicator Values for Different Photographs

This eye-tracking experiment included the selection of three visual cognition indicators—total fixation count, total fixation duration, and total saccade duration—as evidence reflecting participants' attention and interest levels. Based on all the sample data (Table A3), six photographs were screened: P4, P7, P9, P12, P26, and P49. These samples demonstrated higher values in the above eye movement indicators, reflecting participants' more sustained and intensive visual attention toward them.

As visual expressions of fixation data, eye movement heat maps are two-dimensional histograms formed by mapping all selected recorded fixation points to reference images after Gaussian blur processing. In these maps, red areas indicate longer fixation durations, while green areas indicate shorter fixation durations. Through observation of the heat maps shown in Figure 3, we can see that participants' visual attention was clearly concentrated on building facades and distant vegetation areas, indicating these two types of landscape elements have strong attractiveness and information-bearing functions in visual cognition processes. Pupil diameter enlargement count and total blink count, as physiological eye movement indicators, although capable of characterizing physiological arousal, emotional responses, or fatigue levels, are easily influenced by subjective and objective factors, and their values cannot directly equate to actual psychological states.



P4 Eye movement heat map. P7 Eye movement heat map. P9 Eye movement heat map.

P12 Eye movement heat map. P26 Eye movement heat map. P49 Eye movement heat map.

Figure 3. Eye movement heat maps.

3.1.2. Analysis of Eye Movement Indicator Differences Among Different Rural Types

Comparing eye movement indicators across different rural types (Table 3) revealed that characteristic-preservation rural areas ranked highest in total fixation count, total fixation duration, total saccade duration, and total blink count compared to other types (Figure 4), indicating that this landscape type elicited more sustained, frequent, and in-depth visual exploration behavior from participants, while also bringing higher cognitive load and attention investment. In contrast, urban–suburban-integration rural areas showed generally lower values in these indicators, reflecting their relatively limited visual attractiveness. Overall, participants' visual attention clearly tilted toward characteristic-preservation rural areas, highlighting their unique landscape value and visual appeal. Our results show that clustered-improvement rural landscapes less frequently elicited pupil diameter enlargement count in participants, indicating that this type of rural landscape can create a relatively comfortable environment, bringing relaxation and ease to participants.

Table 3. Eye movement indicator data for different rural types.

Rural Type	Total Fixation Count		Total Fixation Duration (s)		Total Saccade Duration (s)		Pupil Diameter Enlargement Count		Total Blink Count	
	M	SD	M	SD	M	SD	M	SD	M	SD
Clustered improvement	15.13	2.02	5.41	0.50	0.98	0.14	9.17	7.83	1.60	0.23
Characteristic preservation	15.91	1.44	5.81	0.69	1.02	0.09	10.11	7.69	1.63	0.31
Urban–suburban integration	14.57	1.42	5.33	0.45	0.92	0.10	11.50	6.67	1.48	0.24

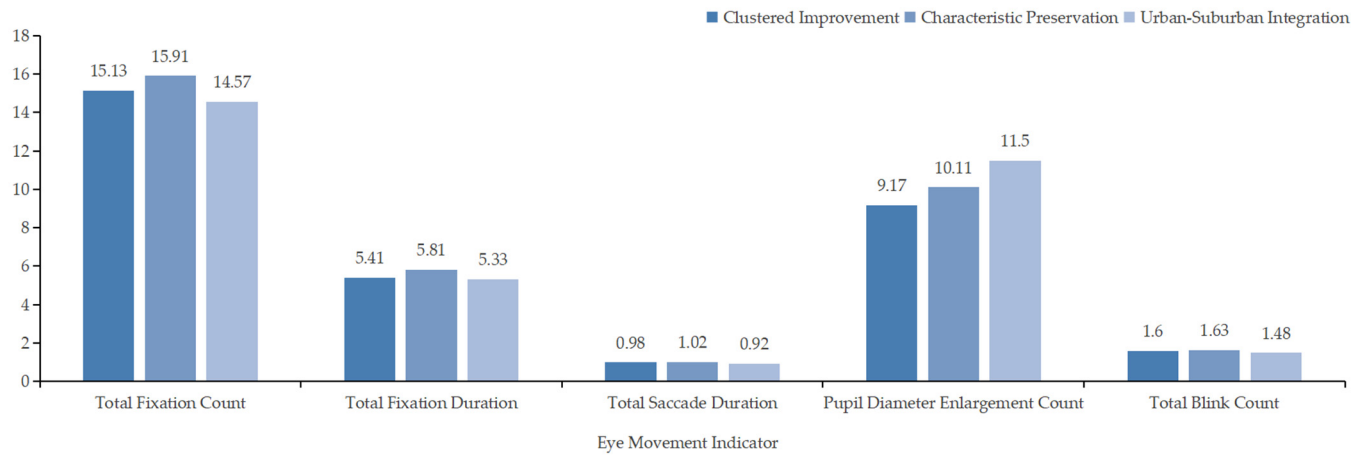


Figure 4. Eye movement indicators for different rural types.

Table 4 shows that rural landscape type had a significant effect on total fixation duration ($p < 0.05$, $F = 3.782$, and $\eta^2 = 0.129$), indicating that participants allocated markedly different amounts of visual attention when observing different rural landscapes. However, landscape type did not significantly correlate with total fixation count ($p > 0.05$, $F = 2.963$, and $\eta^2 = 0.104$); total saccade duration ($p > 0.05$, $F = 3.147$, and $\eta^2 = 0.110$); pupil diameter enlargement count ($p > 0.05$, $F = 0.451$, and $\eta^2 = 0.062$); or total blink count ($p > 0.05$, $F = 1.696$, and $\eta^2 = 0.017$). In summary, different rural settings primarily influenced total fixation duration but did not significantly affect the other four eye movement metrics.

Table 4. One-way analysis of variance for eye-tracking metrics across different rural types.

Source	Dependent Variable	Within-Groups Sum of Squares	Mean Square	*p*	F	η^2
Rural type	Total fixation count	138.936	2.724	0.061	2.963	0.104
	Total fixation duration	15.885	0.311	0.029	3.782	0.129
	Total saccade duration	0.639	0.013	0.051	3.147	0.110
	Pupil diameter enlargement count	2804.778	54.996	0.64	0.451	0.062
	Total blink count	3.467	0.068	0.194	1.696	0.017

3.2. Analysis of Subjective Perception Data

To reduce inter-individual aesthetic differences, scenic beauty values obtained from 54 rural landscape sample photographs underwent scientific standardization processing to eliminate human bias, making different evaluators' scores comparable. Scenic beauty ratings and standardized scenic beauty values (Table A4) were subjected to statistical analysis.

3.2.1. Analysis of Scenic Beauty Evaluation Results

(1) Analysis of High Scenic Beauty Samples

According to the sample scenic beauty results (Table A4), scenic beauty scores ranked from high to low as P9, P44, P12, P7, P50, and P49. High scenic beauty samples (Figure 5) show that rural landscapes with high vegetation coverage, rich plant species, well-preserved buildings, and rich landscape elements have higher scenic beauty ratings and are more favored by people. Among these, P7, P9, and P12 belong to characteristic-preservation rural areas, while P44, P49, and P50 belong to clustered-improvement rural areas.

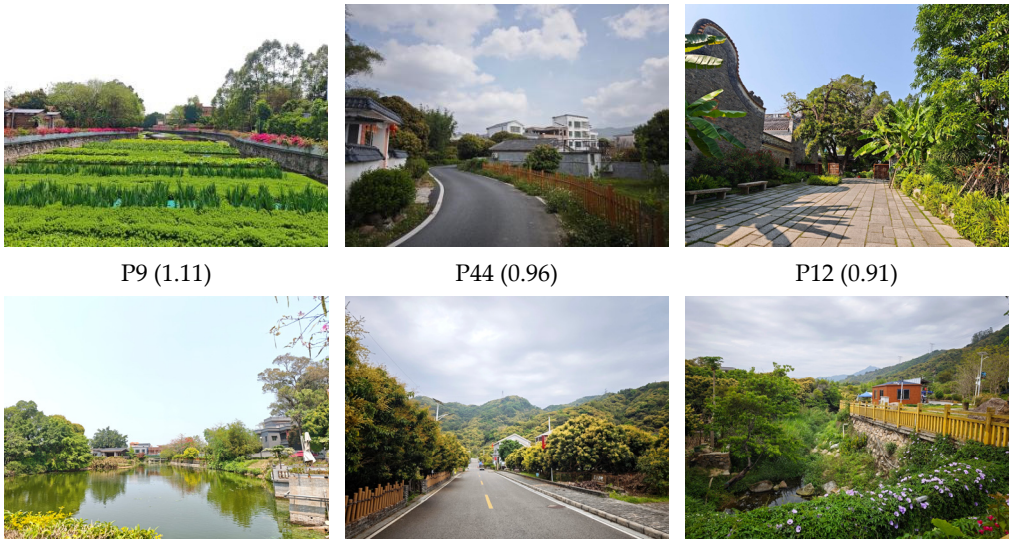


Figure 5. Samples of high scenic beauty.

(2) Scenic Beauty Analysis of Different Rural Types

According to scenic beauty ratings for different rural types (Figure 6), clustered-improvement rural areas had the highest mean scenic beauty rating, while urban–suburban-integration rural areas had the lowest mean scenic beauty rating, indicating clustered-improvement rural landscapes have better overall visual effects, while urban–suburban-integration rural landscapes have relatively poor visual attractiveness and overall visual effects.

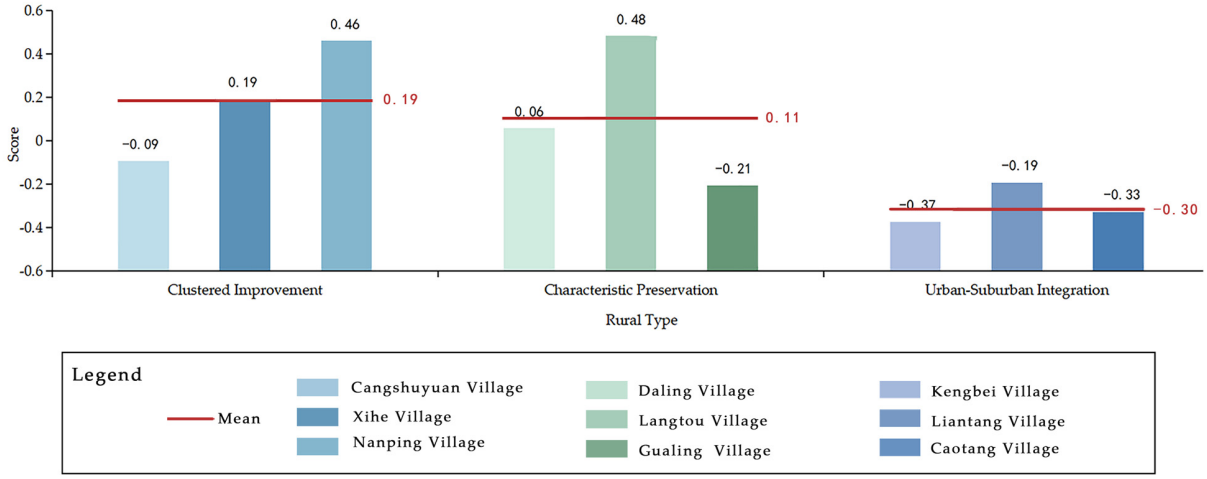


Figure 6. Scenic beauty comparison among rural types.

As shown in Table 5, participants' evaluations of scenic beauty differed significantly across rural types ($p < 0.01$, F = 5.752, and $\eta^2 = 0.184$). The effect size ($\eta^2 = 0.184$) indicates rural type explains 18.4% of the variance in scenic beauty ratings, representing a moderately large influence on participants' subjective evaluations of scenic beauty.

Table 5. One-way analysis of variance for scenic beauty across different rural types.

Source	Dependent Variable	Within-Groups Sum of Squares	Mean Square	*p*	F	η^2
Rural type	Scenic beauty	10.872	0.213	0.006	5.752	0.184

3.2.2. Landscape Characteristic Factor Evaluation Results Analysis

(1) High Landscape Characteristic Factor Sample Analysis

To more intuitively display landscape samples with high landscape characteristic factor values, based on mean landscape characteristic factor values in Table A4, landscape samples with eight landscape characteristic factors scoring above four were selected for detailed analysis. Therefore, six landscape samples were selected (Figure 7): P13, P7, P49, P12, P14, P45, and P50. Among these, P7, P12, and P13 belong to characteristic-preservation rural areas, while P45, P49, and P50 belong to clustered-improvement rural areas.



Figure 7. Samples of high landscape characteristic factor values.

(2) Landscape Characteristic Factor Analysis of Different Rural Types

According to landscape characteristic factor values for different rural types (Figure 8), clustered-improvement rural areas had the highest scores for seven landscape characteristic factors (X1, X2, X3, X9, X10, X11, and X12) and the lowest scores for four landscape characteristic factors (X4, X5, X6, and X7). Characteristic-preservation rural areas had the highest scores for six landscape characteristic factors (X4, X5, X6, X7, X8, and X13) and the lowest score for one landscape characteristic factor (X9). Urban–suburban-integration rural areas had the lowest scores for eight landscape characteristic factors (X1, X2, X3, X8, X10, X11, X12, and X13).

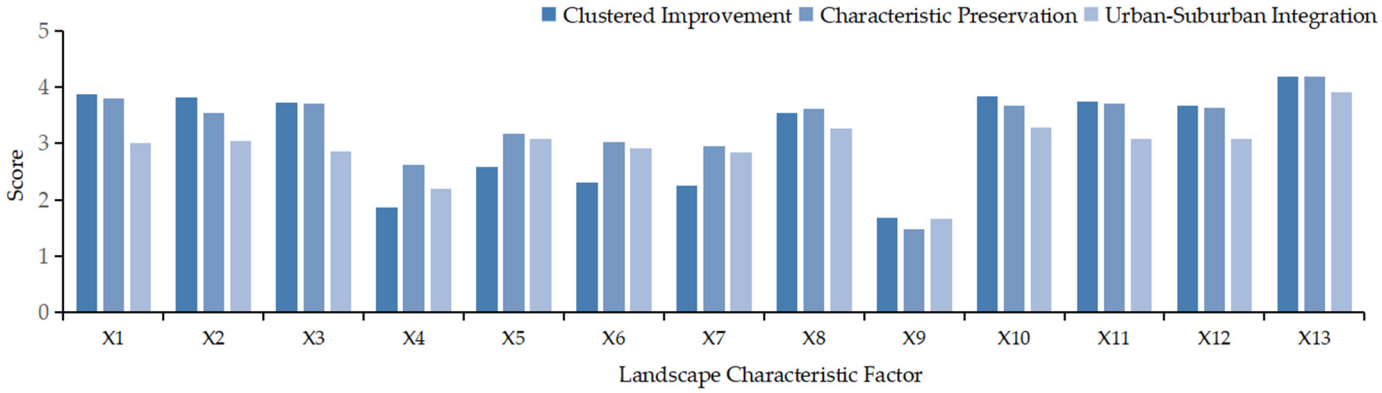


Figure 8. Mean landscape characteristic factor values by rural type.

As shown in Table 6, different rural types exerted significant effects on participants' evaluations across multiple landscape feature factors. Specifically, rural area type significantly influenced participants' evaluations of X1 ($p < 0.01$, F = 7.092, and $\eta^2 = 0.218$); X2 ($p < 0.05$, F = 3.752, and $\eta^2 = 0.128$); X3 ($p < 0.01$, F = 6.627, and $\eta^2 = 0.206$); X10 ($p < 0.05$, F = 4.56, and $\eta^2 = 0.152$); X11 ($p < 0.01$, F = 8.558, and $\eta^2 = 0.251$); X12 ($p < 0.01$, F = 7.588, and $\eta^2 = 0.229$); and X13 ($p < 0.05$, F = 4.462, and $\eta^2 = 0.149$). All seven landscape feature factors had effect sizes that exceeded 0.12, indicating that rural type exerts substantial substantive influence on these factors. However, no significant differences were found for X4, X5, X6, X7, X8, or X9 ($p > 0.05$, F < 3, and $\eta^2 < 0.1$). In summary, different rural types exert significant effects on plant-related factors and overall landscape factors.

Table 6. One-way analysis of variance for landscape characteristic factors across different rural types.

Source	Dependent Variable	Within-Groups Sum of Squares	Mean Square	*p*	F	η^2
Rural type	X1	30.266	0.593	0.002	7.092	0.218
	X2	38.925	0.763	0.03	3.752	0.128
	X3	34.004	0.667	0.003	6.627	0.206
	X4	91.085	1.786	0.246	1.441	0.053
	X5	46.585	0.913	0.15	1.972	0.072
	X6	50.225	0.985	0.079	2.665	0.095
	X7	51.404	1.008	0.09	2.521	0.090
	X8	18.555	0.364	0.2	1.66	0.061
	X9	37.682	0.739	0.728	0.319	0.012
	X10	16.317	0.32	0.015	4.56	0.152
	X11	14.98	0.294	0.001	8.558	0.251
	X12	13.569	0.266	0.001	7.588	0.229
	X13	5.299	0.104	0.016	4.462	0.149

3.3. Correlation Analysis and Regression Analysis Between Objective and Subjective Measures

3.3.1. Correlation Analysis and Regression Analysis of Eye Movement Indicators and Scenic Beauty

Table 7 shows that, except for pupil diameter enlargement count, which showed showing no correlation with scenic beauty ($r = -0.145$, $p > 0.05$), the eye movement indicators showed significant positive correlations with scenic beauty, indicating that higher scenic beauty corresponds with increased total fixation count, longer total fixation duration, more frequent saccade activity, and more blink behavior.

Table 7. Correlation analysis between eye movement indicators and scenic beauty.

	Total Fixation Count	Total Fixation Duration	Total Saccade Duration	Pupil Diameter Enlargement Count	Total Blink Count
Scenic beauty	0.510 **	0.515 **	0.543 **	−0.151	0.481 **

Note: ** $p < 0.01$.

Additionally, multiple stepwise regression analysis was performed using the four eye movement indicators significantly correlated with scenic beauty as independent variables and scenic beauty as the dependent variable. The results in Table 8 show that only total saccade duration ($R^2 = 0.295$) is an important predictor explaining scenic beauty.

Table 8. Regression coefficients for eye movement indicators and scenic beauty.

	Standardized Coefficients	t	Significance	Collinearity Statistics	
	Beta			Tolerance	VIF
Scenic beauty ($R^2 = 0.295$; Sig. < 0.01) Total saccade duration	0.543	4.660	<0.001	1	1

3.3.2. Correlation Analysis and Regression Analysis of Landscape Characteristic Factors and Scenic Beauty

According to Table 9, X4 (aquatic environment), X6 (preservation integrity of architectural style), X7 (architectural characteristic historicity), and X9 (farmland texture sense), landscape characteristic factors showed no significant correlation with scenic beauty ($p > 0.05$); the remaining nine indicators all showed significant positive correlations with scenic beauty ($p < 0.05$). Among these, four landscape characteristic factors—landscape spatial layering, landscape color richness, landscape element richness, and sanitation conditions—had an $r > 0.7$, indicating strong significant positive correlations with scenic beauty.

Table 9. Correlation analysis between landscape characteristic factors and scenic beauty.

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
Scenic beauty	0.443 **	0.353 **	0.463 **	0.151	0.310 *	0.216	0.235	0.528 **	−0.125	0.719 **	0.770 **	0.769 **	0.731 **

Note: * $p < 0.05$; ** $p < 0.01$.

Additionally, multiple stepwise regression analysis was performed, using the nine landscape characteristic factors significantly correlated with scenic beauty as independent variables and scenic beauty as the dependent variable. The results in Table 10 show that only three landscape characteristic factors—X5 (building texture), X11 (landscape color richness), and X13 (sanitation conditions) ($R^2 = 0.698$)—are important predictors explaining scenic beauty.

Table 10. Regression coefficients for landscape characteristic factors and scenic beauty.

	Standardized Coefficients	t	Significance	Collinearity Statistics	
	Beta			Tolerance	Beta
Scenic beauty (R^2 = 0.698; Sig. < 0.01)					
X11	0.542	5.061	<0.001	0.527	1.898
X13	0.314	2.81	0.007	0.484	2.064
X5	0.167	2.03	0.048	0.889	1.125

3.3.3. Correlation Analysis and Regression Analysis of Landscape Characteristic Factors and Eye Movement Indicators

To explore whether rural landscape characteristics influence changes in participants' eye movement behavior, correlation analysis was performed between 13 landscape characteristic factors and five eye movement indicators. The results in Table 11 show that eight landscape characteristic factors (X5, building texture; X6, preservation integrity of architectural style; X7, architectural characteristic historicity; X8, road alignment and landscape coordination; X10, landscape spatial layering; X11, landscape color richness; X12, landscape element richness; and X13, sanitation conditions) showed significant positive correlations with multiple eye movement indicators. Six landscape characteristic factors (X1, plant species; X2, vegetation coverage; X3, plant layering; X4, water environment; X10, landscape spatial layering; and X12, landscape element richness) showed significant negative correlations with pupil diameter enlargement count. X9 (farmland texture sense) showed no correlation with any of the five eye movement indicators.

Table 11. Correlation analysis between landscape characteristic factors and eye movement indicators.

Indicator	Total Fixation Count	Total Fixation Duration	Total Saccade Duration	Pupil Diameter Enlargement Count	Total Blink Count
X1	0.253	0.06	0.24	−0.360 **	0.144
X2	0.181	−0.033	0.194	−0.411 **	0.152
X3	0.263	0.084	0.244	−0.395 **	0.144
X4	0.227	0.073	0.172	−0.396 **	0.109
X5	0.304 *	0.536 **	0.284 *	0.253	0.23
X6	0.316 *	0.568 **	0.311 *	0.355 **	0.258
X7	0.307 *	0.557 **	0.309 *	0.348 *	0.262
X8	0.328 *	0.404 **	0.296 *	0.113	0.231
X9	0.005	−0.098	−0.009	−0.155	0.115
X10	0.419 **	0.259	0.452 **	−0.300 *	0.342 *
X11	0.431 **	0.375 **	0.447 **	−0.258	0.314 *
X12	0.517 **	0.396 **	0.521 **	−0.308 *	0.418 **
X13	0.276 *	0.304 *	0.297 *	−0.239	0.364 **

Note: * $p < 0.05$; ** $p < 0.01$.

To construct regression models between landscape characteristic factors and eye movement indicators, multiple stepwise regression analysis was performed, using landscape characteristic factors as independent variables and each of the five eye movement indicators as dependent variables.

(1) Regression analysis of landscape characteristic factors and total fixation count: Using eight landscape characteristic factors (X5, X6, X7, X8, X10, X11, X12, and X13) as independent variables and total fixation count as the dependent variable for multiple stepwise regression analysis, the results in Table 12 show that only two landscape characteristic factors, X6 (preservation integrity of architectural style) and X12 (landscape element richness) (R^2 = 0.368), significantly influenced total fixation count.

Table 12. Regression coefficients for landscape characteristic factors and eye movement indicators.

	Standardized Coefficient	t	Significance	Collinearity Statistics	
	Beta			Tolerance	VIF
Total fixation count (R^2 = 0.368; Sig. < 0.01)					
X12	0.518	4.65	<0.001	1	1
X6	0.317	2.849	0.006	1	1
Total fixation duration (R^2 = 0.48; Sig. < 0.01)					
X6	0.568	5.628	<0.001	1	1
X12	0.397	3.927	<0.001	1	1
Total saccade duration (R^2 = 0.428; Sig. < 0.01)					
X12	0.602	5.34	<0.001	0.9	1.111
X6	1.286	2.905	0.005	0.058	17.118
X5	−1.007	−2.268	0.028	0.058	17.225
Pupil diameter enlargement count (R^2 = 0.233; Sig. < 0.01)					
X2	−0.301	−2.253	0.029	0.842	1.187
X4	−0.277	−2.072	0.043	0.842	1.187
Total fixation count (R^2 = 0.095; Sig. < 0.01)					
X12	−0.308	−2.339	0.023	1	1

(2) Regression analysis of landscape characteristic factors and total fixation duration: Using seven landscape characteristic factors (X5, X6, X7, X8, X11, X12, and X13) as independent variables and total fixation duration as the dependent variable for multiple stepwise regression analysis, the results in Table 12 show that only two landscape characteristic factors, X6 (preservation integrity of architectural style) and X12 (landscape element richness) (R^2 = 0.48), significantly influenced total fixation duration.

(3) Regression analysis of landscape characteristic factors and total saccade duration: Using eight landscape characteristic factors (X5, X6, X7, X8, X10, X11, X12, and X13) as independent variables and total saccade duration as the dependent variable for multiple stepwise regression analysis, the results in Table 12 show that only three landscape characteristic factors, X5 (building texture), X6 (preservation integrity of architectural style), and X12 (landscape element richness) (R^2 = 0.428), significantly influenced total saccade duration.

(4) Regression analysis of landscape characteristic factors and pupil diameter enlargement count: Using eight landscape characteristic factors (X1, X2, X3, X4, X6, X7, X10, and X12) as independent variables and pupil diameter enlargement count as the dependent variable for multiple stepwise regression analysis, the results in Table 12 show that only two landscape characteristic factors, X2 (vegetation coverage) and X4 (water environment) (R^2 = 0.233), significantly influenced pupil diameter enlargement count.

(5) Regression analysis of landscape characteristic factors and total blink count: Using four landscape characteristic factors (X10, X11, X12, and X13) as independent variables and total blink count as the dependent variable for multiple stepwise regression analysis, the results in Table 12 show that only X12 (landscape element richness) (R^2 = 0.095) significantly influenced total blink count.

4. Conclusions and Discussion

4.1. Discussion

(1) Analysis of Differences Between Eye Movement Behavior and Subjective Perception

Analysis results of eye movement indicators and scenic beauty data show that most samples with higher scenic beauty demonstrated more prominent performance in core eye movement indicators such as total fixation duration, total fixation count, and total saccade duration, indicating that such landscapes can effectively elicit more sustained and frequent visual attention.

However, some samples with higher scenic beauty did not display significant eye movement characteristics. This may be attributed to two interrelated factors: First, these

samples contained relatively simple landscape elements with few visual focal points capable of sustaining prolonged attention, resulting in minimal fluctuations in eye-tracking behavior. Second, 73.3% of participants in this study were highly familiar with rural landscapes, thus possibly reducing their sense of novelty and exploratory motivation, and thereby weakening their active visual engagement with such conventional landscapes [53]. Conversely, some samples with prominent eye movement indicators had lower scenic beauty. This outcome may stem from two contributing factors: first, excessively complex landscape elements with information exceeding cognitive load, thereby reducing overall satisfaction, conforming to people's aesthetic preference for moderately complex images [54]. Second, the gender composition of participants (male-to-female ratio of 1:2) may also have influenced the results. Existing research indicates that gender differences can affect landscape preferences and visual processing. For instance, female participants tend to spend more time observing images; exhibit higher cognitive load and attentional engagement [55]; and are more likely to experience positive emotions and aesthetic pleasure when exposed to rural landscapes characterized by higher vegetation density, rich color gradations, and intricate natural elements [56]. However, these elements were not strongly represented in the photographic samples used in this study. This discrepancy may explain why female participants, despite directing greater visual attention (as evidenced by prominent eye-tracking metrics), did not translate this engagement into correspondingly high aesthetic ratings. Consequently, some samples with prominent eye-tracking metrics were rated lower in perceived aesthetic quality.

Comparing eye-tracking metrics with landscape feature factor scores further revealed that most samples with high landscape feature factor scores also had strong core eye movement metrics, such as total fixation duration, total fixation count, and total saccade duration. This indicates that rural samples with higher landscape feature factor values possess richer landscape elements, eliciting more sustained and frequent attention from participants. A few rural samples with low landscape feature factor scores but prominent eye-tracking metrics likely drew attention because of traditional architectural elements (such as ancient towers and clan halls), which naturally attract greater visual attention from participants [57]. Overall, rural samples with high aesthetic appeal and landscape feature scores generally exhibited strong eye-tracking metrics, indicating consistency between the experimental eye-tracking and participants' subjective evaluations.

From comparison of different rural types, clustered-improvement rural areas had the highest mean scenic beauty rating and possessed more high landscape characteristic factors, but their eye movement indicators, such as total fixation count, fixation duration, and saccade duration, were not the highest, while blink counts were higher. This may indicate that this type of rural landscape has a rational layout and strong visual coherence, allowing participants to efficiently process visual information with fewer fixations. Additionally, pleasant viewing experiences may have induced relaxed states, manifesting as increased blink count, reflecting lower cognitive load and higher psychological comfort. Of course, visual fatigue possibly occurring in later experimental stages may have also influenced blink frequency to some extent.

In contrast, urban–suburban-integration villages showed the lowest values for total fixation count, total fixation duration, total saccade duration, and total blink count. Their scenic beauty and landscape feature scores also ranked lowest, indicating the poorest visual quality among these rural landscapes. These landscapes appear to lack distinctive landscape elements with significant visual appeal, making it difficult to guide effective visual attention. Their spatial environments also exhibit deficiencies in organizational coordination and aesthetic expressiveness, failing to form a complete, harmonious, and compelling visual whole.

Characteristic-preservation villages serve as a vital component of the national heritage protection system. Their rich cultural relics, historic sites, and intangible cultural heritage resources make them pivotal for rural heritage conservation and sustainable development [58]. In this study, characteristic-preservation villages demonstrated the strongest eye-tracking metrics, including the highest total fixation count, total fixation duration, and total saccade duration. This result may stem from the significant visual appeal of historical elements within their spatial layout—such as cultural relics and historic buildings—which are identified and reinforced by the national heritage recognition mechanism. These features likely prompted subjects to engage in more prolonged and in-depth visual exploration and cognitive investment. However, despite these strong eye-tracking responses, these villages did not score highest in scenic beauty or several landscape feature factors. This may indicate issues related to overall landscape complexity and coherence that may impact aesthetic experiences.

Therefore, when advancing the development of villages under special protection, it is crucial to fully leverage the visual high-attention zones revealed by the eye-tracking data—which corresponded to national heritage values (such as ancient pagodas, watchtowers, and clan halls)—and systematically translate them into refined, sustainable planning and design principles for rural areas. The preservation and development of these villages necessitate collaborative efforts among government agencies, civil society, and local residents. By integrating their unique values, current conservation status, and development realities, reasonable policy frameworks and development requirements should be established to achieve sustainable preservation [59]. This visually grounded, refined approach not only supports the sustainable development of characteristic-preservation villages but also offers a micro-level empirical perspective from Chinese rural contexts to global discussions on how national heritage policies can reconcile national heritage values with local perceptions.

(2) Analysis of Eye Movement Behavior and Landscape Characteristic Factors' Influence on Scenic Beauty

Regression analysis of eye movement indicators and scenic beauty indicates that total saccade duration is an important behavioral indicator predicting rural scenic beauty. Longer total saccade duration reflects participants engaging in more extensive spatial exploration and attention transfer during observation, usually meaning that scenes contained more visual elements capable of stimulating interest, demonstrating higher cognitive investment and interest levels, and thereby enhancing scenic beauty evaluation.

Regression analysis of landscape characteristic factors and scenic beauty further reveals that X5 (building texture), X11 (landscape color richness), and X13 (sanitation conditions) are key factors predicting rural scenic beauty. Among these, X11 has the highest contribution rate, indicating that color richness is a core element affecting visual quality, consistent with Liu's [60] research conclusions on forest park landscapes, i.e., that color diversity significantly enhances aesthetic value. X13, as an indicator of sanitation conditions, also has a significant positive impact on scenic beauty, aligning with Feng's [61] findings in traditional village research, i.e., that clean and orderly environments help enhance visitor experience, comfort, and satisfaction. X5 (building texture) also positively impacts scenic beauty by shaping coordinated visual interfaces and conveying regional culture.

(3) Analysis of Landscape Characteristic Factors' Influence on Eye Movement Behavior

In visual cognition, X6 (preservation integrity of architectural style) and X12 (landscape element richness), as core attractiveness elements, have significant positive driving effects on visual exploration behavior. Increases in these values extend total fixation duration, total fixation count, and total saccade duration, reflecting deeper and more sustained visual interest, consistent with existing research conclusions [62]. Conversely, X5 (building texture)

shows a negative influence on total saccade duration, presumably because good building texture enhances spatial-order sense and visual-guidance efficiency, thereby reducing visual search scope and time.

In physiological responses, X2 (vegetation coverage) and X4 (aquatic environment) both show negative influences on pupil diameter enlargement count, indicating higher vegetation coverage and superior water environments help create soothing, natural visual environments, reducing cognitive pressure and inducing relaxed states, and thereby confirming, from a physiological level, the restorative benefits of such landscapes. Additionally, X12 (landscape element richness) also shows negative influence on total blink count, indicating that when facing element-rich scenes, participants invest more cognitive resources, thereby suppressing blink behavior. However, some samples with high landscape element richness showed higher blink counts, possibly related to visual fatigue in later experimental stages or other uncontrolled variables (such as individual differences and environmental interference). Future research needs further control of related factors to reveal underlying mechanisms.

(4) Eye-Tracking Experiment Optimization and Prospects

This study's eye-tracking experiment design has optimization space, such as introducing area-of-interest (AOI) analysis to divide landscape samples into different regions, exploring fixation duration and fixation point counts for each region. Additionally, constrained by experimental conditions and time, participants were mainly university students, with limited sample representativeness, lacking inter-group comparisons of different social populations. Experimental content also focused only on the visual level, not incorporating auditory, olfactory, tactile multi-sensory channels, and other physiological indicators (such as Electroencephalogram). Future research can combine eye-tracking with Electroencephalogram and other technologies [63], through multi-modal data fusion, more comprehensively and objectively revealing landscape space perception mechanisms from both explicit behavior and endogenous neural activity levels. Such methods have been successfully applied in user preference research in the field of product design, deepening the understanding of cultural element cognition through collecting physiological data such as galvanic skin response and eye movements [64]. Applying this approach to landscape research could precisely quantify the visual attractiveness and emotional impact of landscape elements, providing physiological evidence to inform design practice.

(5) Limitations and Prospects of the Study Population

Because this study relied exclusively on university students as research subjects, the homogeneity of the sample limits the generalizability of the findings. Given that university students' life contexts are predominantly centered on campus, their perceptual logic regarding rural landscapes may differ significantly from that of other groups (such as local residents or tourists). This makes it challenging to directly transfer the study's findings to other core stakeholder groups, such as local residents and tourists.

To address these limitations, future research can enhance sample design in two ways: First, by including diverse groups within the study area—such as local residents, tourists, and rural practitioners—researchers can conduct cross-group comparisons to identify perceptual differences in rural landscapes across groups, thereby improving the comprehensiveness and generalizability of findings. Second, future studies could further segment the student group by dimensions such as place of origin (urban/rural background), educational level (university/high school/elementary school students), and frequency of rural experiences. Comparative analysis within these subgroups would reveal structural differences in landscape perception, providing a basis for differentiated and precise landscape planning and development strategies.

4.2. Conclusions

This study combined eye-tracking with subjective evaluations to examine the consistency between objective visual responses and subjective perceptions. It identified differences in visual quality across different rural types and clarified how landscape feature factors influence eye-tracking behavior. The findings provide concrete evidence to inform rural development planning and support sustainable rural development by enhancing visual quality. The main conclusions are as follows:

(1) Eye-Tracking Experiments and Subjective Evaluation Results Show High Consistency

Samples with higher scenic beauty ratings demonstrated more prominent performance in eye movement indicators such as total fixation duration, total fixation count, and total saccade duration, indicating these landscapes can effectively elicit more sustained and frequent visual attention. Further factor analysis shows these samples typically possess higher landscape characteristic factor values.

(2) Significant Differences Exist in Visual Quality Among Different Rural Types

Characteristic-preservation rural landscapes elicited more in-depth and frequent visual exploration, demonstrating stronger visual attractiveness and cognitive engagement. Clustered-improvement rural landscapes had higher scenic beauty ratings and landscape characteristic factor values, with more overall aesthetically pleasing landscapes. Comparatively, urban–suburban-integration rural areas performed poorly in visual attractiveness, scenic beauty ratings, and landscape characteristic factor values, with visual quality significantly lower than the other two types.

(3) Total Saccade Duration is an Important Eye Movement Indicator for Predicting Scenic Beauty

According to correlation and regression analysis between eye movement indicators and scenic beauty, total saccade duration is an important predictor explaining scenic beauty. Additionally, analysis of landscape characteristic factors further reveals that three landscape characteristic factors, X5 (building texture), X11 (landscape color richness), and X13 (sanitation conditions), are key landscape indicators constituting rural landscape scenic beauty.

(4) Landscape Characteristic Factors Have Significant Influence on Eye Movement Behavior

According to correlation and regression analysis between landscape characteristic factors and eye movement indicators, we identified multiple predictors with significant explanatory power for visual behavior. Among these, X6 (preservation integrity of architectural style) and X12 (landscape element richness) have significant positive predictive effects on total fixation count, total fixation duration, and total saccade duration. Additionally, this study found that some factors have significant negative influences: X5 (building texture) significantly negatively predicts total saccade duration, X2 (vegetation coverage) and X4 (aquatic environment) significantly negatively predict pupil diameter enlargement count, and X12 (landscape element richness) also significantly negatively influences total blink count.

4.3. Optimization Strategies

(1) Enhance Color Richness of Rural Landscapes

Color richness has a significant positive influence on scenic beauty. Existing color themes of buildings should be continued while reasonably introducing diversified vegetation to enhance landscape color layering and dynamic changes. Meanwhile, productive landscapes such as farmland and orchards should be incorporated into color-planning

systems, utilizing their seasonal color variations to construct harmonious and vital rural landscape features.

(2) Enhance Element Richness of Rural Landscapes

Landscape element richness can elicit longer fixation and saccade durations, enhancing visual attractiveness and cognitive engagement. It is recommended to systematically enhance element richness from three aspects: ecological, economic, and cultural. Ecologically, improve water environment management and vegetation diversity construction. Economically, integrate resources such as farmland and fishponds, highlighting seasonal and regional characteristics. Culturally, restore ancient buildings, using local materials and folk elements to construct narrative landscape features.

(3) Protect Overall Architectural Styles and Enhance Building Textures

Building texture and style integrity have significant influence on scenic beauty and eye movement behavior. Systematic restoration of ancient buildings should be strengthened, from macro-level settlement patterns to micro-level material craftsmanship, reinforcing building texture integrity and cultural representation. For example, at the macro level, digital technology can be employed to understand village morphological characteristics [65]. At the micro level, historical and cultural symbols can be integrated into architectural details, enhancing artistic value [66,67].

(4) Enhance Overall Landscape Visual Quality of Urban–Suburban-Integration Rural Areas

Landscape transformation of this type of rural area should focus on spatial renewal, adopting "micro-circulation, self-renewal" progressive strategies [68], enhancing visual quality through small-scale, sustainable landscape governance. Architectural-style remediation should follow "micro-transformation, refined enhancement" principles, combined with ecological restoration, optimizing baseline landscapes, and promoting rural coordinated development in the ecological and social dimensions.

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Appendix A

Appendix A.1

Table A1. Basic overview of the nine sample villages.

Village Types	Village Name	Basic Overview of the Village
Clustered improvement	Cangshuyuan Village	The village is located approximately 50 km from downtown Guangzhou, with convenient transportation. It preserves numerous buildings from the Ming and Qing dynasties, fully showcasing the traditional architectural style of Lingnan villages. In recent years, it has actively promoted cultural tourism development and established a base of flower cultivation. Plans are underway to introduce small-scale horticultural attractions such as courtyard flower displays and potted-plant experiences.
	Xihe Village	The village is located approximately 10 km from the Conghua urban area and has convenient transportation. With flower cultivation as its primary industry, the village has actively developed modern sightseeing agriculture, leisure agriculture, and educational tourism, creating signature projects such as the "Nine-Mile Flower Street". Leveraging the platform of the Ten Thousand Flowers Garden, it promotes rural tourism development. The village has been honored with titles including "China's Beautiful Leisure Village" and "National Key Village for Rural Tourism".
	Nanping Village	The village has a forest coverage rate exceeding 80%, earning it the reputation of a "natural oxygen bar". It actively promotes eco-tourism, offering Zen-inspired experiences and pastoral leisure activities. Its specialty agriculture draws numerous visitors and is centered on lychee, longan, and green plum fruits. Recent efforts to develop homestays, farm-to-table dining, and specialty agricultural product sales have boosted residents' incomes. The village has earned multiple honors, including "China's Most Beautiful Village" and "National Forest Village".
Characteristic preservation	Daling Village	The village is located approximately 30 km from downtown Guangzhou and ranks among the city's ten most renowned surrounding ancient villages. Its layout remains remarkably intact, preserving numerous traditional Lingnan-style buildings that form a characteristic "fishbone-pattern" street network. Recognized for its rich historical and cultural heritage alongside pristine natural surroundings, it has been designated a "China Historical and Cultural Village"—the sole recipient of this honor in Guangzhou to date.
	Langtou Village	Located approximately 40 km from downtown Guangzhou, this village is one of the largest preserved traditional Cantonese settlements in Guangdong Province. It has been included in the "National Register of Traditional Villages in China" and designated as one of the "Sixth Batch of China's Historical and Cultural Villages". The village has gradually emerged as a popular destination for rural tourism in Guangzhou due to its rich historical and cultural resources and collection of ancient buildings.
	Gualing Village	The village lies approximately 40 km from downtown Guangzhou and stands as one of the city's oldest existing hometowns of overseas Chinese. It has been included in China's Traditional Villages Register and designated as both a Guangdong Provincial Historic Village and a Guangzhou Municipal Cultural Heritage Site. The village serves as a living specimen for studying modern defensive architecture, and water–village settlement patterns. Its unique combination of watchtowers, canals, and overseas Chinese heritage is unparalleled in the Pearl River Delta region.
Urban–suburban integration	Kengbei Village	The village is located 15 km from Zengcheng's urban center and is adjacent to Kengbei Station on Guangzhou Metro Line 21. In recent years, the village has restructured its industrial base, gradually expanding into sectors such as hardware, plastics, and manufacturing. By integrating culture, agriculture, and tourism, it has driven rural industrial development, significantly boosting villagers' incomes. Furthermore, leveraging the Guangzhou Eastern Intermodal Hub project, the village is accelerating improvements in both rural industries and public services.

Table A1. *Cont.*

Village Types	Village Name	Basic Overview of the Village
	Liantang Village	The village enjoys convenient transportation, being adjacent to the ring expressway. Currently, it is embracing a new development opportunity—the Guangzhou Eastern Intermodal Hub for Road and Rail Transport has been established in Zhongxin Town, with the village falling within its scope. Positioned as a demonstration project that integrates transportation corridors, hubs, and industries, the hub represents a comprehensive distribution system, a modern logistics platform, and a manufacturing supply chain service platform, providing new momentum for the development of Liantang Village.
	Caotang Village	The village is located approximately 30 km from downtown Guangzhou and has a comprehensive infrastructure. Benefiting from the industrial spillover effects of the Economic and Technological Development Zone and the Guangzhou Automobile Corporation Motor base, some villagers engage in non-agricultural work, resulting in an economic structure characterized by a "half-urban, half-rural" profile. Concurrently, traditional agriculture (rice cultivation, floriculture, and fishpond farming) is gradually transitioning toward leisure agriculture and sightseeing/picking activities (strawberry farms and eco-farms).

Appendix A.2

Table A2. Landscape characteristic factors and evaluation criteria.

Evaluation Criteria	Indicator Definition	1 Point	2 Point	3 Point	4 Point	5 Point
X1 Plant species	A collective term for plant categories such as trees, shrubs, herbaceous plants, and vines that constitute specific landscape spaces and possess ornamental or ecological functions.	None or very few plant species	Few plant species	Moderate number of plant species	High number of plant species	Very high number of plant species
X2 Vegetation coverage	The percentage of total area occupied by the vertical projection of vegetation within a specific region.	0–20%	20–40%	40–60%	60–80%	80–100%
X3 Vegetation stratification	The vertical stratification and combination of different plant structures (such as trees, shrubs, herbaceous plants, and groundcovers) within a landscape.	No stratification	Single-layered, with no vertical variation; flat appearance	Few layers, with weak vertical variation; lackluster visual effect	Moderate layering, with some vertical variation; acceptable visual effect	Rich layering, with strong vertical variation; good visual effect
X4 Aquatic environment	Indicates the ecological and environmental status of a body of water.	No water present, or severe water pollution	Poor ecological condition, with slight pollution	Moderate ecological condition, with basic aesthetic appeal	Good ecological condition, with relatively harmonious environment	Excellent ecological condition, with unified and harmonious environment
X5 Building texture	The texture and organization created by the spatial composition, form, materials, and scale combinations of the building structure itself.	No buildings present, or very poor building texture	Poor building texture	Moderate building texture	Good building texture	Very good building texture
X6 Preservation of architectural style	The degree to which historical buildings retain their original characteristics, spatial form, and visual style.	No buildings present, or building architecture in very poor condition	Poor preservation of architectural character	Moderate preservation of architectural character	Good preservation integrity of architectural character	Excellent preservation integrity of architectural character

Table A2. *Cont.*

Evaluation Criteria	Indicator Definition	1 Point	2 Point	3 Point	4 Point	5 Point
X7 Historical character of buildings	Refers to the unique attributes of architecture that embody and reflect the cultural, technological, and aesthetic characteristics of a specific historical period through its form, materials, craftsmanship, or function.	No buildings present, or buildings lack historical character	Weak expression of architectural/historical character	Moderate expression of architectural/historical character	Good expression of architectural/historical character	Excellent expression of architectural/historical character
X8 Road Coordination	Refers to the degree to which a road is integrated visually, ecologically, and functionally with surrounding natural and cultural landscapes, thereby enhancing overall aesthetics and user experience.	No roads present, or very poor road coordination	Poor coordination of roads	Reasonable coordination of roads	Good coordination of roads	Excellent coordination of roads
X9 Farmland texture	Refers to the characteristic textures and patterns formed by elements such as the shape and scale of farmland, as well as the spatial arrangement of crops, reflecting regional agricultural production patterns and natural conditions.	No farmland present, or very poor farmland texture, lacking overall aesthetic	Disorganized texture; bland visual effect	Patterned texture with acceptable visual effect, but lacking aesthetic appeal	Clear and regular texture with good visual effect, possessing aesthetic appeal	Clear and artistically rich texture with strong visual impact; highly aesthetic
X10 Landscape spatial stratification	Refers to the orderly arrangement of landscape elements to form a three-dimensional visual structure with a clear distinction between foreground and background with a hierarchical order of dominance.	No stratification; lacking depth and dimensionality; poor visual effect	Limited stratification, with weak depth and dimensionality; plain visual effect	Moderate stratification, with some depth and dimensionality; acceptable visual effect	Rich stratification, with strong depth and dimensionality; good visual effect	Very rich stratification, with excellent depth and dimensionality; outstanding visual effect
X11 Landscape color richness	Visual diversity created by various natural and artificial elements in a landscape, manifested in light, hue, and color saturation.	Monotonous single color; dull and boring	Limited colors; bland and lacking appeal	Some color variation; harmonious but unremarkable	Rich colors; harmonious, with visual impact	Very rich colors; natural, with strong aesthetic appeal
X12 Landscape element richness	The degree of diversity in the types, forms, and functions of the natural and artificial elements that constitute a landscape.	Monotonous elements, lacking diversity	Limited elements; overall relatively plain landscape	Moderate element diversity; overall acceptable landscape visual effect	Moderate element diversity; overall acceptable landscape visual effect	Very rich elements; overall outstanding landscape visual effect
X13 Sanitation conditions	Refers to the cleanliness of the landscape space.	Extremely poor sanitation conditions	Poor sanitation conditions	Reasonable sanitation conditions; no evident accumulation of trash	Good sanitation conditions; no trash along sidewalks	Excellent sanitation conditions; very clean and tidy

Appendix A.3

Table A3. Eye movement indicator data.

Photo Number	Total Fixation Count	Total Fixation Duration (s)	Total Saccade Duration (s)	Pupil Diameter Enlargement Count	Total Blink Count
P1	14.1	5.65	0.9	10	1.33
P2	16.7	6.06	0.99	25	1.67
P3	16.3	5.49	0.98	16	1.41
P4	17.7	5.99	1.25	7	2.04
P5	17.4	6.17	1.09	26	1.93
P6	17.6	5.89	1.19	1	1.74
P7	18.1	6.65	1.21	44	1.74
P8	16.1	6.93	1.08	4	1.96
P9	18.7	6.51	1.17	54	2.26
P10	16.2	5.76	1	32	1.78

Table A3. *Cont.*

Photo Number	Total Fixation Count	Total Fixation Duration (s)	Total Saccade Duration (s)	Pupil Diameter Enlargement Count	Total Blink Count
P11	14.5	5.57	0.9	45	1.7
P12	17.1	6.41	1.08	27	2
P13	17.2	6.53	1.06	19	1.81
P14	16.2	5.55	1.02	50	1.41
P15	16.6	6.55	1.02	13	1.52
P16	14.2	4.81	0.95	36	1.15
P17	16.5	6.16	1.03	38	1.63
P18	17.1	6.1	1.07	3	1.22
P19	15.1	5.35	0.94	6	1.22
P20	15.2	5.42	0.93	2	1.19
P21	13.2	5.92	0.81	17	1.41
P22	14.6	5.6	0.94	27	1.59
P23	16.9	5.83	1.08	17	1.48
P24	14.7	5.46	0.92	21	1.48
P25	14.2	5.22	0.86	7	1.37
P26	17.6	5.92	1.14	13	2.22
P27	13.9	5.17	0.85	3	1.3
P28	15.0	5.69	0.9	14	1.26
P29	13.3	4.59	0.85	18	1.52
P30	13.2	5.02	0.89	11	1.52
P31	16.1	5.77	1.06	3	1.67
P32	13.8	5.44	0.92	11	1.44
P33	11.7	4.26	0.75	9	1.3
P34	14.9	5	0.96	10	1.67
P35	15.4	5.38	1	11	1.63
P36	13.6	4.87	0.84	7	1.33
P37	14.6	5.12	0.91	4	1.26
P38	14.2	4.81	0.93	12	1.48
P39	15.0	5.38	0.86	18	1.31
P40	14.5	5.51	0.98	21	1.44
P41	15.5	5.31	1.01	11	1.96
P42	13.8	4.82	1.05	8	1.63
P43	15.0	4.96	1	2	1.48
P44	16.9	5.78	1.16	15	1.85
P45	15.8	5.51	0.99	16	1.44
P46	13.6	5.36	0.87	10	1.56
P47	12.2	4.68	0.74	4	1.15
P48	12.9	4.84	0.8	7	1.59
P49	18.5	5.84	1.1	1	1.89
P50	14.8	5.48	1.02	1	1.59
P51	14.3	4.86	0.95	5	1.7
P52	13.4	4.95	0.88	2	1.37
P53	12.9	5.15	0.87	2	1.67
P54	12.3	4.66	0.8	1	1.44

Appendix A.4

Table A4. SBE mean and mean landscape characteristic factor values.

Photo Number	SBE Mean	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
P1	−0.68	1.44	1.44	1.11	1.22	3.56	3.89	3.89	2.67	1.00	2.11	2.56	2.33	3.56
P2	−0.03	3.67	3.89	3.78	3.56	3.11	3.22	3.00	3.44	1.33	3.89	3.22	3.78	3.89
P3	−0.20	3.67	3.17	3.00	1.00	1.67	1.17	1.17	3.83	3.33	3.50	3.17	3.33	3.50
P4	−0.03	4.17	3.50	3.67	1.00	3.83	4.17	4.17	3.50	1.00	3.83	4.00	4.00	4.17
P5	0.31	4.17	4.33	3.33	1.00	1.00	1.00	1.00	3.50	4.17	3.50	3.50	3.33	3.83
P6	0.07	3.89	4.22	4.11	1.44	2.44	2.33	2.00	4.33	1.67	4.00	3.56	3.67	4.44
P7	0.87	4.83	4.67	4.67	4.50	4.17	3.67	3.67	2.83	1.17	4.50	4.50	4.50	4.50
P8	0.60	2.56	1.78	2.56	1.33	4.56	4.56	4.56	4.33	1.33	3.22	3.89	3.22	4.56
P9	1.11	4.56	4.67	4.67	3.67	3.11	2.67	2.67	3.89	2.67	4.22	4.67	4.56	4.56
P10	0.00	3.00	2.83	3.00	1.17	3.33	3.33	3.17	3.67	1.17	3.17	3.17	3.17	4.17
P11	−0.59	3.56	3.44	3.56	4.11	1.78	1.67	1.56	3.22	2.44	2.56	2.67	3.11	4.00
P12	0.91	4.50	4.33	4.67	1.67	3.67	3.67	3.50	4.33	1.67	4.50	4.00	4.33	4.67
P13	−0.03	4.44	4.00	4.33	3.00	4.22	4.33	4.22	3.67	1.56	4.00	4.33	4.11	4.00
P14	0.24	4.17	3.83	4.33	4.50	3.83	3.67	3.33	4.00	1.17	4.50	4.50	4.33	4.50
P15	0.68	3.78	2.78	3.56	1.33	4.33	4.11	4.11	4.22	1.33	3.44	3.78	3.67	4.44
P16	−0.82	3.22	3.22	2.78	3.33	1.67	1.56	1.44	2.11	3.00	2.67	2.56	2.56	3.22

Table A4. *Cont.*

Photo Number	SBE Mean	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
P17	0.02	3.50	3.50	3.67	3.33	3.83	3.50	3.33	4.17	1.00	4.17	4.17	4.00	4.33
P18	0.26	3.00	3.00	3.17	1.00	3.67	3.83	3.83	4.00	1.00	3.50	3.67	3.33	3.67
P19	−0.33	3.56	3.00	3.56	1.33	2.56	2.11	1.78	3.67	1.00	3.44	3.33	3.22	4.11
P20	−0.18	3.22	2.67	3.44	3.78	2.78	2.44	2.44	3.44	1.33	3.44	3.11	3.22	4.00
P21	−0.45	2.17	2.00	2.00	1.00	4.00	3.83	3.83	3.67	1.00	2.67	2.33	2.50	3.83
P22	−0.04	2.78	2.89	2.44	1.22	4.11	4.11	4.11	3.67	1.44	3.44	2.78	3.33	4.00
P23	−0.41	3.67	3.67	3.17	1.17	2.50	2.50	2.67	3.67	1.00	3.50	3.67	3.33	4.00
P24	−0.54	2.50	2.33	2.50	1.00	3.33	3.33	3.00	2.67	1.00	3.17	3.00	2.83	3.50
P25	0.19	3.44	4.11	2.78	4.44	2.78	2.22	2.22	2.67	3.44	3.44	3.56	3.56	4.33
P26	0.63	1.89	1.56	1.56	4.00	4.44	4.44	4.56	4.11	1.22	4.00	3.11	3.44	4.33
P27	−0.67	3.50	3.33	3.50	1.00	2.50	2.33	2.17	3.67	2.33	3.00	2.67	3.00	3.83
P28	0.15	3.33	3.33	3.17	1.00	3.83	3.67	3.67	3.50	1.00	3.67	3.50	3.33	3.83
P29	−0.79	1.56	1.56	1.67	1.22	3.78	3.67	3.56	3.11	1.22	1.56	2.00	1.78	3.78
P30	−0.66	2.83	3.67	2.50	1.17	2.50	2.33	2.00	2.17	3.83	3.17	3.00	2.83	3.50
P31	−0.21	3.11	4.00	3.44	3.89	3.44	3.67	3.56	3.33	1.67	3.67	3.33	3.78	4.11
P32	−0.35	1.00	1.00	1.00	1.00	4.17	4.00	4.00	3.67	1.00	3.50	3.17	2.67	4.17
P33	−0.59	3.78	4.00	3.78	1.56	1.89	1.33	1.56	3.67	1.89	3.44	3.33	3.44	3.89
P34	−0.81	3.56	3.56	3.11	2.44	1.22	1.22	1.11	2.00	3.56	2.78	2.44	2.56	3.22
P35	−0.05	3.50	3.33	3.33	4.17	3.17	3.00	2.83	3.33	1.00	3.50	3.50	3.17	4.00
P36	−0.23	4.67	4.67	4.67	4.00	2.33	2.17	2.00	2.83	1.00	3.83	3.50	3.33	4.00
P37	−0.17	4.67	4.67	4.67	4.00	1.83	1.67	1.67	2.67	1.17	4.00	4.00	3.67	4.17
P38	−0.36	4.33	3.78	3.89	3.33	1.67	1.56	1.56	4.00	1.56	3.78	3.44	3.67	4.22
P39	−0.62	3.22	2.67	3.00	1.22	2.67	2.33	2.11	3.56	1.11	2.89	2.89	2.78	4.33
P40	0.27	3.89	3.44	3.56	1.22	3.89	3.44	3.56	3.89	1.22	3.56	3.78	3.67	4.22
P41	−0.52	3.17	3.17	3.00	1.00	3.33	3.33	3.50	3.17	1.00	3.67	3.17	3.17	4.00
P42	0.16	4.00	4.00	3.83	3.50	1.50	1.50	1.50	3.33	1.00	3.83	3.50	3.50	4.00
P43	0.23	3.17	3.17	3.17	1.00	3.67	3.00	3.00	3.83	1.00	3.83	3.33	3.50	4.33
P44	0.96	4.22	3.89	4.33	1.22	3.56	3.00	2.78	4.22	1.78	4.22	4.11	4.22	4.44
P45	0.52	4.67	4.50	4.67	4.67	1.00	1.00	1.00	2.83	1.17	4.50	4.67	4.17	4.33
P46	−0.18	4.44	4.22	4.11	4.11	2.56	2.22	2.00	3.11	1.33	3.78	3.89	3.78	3.89
P47	−0.02	3.67	3.00	3.50	1.00	3.17	2.67	2.67	4.00	1.00	3.50	3.50	3.33	4.33
P48	−0.34	3.67	4.22	4.00	1.22	1.22	1.11	1.00	3.00	1.44	3.78	3.67	3.44	4.33
P49	0.70	4.67	4.67	4.67	4.00	3.33	2.33	2.33	4.00	1.17	4.50	4.50	4.50	4.50
P50	0.71	4.22	4.89	4.44	1.22	2.33	1.78	1.78	4.11	1.56	4.44	4.22	4.11	4.44
P51	0.00	4.33	4.56	4.33	2.44	1.56	1.22	1.22	2.00	3.44	4.22	3.56	3.78	4.11
P52	0.34	4.00	4.00	4.00	1.33	2.67	2.33	2.67	3.83	1.67	3.83	3.67	3.50	4.50
P53	0.50	3.83	3.83	3.67	1.00	3.00	2.83	2.83	3.83	1.00	4.00	4.17	3.83	4.50
P54	0.52	3.89	3.33	3.33	1.22	2.78	2.33	2.11	3.78	1.22	3.78	4.00	3.56	4.22

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