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Landscape Design Intensity and Its Associated Complexity of Forest Landscapes in Relation to Preference and Eye Movements

Yuanping Shen, Qin Wang, Hongli Liu, Jianye Luo, Qunyue Liu and Yuxiang Lan *

College of Architecture and Planning, Fujian University of Technology, Fuzhou 350108, China
* Correspondence: 19912325@fjut.edu.cn

Abstract: Understanding how people perceive landscapes is essential for the design of forest landscapes. The study investigates how design intensity affects landscape complexity, preference, and eye movements for urban forest settings. Eight groups of twenty-four pictures, representing lawn, path, and waterscape settings in urban forests, with each type of setting having two groups of pictures and one group having four pictures, were selected. The four pictures in each group were classified into slight, low, medium, and high design intensities. A total of 76 students were randomly assigned to observe one group of pictures within each type of landscape with an eye-tracking apparatus and give ratings of complexity and preference. The results indicate that design intensity was positively associated with subjective landscape complexity but was positively or negatively related to objective landscape complexity in three types of settings. Subjective landscape complexity was found to significantly contribute to visual preference across landscape types, while objective landscape complexity did not contribute to preference. In addition, the marginal effect of medium design intensity on preference was greater than that of low and high design intensity in most cases. Moreover, although some eye movement metrics were significantly related to preference in lawn settings, none were found to be indicative predictors for preference. The findings enrich research in visual preference and assist landscape designers during the design process to effectively arrange landscape design intensity in urban forests.

Keywords: landscape complexity; fractal dimension; eye tracking; preference; urban forest; forest landscape

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1. Introduction

Chinese urbanization has opened up numerous opportunities to expand urban forests. However, a major challenge to landscape designers in China is designing forest landscapes that meet the demands and preferences of the general public. Understanding public perceptions and preferences is critical for effective landscape planning and design. It is the citizens who will ultimately utilize these landscapes [1], and without their support, proposals for urban forest renewal projects may fail [2]. Therefore, it is necessary to gather information about the general public's landscape perceptions and preferences, so that practitioners may incorporate this vital information in the design process to achieve better outcomes.

Previous research has found that environments preferred by the public increase well-being [3] and mental restoration [4–6], as well as generate further positive health outcomes [6,7]. Research has found that landscape preference predicts how well people will function in a given environment [6], and it should be taken into account as an essential factor in the design process [8]. Furthermore, numerous studies have been conducted on the preference for different types of landscapes [9–11], different cultural backgrounds and landscape preferences [12,13], and preferences for potential physical features [14–18].

Few studies have investigated whether varying landscape design interventions in urban forest settings affect respondents' perceptions of landscape complexity and their ratings on preference, particularly regarding Chinese urban forests. Scarce research is available on how these interventions affect landscape complexity and whether the increased complexity influences preferences. Consequently, research on the public's preferences for different levels of landscape design interventions in various forest settings will help designers examine the design outcomes and subsequently develop effective design guidelines. The extent of design intervention refers to design intensity, which was initially put forward by Xu et al. [19] and described as "the amount of the original landscape changed and the degree of artificiality of added elements to the landscape by design." The current study modified this concept to cover a number of different landscape elements used, the complexity of different landscape elements in a configuration, and the extent of landscape maintenance requirements in the present landscape, as well as take it a step further by investigating the influence of design intensity on landscape complexity (including both objective and subjective measures), and thereby on people's preferences.

Research has found that eye movements tend to indicate individuals' preferences for certain landscapes [20]. However, the question of how eye movements can predict these preferences is relatively unexplored, especially for Chinese urban forest settings. In addition, with few studies conducted on the associations between design intensity and eye movement, how landscape design intensities affect eye movements remains unclear. The present study utilizes eye-tracking technology, which offers a great opportunity to explore these questions and provide valuable insights.

1.1. The Association between Landscape Design, Complexity, and Preference

Landscape preference, which refers to "liking" specific scenes or places [21], or finding any place aesthetically pleasing [22], has generated an extensive body of published literature [23]. Several studies suggest that landscape design significantly affects public preference. For example, people prefer built environments with natural landscape elements in comparison with those without natural elements [24,25]. Furthermore, the presence of anthropogenic elements in the landscape, such as wind turbines, could have a negative impact on individuals' perceptions [25]. Previous studies also indicate a significant relationship between physical landscape features and people's preferences [26–28]. Within the discussion on physical features, landscape complexity is an important term used for describing visual character [29], and it has been used to explain landscape preference [30]. It refers to the richness and diversity of the visual formation people receive, as well as a measure index for how much is "going on" and how much to look at in a particular scenario [31]. Although there are many visual indicators related to landscape preference, such as historicity, visual scale, and naturalness [32,33], landscape complexity may serve as a bridge between visual aesthetics and landscape ecology [34,35]. Studies suggest that complexity and coherence, which have been examined as potential predictors of landscape preference [36], are closely associated concepts. Landscape complexity, defined based on the distribution, spatial organization, and variation and shape of landscape elements and patterns, can relate to coherence [29,30]. Thus, the present study considers landscape complexity as a good indicator for describing landscape characteristics in urban forest settings, as well as for linking landscape design intensity to preference. However, previous studies that examined landscape and preference were generally only based on subjective ratings of landscape complexity. Additionally, researchers have criticized the existing studies on environmental perception for often lacking quantitative evidence linking the given landscape metrics to human response [30]. Thus, this study uses both objective and subjective measurements of landscape complexity to offer better insights into studies regarding landscape preference and complexity.

Furthermore, previous studies on landscape perception were generally based on extreme examples (e.g., urban vs. rural) [37], and studies on landscape preference were primarily based on photographs without control over image content. These photographs may cause some bias of individuals' perceptions [29], especially when research seeks to test and validate the indicators systematically. As a result, previous studies offer limited guidance in designing landscapes within an urban context, wherein knowledge is required regarding design interventions and preferred level of complexity. One of the aims of this study is thus to examine the association between landscape complexity and preference by using both objective and subjective measures of complexity and ensuring control over the properties of the landscape images.

1.2. The Objective and Subjective Measurement of Landscape Complexity

The recently emerged concept of fractal dimension, a parameter used to describe fractured shapes [38], has been extensively used in urban landscape structure studies. Fractal dimension has good ability to consistently describe objective landscape complexity [39]. For instance, Stamps [40] used fractal dimension to describe the physical features of a skyline and attempted to link fractal dimension to preference. In another instance, Cooper [41] employed fractal dimension to characterize the complexity of street edges. In the area of urban design, Robertson [42] investigated fractal dimension in relation to urban character and urban design qualities. Concerning landscape evaluation, fractal dimension has been used to assess fractal characteristics and has been used as a predictor of landscape preference [38]. These studies generally demonstrated a significant relationship between fractal dimension and landscape preference [43,44]. Concerning fractal dimension and landscape complexity, fractal dimension has been described as a statistical quantification of complexity [45]. In addition, it has a good ability to describe complexity of line and composition in the landscape [46]. Sandau and Kurz [47] showed that fractal dimension could be used as a parameter for complexity, as it is related to surface roughness, classification of textures, and line patterns. Hsieh and Lin [39] investigated landscape complexity in relation to preference by using fractal dimension to measure complexity. They pointed out that fractal dimension not only measures the complexity of line and composition but also characterizes the textural details and structural richness. Furthermore, fractal dimension could also be applied to measure the complexity of built environments [43,44]. Moreover, from the perspective of landscape perception and landscape design, the fractal dimension is particularly interesting, since it can be used directly in design work. Therefore, fractal dimension can be regarded as a comprehensive and objective measure of landscape complexity. This study also measures landscape complexity with fractal dimension, which can be easily calculated using software packages such as Fractalyse 2.4 and Benoit 1.3.

Regarding the subjective approach to measuring landscape complexity, previous studies [4,48,49] have commonly asked participants to rate the level of complexity on a Likert scale. For example, to verify the restorative benefits of green landscapes in their study, Kang and Kim [48] asked respondents to rate their perceived complexity using a seven-point scale. In another study, Han asked 274 undergraduate students to report their evaluations of landscape complexity on a five-point Likert-type scale [4]. The evaluations served as controlling and descriptor variables in exploring the relationships between landscape scenic beauty, preference, and restoration. The current study also uses respondent ratings on a seven-point Likert-type scale to subjectively measure landscape complexity.

1.3. Using Eye-Tracking Technology in Landscape Perception Research

Questionnaire surveys and in-depth interviews have long been used as subjective approaches to study landscape perception [50]. However, the objective approach, such as eye tracking, has only recently been utilized in landscape studies. The eye-tracking measure can record observers' eye movements when they look at photographs, making it possible to observe the respondents' visual exploration patterns [51]. Dupont et al. [52] have used the eye-tracking measure to explore differences between expert and laypeople's perceptions of landscape photographs. Their study found that these groups may not observe landscapes in the same way and may not even perceive the same landscape features. By analyzing the metrics of eye movement, Valtchanov and Ellard found a longer fixation time for nature scenes than for urban landscapes [53]. However, Berto et al.'s use of eye-tracking technology indicated a greater eye travel distance and number of fixations for urban landscapes than for nature scenes [54]. Both studies formulated and analyzed landscape perception paradigms with the use of eye-tracking technology. However, following the general trend, these studies focused only on landscape properties. Few studies have investigated the association between landscape design intensity, complexity, eye movements, and landscape preferences. There is a need for research focused on landscape design intensity, landscape complexity, and visual exploration.

1.4. The Study Objective

The lack of studies concerning objective measures of landscape complexity, and the availability of the relatively new and promising eye-tracking technology, are the key factors for undertaking this study. We use objective and subjective approaches to investigate the landscape design intensity in relation to landscape complexity, visual preference, and eye movements by using urban forest setting photographs. The study seeks to answer the following research questions:

(1) How do landscape design intensities affect objective and subjective landscape complexity and eye movements?
(2) How dose objective and subjective landscape complexity affect visual preference and eye movements?
(3) What are the relationships between eye movement metrics, landscape complexity, and landscape preference?

2. Methods

2.1. Study Area

The stimuli for the experiment conducted in this study were photographs representing three types of urban forest settings, namely the settings of lawns, paths, and waterscapes, which can be widely seen in the urban forest of Fuzhou, China. These photos were selected from a photo bank of over 678 photos taken by several of the authors in different parks in Fuzhou in similar weather and seasonal conditions. Based on the following criteria, we initially selected 60 images (20 for 1 type of setting): (a) each image should be commonly seen in urban parks of China; (b) each type of landscape image should have similar landscape structures; (c) each type of landscape should include images with varying design intensities; and (d) in the images, it should be feasible to add or remove certain landscape components to create landscapes with certain design intensities (optional). Each type of setting image was then classified into four categories (slight, low, medium, or high design intensity) according to their artificial landscape components, with each category including five images by ten landscape architects. Following this procedure, another ten landscape architects were asked to select two pictures from the five images for each category according to their representativeness and suitability. As there was only minimal difference in design intensities between some images and their counterparts, these images were further modified following the photomontage method to control the landscape design intensity. The photomontage method allows researchers to integrate landscape components to create new landscape settings [55]. Following Xu et al. [19], we added a few sketches or manmade facilities to strengthen the design intensity, and we removed some of these to weaken the design intensity. In addition, the buildings in the background of the images were also removed. To improve the realistic look of the modified images, the addition or removal of certain landscape elements (such as bench, stone, lamppost, etc.) was based on real urban forest settings widely seen in China, and all added components were derived from actual forest setting photos that had similar landscape structures. To ensure the rationality and suitability of the landscape contexts in the manipulated images and the landscape design intensity they represent, these images were subsequently reviewed by senior researchers with research experience on similar topics, as well as by ten landscape architects with extensive experience in landscape design.

Finally, a total of 24 photos were selected for use in the eye-tracking experiment and preference rating survey (Figure 1). The photos were divided into six groups (each type of setting having two groups, A and B), with each group comprising four photos, which indicated slight, low, medium, and high design intensity. The six groups for the three types of settings are lawn settings A and B; path settings A and B; and waterscape settings A and B.

Figure 1. Presentation of the stimuli.

2.2. Eye-Tracking Apparatus and Measurements

Eye Link 1000 Plus, which has been shown to have high accuracy and precision in eye-tracking measurement, was used to record eye movements. The eye-tracking technology can record observers' point-of-regard every millisecond, as well as continuously record the observers' eye movements while viewing photographs. The records are displayed on a 19 in color monitor with a resolution of 1280 × 1024 pixels. The technology uses infrared light to reflect off the cornea and retina of the eye using low-power infrared light [56,57]. The reflected signal reveals the precise location of the point-of-regard, which is expressed by horizontal and vertical coordinates [56]. Subsequently, the entire gaze pattern is recorded, including fixations and saccades [57]. Although both eyes are engaged in observing the photo, the movements of only one eye are recorded at a measurement rate of 1000 Hz.

Participants' fixations and saccades were continuously recorded by the system throughout the experiment. According to Poole and Ball [57], a fixation is defined as the period of time when the eyes are relatively stationary, which allows for visual perception. It is recommended to set the lower threshold for determining a fixation t at 100 milliseconds. Consequently, in this study, a fixation was depicted as a stationary eye position lasting a minimum of 100 milliseconds. The fixation count and duration were recorded and used to analyze gaze pattern characteristics. Fixation count is the number of fixations in the photo, and fixation duration is the duration time of a fixation. With respect to the metric of saccade, saccade count and saccade amplitude (degree) were used to observe the main viewing pattern. Saccades are the eye movements that move the fovea rapidly from one point of interest to another. Saccade count is the number of saccades in the photo, and saccade amplitude is the angular distance the eye travels during the movement.

2.3. Study Participants

The study recruited 76 people (37 males and 39 females) between 20 and 58 years of age to voluntarily participate in the landscape preference rating and eye-tracking experiment. The sample was divided into two groups, each with 38 participants, which was deemed large enough for eye-tracking research and sufficient to detect major effects [58,59]. All participants had normal or corrected-to-normal vision. The participants were given brief practical information about the eye-tracking experiment. The participants were randomly assigned to view one group of photos from each type of setting, and each participant viewed 4 groups of 12 photos in total in random order.

2.4. Research Procedure

The experiment was conducted one subject at a time over a period of fifteen days in September 2020 at a lab of a university. After arriving at the lab, the subjects first read and signed the informed consent letter and then were randomly assigned to view one group of images from each setting, for a total of three groups of photographs. The photographs were displayed on the screen for 10 s each in random order to avoid the effects of a fixed order. This specific timespan for observation was derived from prior similar studies [52,60]. Participants were asked to observe the images freely, without any task in mind, because this is how people usually observe landscapes in real life [50]. During the experiment, the subjects were seated at a distance of approximately 50 cm from the color monitor. Before each test, brief instructions were given to the participant, and a 9-dot calibration procedure was executed to match the pupil-center/corneal reflection relationship with the specific x-, y-coordinates of the fixed dots [51]. As a result, an accurate calibration over the entire screen was achieved. To eliminate the effect of unintentional movements or eye breaks, the same calibration procedure was repeated for every image [50]. Before each trial, the participants were informed to look at a dot shown on the center of a blank screen. This was carried out to reduce measurement errors and ensure consistency in the initial conditions of the observation path of each photo [50].

During the experiment, the participants were prohibited from speaking to ensure their full concentration and were asked to use a chin rest to restrict head movements, thus eliminating any deviations. However, the participants were allowed to take a break at any time to avoid the effects of eye fatigue caused by repeatedly looking at a monitor [61]. Fatigue can cause a decrease in fixation count [62] and in the accuracy of observation [63].

After the eye-tracking experiment, the participants were asked to assign ratings of preference and perceived complexity for the photos on a seven-point scale. Participants were asked to rate the photos after the experiment to avoid influence on their viewing patterns in advance and to ensure a free viewing pattern to increase the accuracy of the eye-tracking measurements. In addition, the participants also provided basic demographic information, such as gender and age.

2.5. The Measurement of Fractal Dimension

Objective landscape complexity was measured in terms of fractal dimension. Fractal dimension can be calculated using different methods, including the box counting method, divider method, and area–perimeter method [39]. Of those listed, the box counting method is the most used approach to measure fractal dimension among the studies concerning fractal dimension and landscape preference [39]. The fractal dimension using box counting can be used as a comparative measure of visual complexity to quantify the change in landscape [64]. The box counting method involved dividing the graph to be measured into small grids of equal side length δ and calculating how many small grids the pattern occupied. The current study also employs the box counting method to estimate the fractal dimension of landscapes using Fractalyse 2.4. Developed by Gilles Vuidel in 2006, this software was initially developed to measure fractal dimension of built-up areas of cities [65]. Thus, it is particularly suitable to study the fractal dimension of built urban forest landscapes.

2.6. Statistical Analysis

Statistical analysis was conducted with SPSS 23.0 software. Firstly, objective landscape complexity and the mean of subjective landscape complexity for every photograph were computed. Spearman's correlation analysis was conducted to explore the relationship between landscape design intensity and objective and subjective landscape complexity. A one-way analysis of variance (ANOVA) was conducted within each group of images and each type of setting to determine whether participants' preference ratings were significantly different among the four design intensities, followed by a post hoc pairwise comparison using Tukey's Honestly Significant Difference (HSD) test to determine where the difference occurred. As the eye-tracking data were not parametric, a nonparametric Kruskal–Wallis test was conducted to examine whether participants' eye movement metrics were significantly different among different design intensities within each type of setting. Finally, Spearman's correlation analysis and linear regression analysis were employed to explore the associations between objective and subjective landscape complexity, preference, and eye movement metrics. The ratings for each image were calculated by the mean value of all participants, while the ratings for each type of setting were determined by the mean score of two related pictures.

3. Results

3.1. Objective and Subjective Landscape Complexity

The results of the objective and subjective landscape complexity measurements of each image are presented in Figure 2. All objective landscape complexity values ranged between 1.814 and 1.911, which corresponds with the standard range of fractal dimensions (fractal dimensions normally range between 1 and 2). With respect to subjective landscape complexity, the images that displayed slight design intensity were regarded as having the lowest level of complexity in lawn settings A, path settings A and B, and waterscape settings B. However, the images that displayed high design intensity were regarded as having the highest level of complexity across the six groups of settings.

Additional Spearman's correlation analysis results (Table 1) revealed that except in lawn settings B, landscape design intensity has a significant positive or negative relationship with objective complexity in different groups of settings. The relationships between design intensity and subjective complexity in the six groups of settings were all positive. Additionally, significant positive relationships between design intensity and subjective complexity were found in each type of setting, while design intensity positively associated with objective landscape complexity only in lawn and path settings.

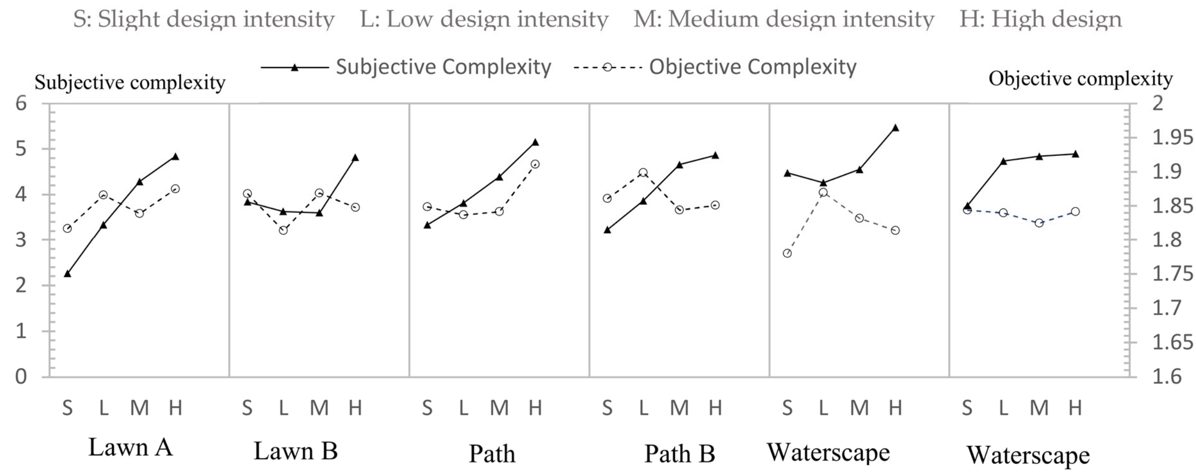

Figure 2. Objective and subjective landscape complexity for each image.

Table 1. Correlations between landscape design intensity and complexity in each group and type of settings.

Complexity	Landscape Design Intensity								
	Lawn A	Lawn B	Lawn	Path A	Path B	Path	Waterscape A	Waterscape B	Waterscape
OLC	0.80 **	0.00	0.39 ***	0.40 ***	−0.60 ***	0.15 *	0.20 *	−0.40 ***	−0.15 *
SLC	0.71 ***	0.33 ***	0.53 ***	0.63 ***	0.60 ***	0.61 ***	0.34 ***	0.41 ***	0.37 ***

Note: OLC: objective landscape complexity; SLC: subjective landscape complexity; *: $p \leq 0.05$, **: $p \leq 0.01$, and ***: $p \leq 0.001$.

3.2. Comparison of Preference for Each Setting

The mean preference rating for each image and each type of setting is shown in Figure 3. Excepting path settings A and the type of path settings, the photos with high design intensity received higher preference scores than their three counterparts. Additional Spearman's correlation analysis of lawn, path, and waterscape settings revealed that the correlation coefficients between landscape design intensity and preference were 0.326, 0.332, and 0.352 respectively. The ANOVA results indicate that all preference ratings were significantly different in each group (excepting path settings A) and in each type of setting (F values ranged between 3.464 and 16.508). Furthermore, the post hoc pairwise comparison results using Tukey's HSD test are presented in Table 2. These results indicate that in terms of all types of settings, the pairwise comparisons of preference scores between slight and high design intensity were significantly different. However, in terms of each group of setting, the pairwise comparisons of preference between slight and high design intensity in lawn settings B was not significant. In all types of settings and in each group of settings, medium vs. high design intensity in terms of preference were nonsignificant. The results seem to indicate that the effect of landscape design intensity on the increase in preference is linked to landscape types.

3.3. Marginal Effect of Landscape Design Intensity on Preference Ratings

To further explore the effect of landscape design intensity on increased preference, we calculated the marginal effects of design intensity on landscape preference scores (Figure 4). In terms of the six groups of settings, the marginal effects of low design intensity were only higher than those of medium and high design intensity in lawn settings A. However, the marginal effects of high design intensity were only higher than those of low and medium design intensity in waterscape settings B. In addition, the marginal effects of medium design intensity were higher than those of low and high design intensity in other groups of settings. For the types of lawn and path settings, the marginal effects of medium design intensity were greater than those of low and high design intensity. However, for the type of waterscape settings, the marginal effects of high design intensity were greater than those of low and medium design intensity. These results further indicate that the marginal effect of medium design intensity on preference was greater than that of low and high design intensity in most cases, and the influence of design intensity on improved preference was dependent on the landscape type.

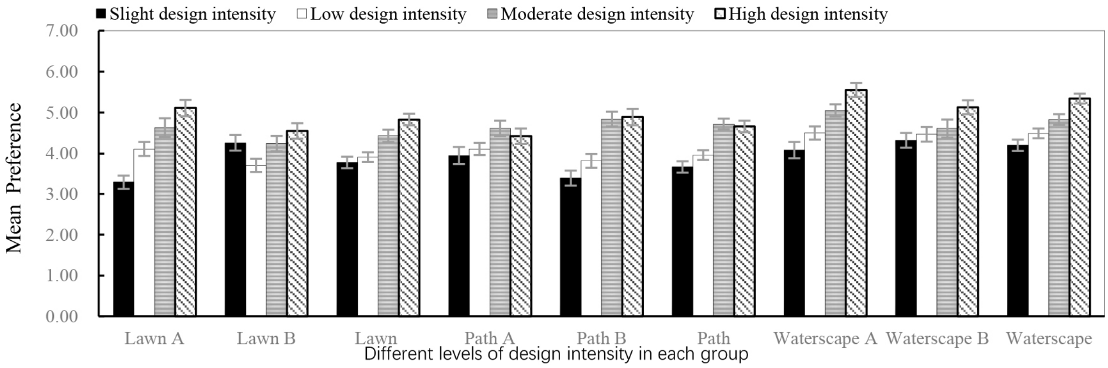

Figure 3. The mean of participants' preference ratings for the four images in each group. Error bar: standard error.

Table 2. Tukey's HSD test results for individuals' preference in groups.

I	J	Mean Difference (I–J)							
		Lawn A	**Lawn B**	**Lawn**	**Path B**	**Path**	**Waterscape A**	**Waterscape B**	**Waterscape**
S	L	−0.82 **	0.55	−0.13	−0.42	−0.29	−0.42	−0.16	−0.29
	M	−1.34 ***	0.03	−0.66 **	−1.45 ***	−1.05 ***	−0.97 ***	−0.29	−0.63 **
	H	−1.82 ***	−0.29	−1.05 ***	−1.50 ***	−0.99 ***	−1.47 ***	−0.82 *	−1.14 ***
L	M	−0.52	−0.53	−0.53*	−1.03 **	−0.76 ***	−0.55	−0.13	−0.34
	H	−1.00 **	−0.84 **	−0.92 ***	−1.08 ***	−0.70 **	−1.05 ***	−0.66	−0.86 ***
M	H	−0.47	−0.32	−0.39	−0.05	.07	−0.50	−0.53	−0.51

Note: S: slight design intensity; L: low design intensity; M: medium design intensity; H: high design intensity; *: $p \leq 0.05$, **: $p \leq 0.01$, and ***: $p \leq 0.001$.

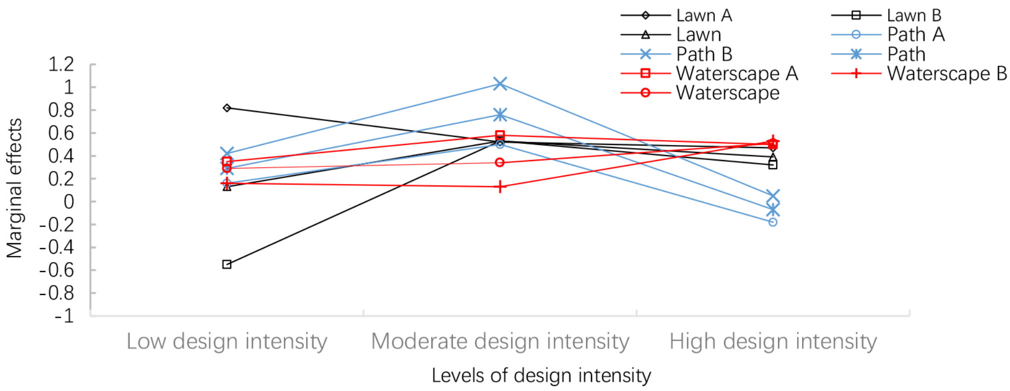

Figure 4. Marginal effects of three design intensities on landscape preference in each group and type of landscape.

3.4. Comparisons of Eye Movement Metrics among Different Levels of Design Intensities within Each Type of Setting

The Kruskal–Wallis test results are presented in Table 3. They reveal that there were no significant differences in any eye movement metrics between images with different design intensities in the type of path settings. There was also no significant difference in average saccade amplitude between images with different design intensities in the types of lawn (χ^2 = 1.165, p = 0.761) and waterscape settings (χ^2 = 6.121, p = 0.106). However, significant differences were detected in fixation count, average fixation duration, and saccade count between imagines with various design intensities in the path and waterscape landscapes. Additional pairwise comparison suggests that the fixation count and saccade count for images with high design intensity were significantly more than those with slight design intensity ($p < 0.01$). In addition, the average fixation duration for photographs with high design intensity was significantly shorter than that of images with slight design intensity ($p < 0.01$).

Table 3. The Kruskal–Wallis test results of eye movement metrics within each type of setting.

Settings	Eye Movements	N	χ^2	df	Mean Rank					Real Mean Values			
					Sligh	Low	Medium	High	p	Sligh	Low	Medium	High
Lawn	FC	76	20.079	3	126.36	138.81	158.82	186.02	0.000	27.18	27.96	29.70	30.84
	AFD	76	12.310	3	173.01	161.29	150.59	125.11	0.006	332.17	331.88	292.84	285.66
	SC	76	19.013	3	127.59	139.33	157.28	185.81	0.000	26.50	27.29	28.92	30.14
	ASA	76	1.165	3	152.07	150.30	146.40	161.23	0.761	5.83	5.70	5.66	5.94
Path	FC	76	4.322	3	142.34	142.13	159.91	165.62	0.229	28.70	28.58	30.09	30.51
	AFD	76	3.202	3	159.43	163.30	144.95	142.31	0.361	358.25	324.29	288.40	283.41
	SC	76	4.604	3	142.16	141.95	159.07	166.82	0.203	27.92	27.83	29.33	29.86
	ASA	76	5.366	3	137.80	158.80	167.98	145.41	0.147	5.65	5.98	6.18	5.80
Waterscape	FC	76	14.179	3	124.84	148.18	160.12	176.86	0.003	27.30	28.84	30.17	31.07
	AFD	76	12.494	3	177.97	155.22	148.80	128.00	0.006	359.08	320.53	294.29	276.44
	SC	76	13.876	3	124.83	148.74	160.09	176.34	0.003	26.54	28.11	29.41	30.30
	ASA	76	6.121	3	160.94	167.16	135.06	146.84	0.106	5.71	5.90	5.45	5.51

Note: N: number of participants; χ^2: chi-square; df: degrees of freedom; FC: fixation count; AFD: average fixation duration; SC: saccade count; ASA: average saccade amplitude.

3.5. Identifying the Correlations between Landscape Eye Movements, Complexity, and Preference

The Spearman correlation analysis was conducted to determine whether preference levels were consistent with landscape complexity levels and whether the eye movement metrics were related to landscape complexity and preference (Table 4). Subjective landscape complexity was positively and significantly related to preference across three types of settings, while objective landscape complexity was not correlated with preference. In addition, both subjective and objective landscape complexity was found to be significantly and positively related to fixation count and saccade count and negatively related to average fixation duration in lawn settings. Moreover, subjective landscape complexity had a positive relationship with average saccade amplitude in path settings, while objective landscape complexity had a positive relationship with average saccade amplitude in waterscape settings.

Table 4. Correlations among eye movement parameters, preference andcomplexity.

	Lawn			Path			Waterscape		
	P	**OLC**	**SLC**	**P**	**OLC**	**SLC**	**P**	**OLC**	**SLC**
Fixation Count	0.19 **	0.14 *	0.23 ***	0.09	0.04	0.08	0.09	−0.11	0.07
Average Fixation Duration	−0.13 *	−0.12 *	−0.16 **	−0.08	−0.03	−0.08	−0.06	0.08	−0.07
Saccade Count	0.18 **	0.14 *	0.22 ***	0.09	0.04	0.08	0.09	−0.10	0.07
Average Saccade Amplitude	0.01	0.04	−0.05	0.02	−0.03	0.11 *	−0.09	0.11 *	0.00
OLC	0.02	-	0.19 **	−0.11	-	0.10	−0.05	-	−0.28 ***
SLC	0.53 ***	0.19***	-	0.50 ***	0.10	-	0.52 ***	−0.28 ***	-

Note: P: preference; OLC: objective landscape complexity; SLC: subjective landscape complexity; FC: fixation count; AFD: average fixation duration; SC: saccade count; ASA: average saccade amplitude; *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$.

Significant positive relationships between landscape preference and fixation count and saccade count, and negative association between preference and average fixation duration, were found only in lawn settings. However, further linear regression analysis revealed that none of the eye movement metrics were significant predictors for objective and subjective landscape complexity or for landscape preference. Additionally, linear regression analysis (Table 5) revealed that subjective landscape complexity was a positive predictor for landscape preference in the three types of landscapes. These results indicate that the significant relationship between eye movement parameters, landscape complexity, and preference is largely determined by landscape type.

Table 5. Regression results for the effect of landscape complexity on preference.

	Lawn				Path				Waterscape			
	B	SE B	β	*p*	B	SE B	β	*p*	B	SE B	β	*p*
Constant	2.17	0.20		<0.001	1.83	0.23		<0.001	1.86	0.28		<0.001
SLC	0.54	0.05	0.53	<0.001	0.58	0.05	0.53	<0.001	0.62	0.06	0.52	<0.001
Adjusted R2		0.28		<0.001		0.27		<0.001		0.27		<0.001

Note: OLC: objective landscape complexity; SLC: subjective landscape complexity.

4. Discussion

4.1. Landscape Design Intensity, Complexity, and Preference Ratings

This study revealed that variations in landscape design intensity make different contributions to objective and subjective landscape complexity and to landscape preference. As design intensity increased, participants' responses toward subjective complexity also consistently increased in lawn settings A, path settings A and B, and waterscape settings B (see Figure 2). However, this trend was not found in any groups of settings in terms of objective complexity. Previous studies have described landscape complexity arising from the diversity and richness of landscape elements and features [66,67]. In the present study, landscape design intensity was judged based largely on the amount or richness of artificial landscape elements. Thus, with higher design intensity, it is reasonable that the presence of increasing artificial landscape elements enhance participants' feeling of landscape complexity. With regards to the inconsistent trend between design intensity and objective landscape complexity, the reasons may be attributed to the greater amount of artificial landscape elements not being necessarily related to a higher number of occupied small grids. In addition, subjective landscape complexity was positively related to objective landscape complexity in lawn and path settings, while negatively related to objective landscape complexity in waterscape settings. This may further indicate that there are differences between subjective landscape complexity and objective landscape complexity of various green space settings, and participants perception of landscape complexity does not corresponded with fractal dimension. Additional studies using both subjective and objective approaches to measure landscape complexity would provide a more comprehensive insight into this and verify the inference of the present study.

Complexity has been identified as an important characteristic [29] and has been proven to be a good predictor of preference [30]. The current study also found that subjective landscape complexity had a significant positive relationship with landscape preference, regardless of landscape type. This finding supports Kuper's finding of a positive relationship between participants' ratings of complexity and preference [36], as well as the findings of some other research [29,38,68]. Moreover, this finding also echoes [69]'s landscape preference model, which defined complexity as an important construct of preference. However, it is worth noting that subjective landscape complexity positively contributed to preference in all three types of settings, while objective landscape complexity only significantly contributed to preference in lawn settings. This may be attributed to the different effects of design intensity on subjective landscape complexity and objective landscape complexity.

Overall, the study findings suggest that design intensity positively contributes to subjective landscape complexity across landscape types and positively influences respondents' preferences. When landscape architects design forest landscapes that suit public preference, they should prioritize and consider increasing design intensity by arranging artificial landscape elements or organize the landscape contents with a certain level of design intensity to increase individuals' perceived complexity. However, previous studies also indicated an inverted-U-shaped relationship between landscape preference and complexity [70,71], which means a moderate level of landscape complexity may obtain higher preference, and a high level of landscape complexity may lead to a decrease in individuals' preference. In addition, the marginal effect of medium design intensity on preference was greater than that of low and high design intensity in most groups of settings. Thus, creating landscapes with a medium level of complexity may be more suitable and reliable to increase individuals' preference in forest landscape design, which may also help to avoid overdesigning. Although determining a moderate level of complexity or design intensity may be difficult, comparisons among different landscape proposals may help determine which proposal may reflect a medium level of design intensity or complexity. In addition, the present settings with moderate design intensity in the present study would also serve as references.

4.2. Design Intensities, Complexity, and Eye Movement

There were significant differences in fixation count, average fixation duration, and saccade count among different design intensities in lawn and waterscape settings. This may largely account for the variations in landscape complexity, as design intensity positively contributed to subjective landscape complexity. Egaña et al. found that landscape complexity is strongly related with eye movement behaviors [72]. Wohlwill argued that as landscape complexity increases, the amount of exploratory activity in terms of eye movement seems to increase linearly [71]. Likewise, Dupont et al. found that the complexity of a given landscape has a great influence on visual exploratory activity, and that the increased complexity of the images can result in a greater fixation and saccade count [51]. In other words, there is a positive relationship between landscape complexity and the metrics of fixation and saccade counts. This is understandable, as studies have claimed that a more complex landscape provides a greater volume of information to process [71] and a greater interest value for the stimulus [70]. Part of our findings indicated there are more fixation and saccade counts for high design intensity settings than slight design intensity in lawn and waterfront settings, which also supports this notion.

However, we also detected nonsignificant differences in any eye movements between different design intensities in path settings. In addition, there was only significant positive relationship between average saccade amplitude and subjective landscape complexity in path settings. We speculated that the inconsistent results in the different settings are because, in the present study, participants' visual exploration was affected not only by landscape design intensity but also by the configuration of landscape components and landscape types. This speculation is in line with the notion that visual exploration is linked with landscape structure [69]. Another possible reason for the inconsistent results is that there may be a threshold for complexity. Perhaps complexity has a significant impact on eye movement metrics only when it reaches a certain threshold. This inference is supported by Dupont et al.'s findings that in heavily urbanized landscapes, if the number of built areas represented in an image reaches a threshold, the built areas will no longer catch the viewer's eyes [51]. In this study, the pictures within each group have a similar landscape structure and may not differ much from their counterparts, which means the complexity between different images within most of the groups may not reach the necessary threshold.

4.3. Preference and Eye Movements

It was also found that preference and eye movement patterns were inconsistent across the three settings. Significant relationships between fixation count, average fixation duration, saccade count, and preference were found only in the lawn landscapes. This indicated that the associations between eye movements and preference were determined by landscape types. Supporting our results, a recent study by Huang and Lin [73] revealed strong relationships between landscape preference and fixation count in mountain, aquatic, and forest landscapes, and that people have different preferences and viewing behaviors when observing different landscape types. The present results do not show any significant role of eye movement metrics in predicting preference. Similarly, an earlier study focusing on nightscape preference demonstrated that total fixation duration, total scan path length, and total time spent on images were not good predictors of preference [74]. Perhaps this could also be attributed to the influence of different landscape configuration patterns or image contents. For example, people usually prefer a natural landscape to an urban landscape. However, higher fixations and saccades for urban landscapes were observed despite people's lesser preference for urban landscapes [51].

4.4. Limitations and Further Research

While we selected three different but commonly seen urban forest landscape settings and classified four design intensities for each type of setting, the study only used a small sample of landscape scenes. A larger number of settings with different landscape components and a larger sample of respondents should be considered in future research to enhance the validity of the findings. Another limitation is that we only measured the complexity of the landscape. Although landscape complexity has been regarded as a good indicator for describing landscape characteristics, further studies measuring more variables, such as biodiversity, coherence, and naturalness, could be helpful to strengthen understanding of the link between landscape complexity and preference. Following existing studies [52,60], participants' viewing time for one image was limited to 10 s. However, this may skew the eye-tracking results. Additional studies should allow participants to observe the images freely without a time limit. Additionally, although the same group of landscapes were kept the similar colors of water and sky, the brownish color of the water and the white sky may have affected the participants ratings. Finally, we measured objective landscape complexity using fractal dimension with the box counting method, which is recommended by many architects. Additional studies may conduct similar research by using spectral entropy or other approaches to measure objective landscape complexity.

5. Conclusions

This study combined objective and subjective landscape complexity to investigate the effects of landscape design intensity on preference and eye movement. Our study suggested that design intensity can positively affect individuals' subjective landscape complexity and promote preferences across various kinds of landscapes, but either significantly or nonsignificantly contribute to objective landscape complexity in different types of landscapes. The significant relationship between objective or subjective landscape complexity, or preference and eye movement metrics, was also dependent on landscape types. However, none of the eye movements were significant predictors for preference in any landscape. These results can enhance our understanding of landscape design intensity in relation to preference and eye movements. They also provided valuable information for urban forestry design to improve public preference. For practitioners, incorporating these findings into the design process to create forest landscapes with medium design intensity could contribute to improved designs for future urban forests in China. For researchers, further research regarding landscape complexity, preference, and eye movements should include more landscape types, as well as both objective and subjective measures of complexity. Thus, the present study not only enriches current research into landscape complexity but also provides a reference for those seeking to promote the outcome of urban forest landscape design. Additionally, it also demonstrates the potential contributions of eye-tracking technology in the visual landscape preference study field.

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