Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Quantifying Spatial Patterns of Rockery–Plant Arrangements in Suzhou Classical Gardens: A Coding Framework and Perceptual Evaluation

yakun chang
Jiangsu University
Danqing Mo
Jiangsu University
Danyang Zhuang
Jiangsu University
Yingnan LI
lyn48512@hotmail.com

Jiangsu University

Article

Keywords: rockery landscape, spatial coding, eye-tracking experiment, Suzhou classical gardens, micro-scale landscape

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11143089/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Quantifying Spatial Patterns of Rockery–Plant Arrangements in Suzhou Classical Gardens: A Coding Framework and Perceptual Evaluation

Yakun Chang [a], Danqing Mo [a], Danyang Zhuang [a], Yingnan Li [a,b,*],

[a] *School of Design and Art, Jiangsu University, Zhenjiang 212013, China*

[b] *OJEong Resilience Institute, Korea University, Seoul 02841, Republic of Korea*

[*] *Correspondence: Yingnan Li,*

Email: lyn48512@hotmail.com

Abstract: Traditional cultural landscapes preserve not only physical forms but also implicit design knowledge developed through long-term human practices. However, such knowledge is often transmitted through textual interpretation and expert experience, making it difficult to describe, compare, and analyze systematically. This study examines how the spatial knowledge embedded in Suzhou classical gardens can be transformed into measurable evidence through the analysis of rockery–plant configurations. A structured coding framework was developed to represent three interconnected dimensions of garden composition: rockery features, plant features, and their relative spatial relationships. The framework was applied to 23 micro-scale courtyard landscapes from the Lingering Garden and Lion Grove Garden in Suzhou. Combining field documentation, eye-tracking-based identification of visual focal elements, and perceptual evaluation, this study investigated recurring spatial configurations and their relationship with contemporary visual interpretation. The analysis revealed recurrent patterns in rockery–plant arrangements, including the layered relationship of foreground plants, middle-layer rockeries, and background trees. Taihu stone represented the dominant rockery material, while low shrubs and taller trees frequently contributed to different vertical layers of courtyard composition. Perceptual results indicated that these recurring configurations showed certain correspondence with contemporary visual responses, although no single arrangement demonstrated universal preference. The findings demonstrate how traditional landscape knowledge can be translated from tacit design practices into structured spatial evidence. This approach provides a possible pathway for connecting heritage interpretation, human perception studies, and contemporary landscape research.

Keywords: rockery landscape; spatial coding; eye-tracking experiment; Suzhou classical gardens; micro-scale landscape

1. Introduction

Chinese classical gardens have long valued the coordination between stones and plants[1,2]. The deliberate orchestration of rockeries and plantings creates microcosmic landscapes that emulate the grandeur of natural scenery within confined urban or residential spaces. In The Garden Manual, Cheng Ji argued that rock arrangement should vary with the character of the stone[3]. In On Chinese Gardens, Congzhou Chen also emphasized the visual logic of combining stones with plants[4]. These theories indicate that the arrangement of rockeries and plants reflects systematic spatial principles developed through traditional garden practices. Research on Chinese classical gardens has gradually moved beyond historical description and summaries of traditional practice. It now makes increasing use of modern analytical tools[5,6]. These tools are used to study spatial structure, visual perception, and digital representation. Researchers have used terrestrial laser scanning, UAV(Unmanned aerial vehicle) photogrammetry, and semantic-based 3D information modeling to document gardens and rockeries in a more systematic way[7–9]. Eye-tracking has also been introduced to link visual attention to perceptual responses, while spatial diagramming, space syntax, BIM(Building information modeling), and GIS(Geographic information system) have supported more explicit analysis of layout, sequence, and narrative structure[10–15]. These studies have deepened our understanding of classical gardens and opened new possibilities for making traditional spatial characteristics more analyzable. At the same time, rockery and plants are the two elements that most directly shape sightlines, spatial layering, and artistic mood in courtyard landscapes[16,17]. Together they build the garden's three-dimensional structure. Rockery is not only a visual object. It also helps shape terrain, divide space, and guide movement[18]. Plants then strengthen or soften these effects through their size, form, and seasonal change[5]. The traditional principle of

“scenes changing as steps move” is supported by the coordinated arrangement of stone and plants[1], through which shifting contrasts of solid and void, hard and soft, texture, season, sound, and scent create a continuously changing multisensory spatial experience[19]. Their coordination still needs finer and more systematic quantitative study.

Related work in cognitive science, environmental psychology, and semantic analysis further suggests that complex environments can be interpreted through identifiable features and relationships[20–24]. In garden and landscape studies, this perspective has supported research on textual interpretation, visual recognition, digital footprints, point-cloud-based modeling, and other forms of structured spatial analysis[12,20,25–29]. These developments provide important methodological foundations for the quantitative study of classical garden spaces.

However, current research still has two clear limitations. First, rockeries and plants are often discussed separately, while their configurational relationships lack systematic quantitative description. This is especially true for relative positions such as front and back, left and right, and high and low[5,30]. Second, although digital tools and quantitative methods have been introduced, few studies have transformed traditional design knowledge into a structured analytical framework that allows comparison across different spatial cases. This makes cross-sample comparison and pattern identification difficult[30–33].

To address these gaps, this study asks three main questions. First, how can a systematic and replicable feature coding system be developed? Such a system should describe the compositional features of rockery and plants, as well as their spatial relationships, in courtyards of Suzhou classical gardens. Second, in micro-scale courtyard landscapes, what relatively stable spatial organization patterns can be identified around the visual focus formed by rockery and plants? Third, to what extent can these high-frequency structural patterns be translated into heuristic reference for modern micro-scale green

space design, and do they show directional compatibility with contemporary aesthetic perception?

Accordingly, this study develops a coding system structured around rockery features, plant features, and spatial relationships. The aim is to convert traditional garden-making techniques into operational and verifiable variables. It also aims to provide a standardized framework for the quantitative description of traditional garden wisdom. Based on coded real samples from Suzhou classical gardens, this study examines micro-scale courtyard landscapes and identifies recurring patterns in the coordinated arrangement of rockeries and plants. It further compares structural features from real samples with visual perception results from experimental scenes, providing evidence for understanding how traditional spatial patterns are interpreted by contemporary observers. The study contributes a transferable coding framework that transforms implicit garden-making knowledge into measurable spatial relationships.

2. Study Area and Methods

The workflow consists of three main steps (Figure 1). First, coded real samples from micro-scale courtyards in Suzhou classical gardens are analyzed. Second, visual focus identification is combined with sample statistics to identify relatively stable spatial organization patterns in the coordinated arrangement of rockery and plants. Third, the structural features of real samples are compared with perceptual evaluation results from virtual scenes to assess their directional correspondence with contemporary perception.

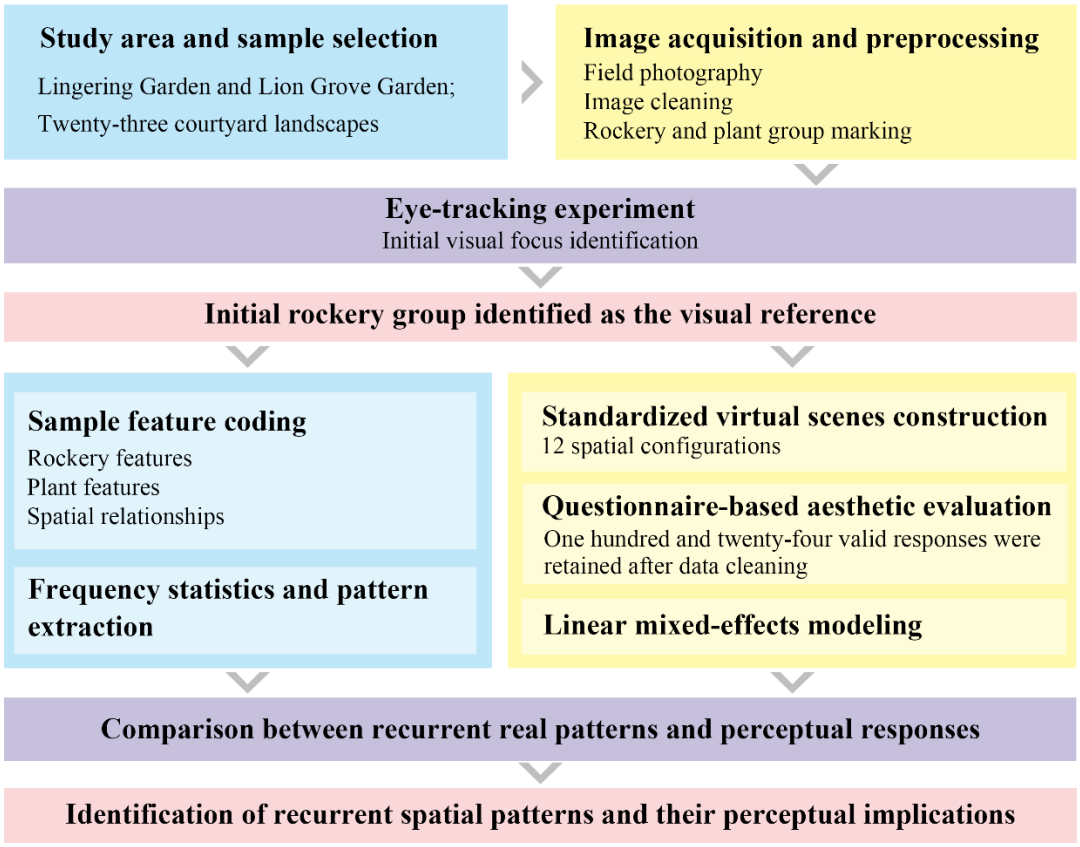


Figure 1. Workflow of the study

2.1 Study Area and Sample Selection

This study takes the Lingering Garden and Lion Grove Garden in Suzhou as case sites. These two gardens were selected because they preserve representative courtyard structures and layered planting arrangements. As important examples of Suzhou classical gardens, they provide suitable cases for examining how traditional spatial principles are expressed through the relationship between rockeries and plants. The study focuses on small courtyard spaces. Each sample is smaller than 20 m² and clearly enclosed by buildings or walls. According to Liu Dunzhen's distinction between "courtyard" and "garden", such spaces are important carriers of the design logic of "creating a larger realm within a small space." Based on these criteria, 23 courtyard landscapes were selected as samples (Figs. 2 and 3). The samples cover different stone types and different combinations of trees, shrubs, and groundcover plants. Detailed sample codes are listed in Table 1. Although the sample size is limited, the selected

courtyards represent typical small-scale spatial units where rockery–plant relationships are clearly observable and comparable.

Table 1 Selected Samples and Their Codes

No.	Name	Code	No.	Name	Code	No.	Name	Code
1	Entrance of the Lingering Garden	L-ENT	9	Waterscape north of the Bonsai Garden, Lingering Garden	L-PJ-N-W	17	South of Yanyu Hall, Lion Grove Garden	SZL-YY-S
2	Southeast corner of the Peony Garden, Lingering Garden	L-MD-SE	10	West side of the lake, Lingering Garden	L-L-W	18	Southwest of Fan Pavilion, Lion Grove Garden	SZL-S-SW
3	Jigu Dexiugeng, Lingering Garden	L-JG	11	Guanyun Peak, Lingering Garden	L-GY	19	West side of the exit, Lion Grove Garden	SZL-OUT-W
4	Northwest of Huanwo Dushu Zhai, Lingering Garden	L-HW-NW	12	Southeast of Zhibai Pavilion, Lion Grove Garden	CZL-ZB-SE	20	Xiaofang Hall, Lion Grove Garden	SZL-XF
5	East Garden corridor, Lingering Garden	L-DYLD	13	Southeast of Guwusong Garden, Lion Grove Garden	SZL-GWS-SE	21	East side of Guwusong Garden, Lion Grove Garden	SZL-GWS-E
6	East corner of the rest pavilion in the Peony Garden, Lingering Garden	L-MD-T-E	14	West side of Guwusong Garden, Lion Grove Garden	SZL-GWS-W	22	Northeast of Zhibai Pavilion, Lion Grove Garden	CZL-ZB-NE
7	East side of Wufeng Xianguan, Lingering Garden	L-WFX-E	15	East side of Jiejia Bridge, Lion Grove Garden	SZL-JJ-E	23	East side of the exit, Lion Grove Garden	SZL-OUT-E
8	East-side path of Rihua Peak, Lingering Garden	L-RH-E-R	16	West side of Lixue Hall, Lion Grove Garden	SZL-LX-W			

2.2 Data Collection

2.2.1 Image Collection

Field photographs were taken in the Lingering Garden and Lion Grove Garden on November 23, 2024, from 12:00 to 16:30. They were collected to create standardized visual samples for subsequent spatial coding and perception analysis. A Canon EOS M50 Mark II was used. The shooting height was fixed at 1.5 m. All images were taken in horizontal format from the main viewing point and from a frontal angle. In post-processing, non-target elements such as the sky, ground, and visitors were removed. Only the rockery and plant subjects were kept. Rockery groups and plant groups were

then identified and labeled. In the end, 23 standardized experimental images were produced (Table 2).

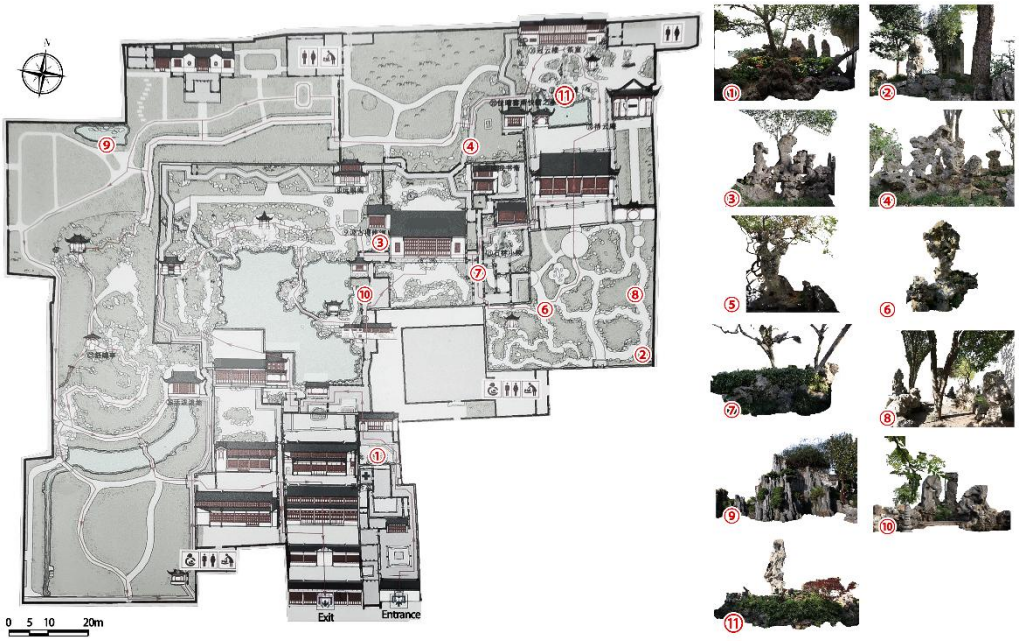


Figure 2 Sample collection sites in Lion Grove Garden

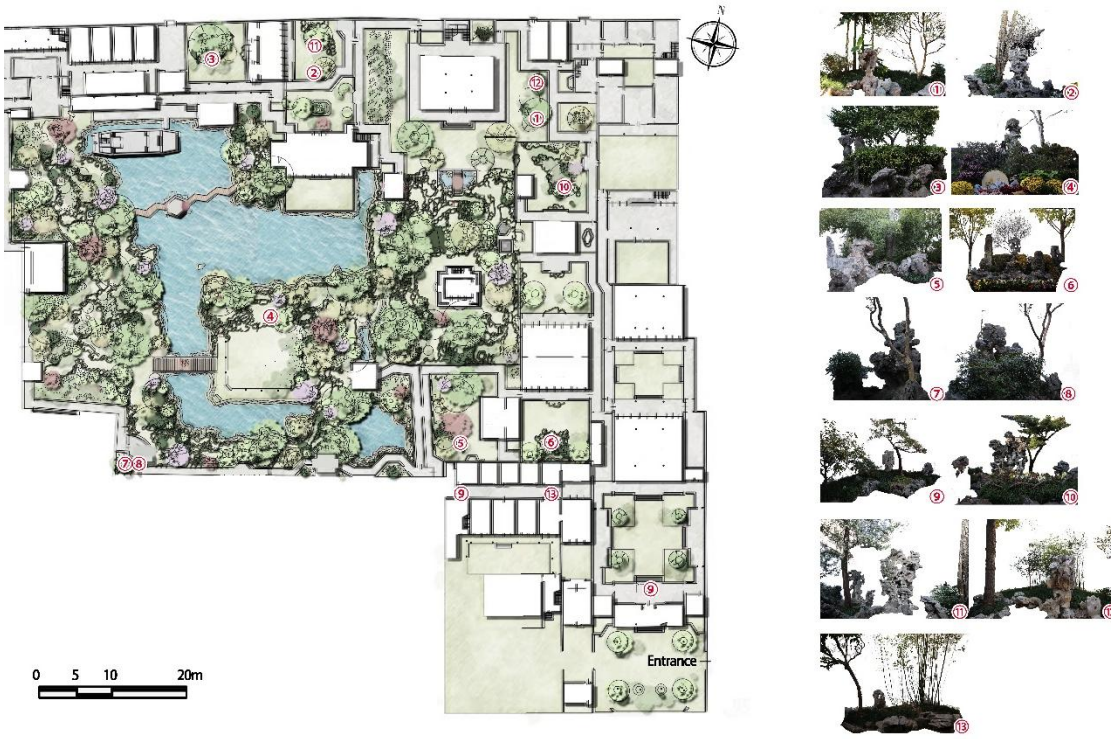
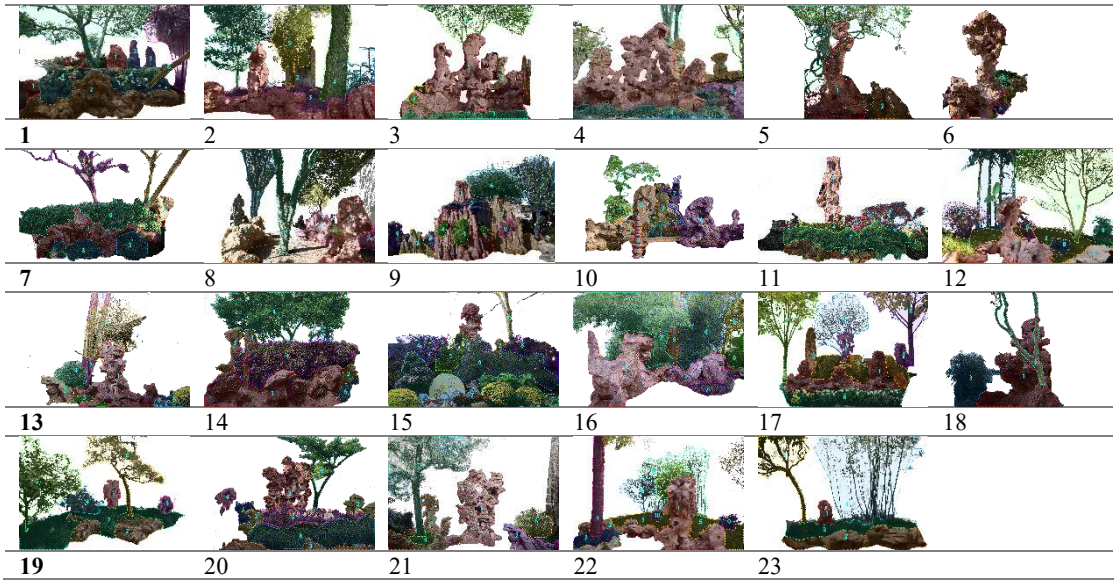


Figure 3 Sample collection sites in the Lingering Garden

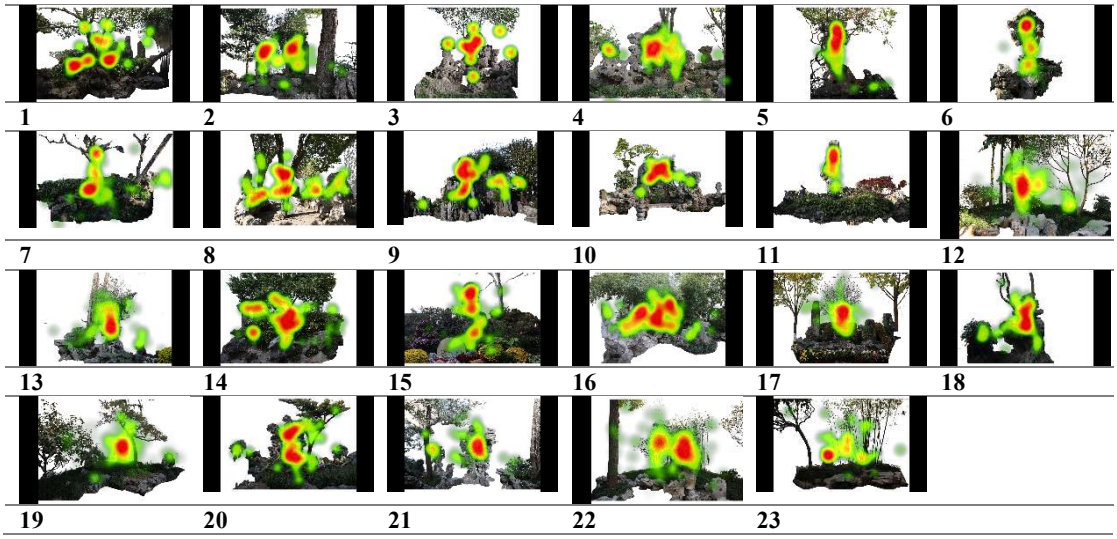
Table 2 Marked Rockery and Plant Groups in the Processed Images



2.2.2 Eye-Tracking Experiment

To identify the initial visual focus in each sample, an eye-tracking experiment was conducted with 10 participants. None of the participants had a background in landscape architecture. They were 22–28 years old and had normal or corrected-to-normal vision, which helped reduce the influence of professional knowledge on initial visual attention. The experiment was conducted under stable lighting conditions. The 23 processed images were presented in random order. Each image was displayed for 5 s, after which participants provided a brief rating. Eye movement data were recorded using a Tobii Pro Fusion eye tracker at 120 Hz (Tobii AB, Sweden), and heat maps were generated in Tobii Pro Lab (Tobii AB, Sweden). Based on the combined results, the "initial rockery group" was identified for each sample[12]. This group was then used as the reference point in later spatial relationship analysis (Table 3). The image ratings were not included in the analyses reported in this study. All participants provided informed consent before the experiment.

Table 3 Heat-Map Results



2.3 Feature Coding System

2.3.1 Coding of Rockery Features

Rockery features were represented in three dimensions: technique, height, and stone type. Rockery techniques were classified with reference to Liu Dunzhen's Suzhou Classical Gardens[34]. Eighteen basic types were identified and marked with letters. Subtypes were marked with the numbers 1–3 (Table 4). Height was divided into six categories based on ergonomic scale (Table 5). Stone type was divided into Taihu stone, yellow stone, and bamboo-shoot stone (Table 6)[32]. For example, "S3A2RV1" means that the rockery group is in height class S3, uses the techniques of double flat placement and stone piecing, and is made of Taihu stone.

Table 4 Coding of Rockery Techniques

Technique Name	Explanation			
	Code	1	2	3
Flat Placement	A	 one stone laid flat and steady	 two stones laid flat in sequence	 three stones laid flat in sequence
Horizontal Linking	B	linking stones side by side		
Vertical Jointing	C	joining stones upward in a vertical way		
Arched Support	D	forming an arched or bridging support		

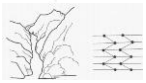
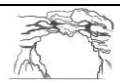
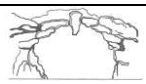
Suspended Linking	E	linking stones in a hanging or overreaching way	
Front Suspension	F	hanging a stone outward on the front face	
Side Suspension	G	hanging a stone downward from the side	
Stone Gap	H	creating or using a natural gap between stones	
Blade-like Upright Stone	I	setting a stone upright like a blade or peak	
Floating Projection	J	making a stone appear light, projecting, or floating	
Cantilevered Projection	K	projecting a stone outward like a cantilever	
Pressing	L	pressing or weighing one stone against another	
Layered Stacking	M	stacking stones layer by layer	
Vertical Setting	N	setting stones in an upright vertical manner	
Under Support	O	supporting upper stones from below	
Hooking	P	hooking one stone against another	
Padding Support	Q	padding or wedging stones to stabilize them	
Stone Piecing	R	piecing stones together into a unified whole	
Distance Views	Y		 
		Elevated Distance — viewing upward into height and distance	Deep Distance — viewing inward into depth and recession
			Level Distance — viewing across broad and level distance
Rock Cave	T		 
		Beam-and-Column Type — cave formed with beam-and-post support	Cantilever-Beam Type — cave formed with projecting support
			Arched Type — cave formed with an arched opening

Table 5 Coding of Rockery Height

Rockery Height (m)	**0–0.4**	**0.4–0.8**	**0.8–1.7**	**1.7–2.5**	**2.5–4**	**≥4**
Code	S1	S2	S3	S4	S5	S6

Table 6 Coding of Rockery Stone Types

Stone Type	**Taihu stone**	**Yellow stone**	**Bamboo-shoot stone**
Code	**V1**	**V2**	**V3**

2.3.2 Coding of Plant Features

Plant features were represented in eight dimensions: height, type, growth form, leaf habit, leaf shape, crown density, crown width, and botanical category (Table 7)[35–38]. Plant height was divided into eight classes, from A1 to A8. Plant type was divided into five classes, from B1 to B5. The other dimensions describe plant form and visual characteristics. All letters and numbers are nominal labels. They do not indicate rank or value. "Not applicable" was allowed when necessary. For example, "A8B5C2D1E1F2G4H4" refers to a tree over 8 m high, with a horizontal form, evergreen broad leaves, medium crown density, a crown width of 3–5 m, and a timber/tree category.

Table 7 Coding of Plant Morphological Features

Category	Code	1	2	3	4	5	6	7	8
Height (m)	A	0–0.1	0.1–0.3	0.3–0.8	0.8–1.2	1.2–1.8	1.8–2.5	2.5–4	≥4
Type	B	Groundcover plants	Low shrubs and herbaceous plants	Small shrubs and medium-height herbaceous plants	Medium shrubs and tall herbaceous plants	Tall shrubs and trees			
Growth form	C	Vertical	Horizontal	Clumped					
Leaf habit	D	Deciduous	Evergreen						
Leaf shape	E	Broadleaf	Needleleaf						
Crown density	F	Sparse	Medium	Dense					
Crown width (diameter / m)	G	0–1	1–2	2–3	3–5	5–8	≥8		
Botanical category	H	Ornamental flower	Ornamental fruit	Ornamental foliage	Timber / shade tree	Vine	Bamboo	Herbaceous / aquatic	

2.3.3 Coding of Spatial Relationships

Beyond individual characteristics of rockeries and plants, the spatial relationship between these elements represents an important aspect of traditional garden composition. Therefore, this study recorded relative positions and vertical relationships

using the initial visual focus as a reference point. Spatial relationships were coded with the initial rockery group identified by eye tracking as the reference point. Other rockery groups and plant groups were then coded relative to this point. The coding system has two dimensions: planar relationship and vertical relationship. The planar relationship uses a nine-grid reference and is reduced to four main directions: 1 (front-left), 2 (rear-left), 3 (rear-right), and 4 (front-right) (Figure 4a). The vertical relationship is based on the height of the initial rockery group. It includes three categories: 1 (clearly higher than the initial rockery), 2 (similar in height to the initial rockery, or higher than half of it), and 3 (lower than half of the initial rockery) (Figure 4b). For example, “43” means that the object is located at the front-right of the initial rockery and is lower than half of its height.

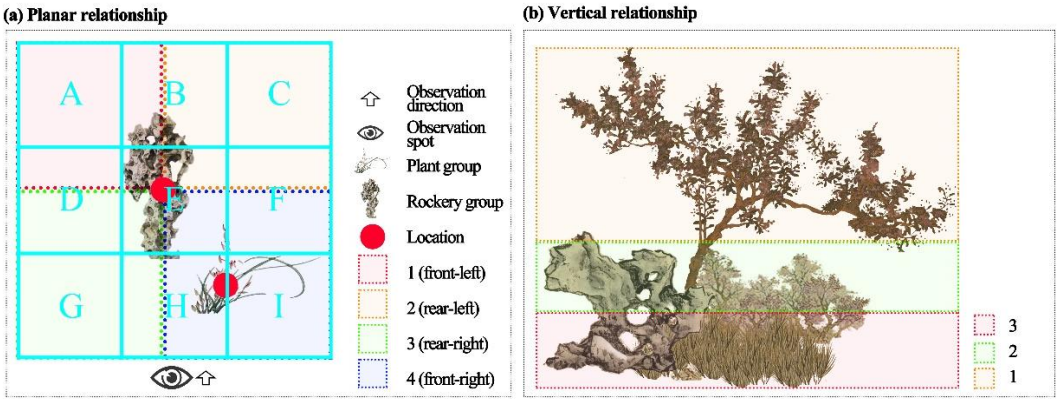


Figure 4 Diagram of spatial relationships

Rockery-related and plant-related variables were coded separately by two researchers. After the first round of coding, the results were cross-checked item by item. For ambiguous cases, the researchers repeatedly consulted the original images and relevant literature definitions until a consensus was reached. The final dataset was confirmed jointly.

2.4 Questionnaire Survey and Experimental Materials

Recent landscape assessment studies have shown that combining quantitative evaluation with user perception can better capture differences in visual quality, cultural

connotation, and user experience[39]. Based on the statistical results of feature coding (see Section 3.1), high-frequency feature combinations were selected to build standardized experimental materials. By controlling the planar position of plants relative to the initial rockery (positions 1–4) and their vertical relationship (heights 1–3), 12 spatial configuration scenes were created.

To evaluate aesthetic perception of these 12 scenes, an online questionnaire was designed. The corresponding rendered images were shown in random order (Figure 5). Participants rated each scene on a 5-point Likert scale from four dimensions: formal beauty, artistic form, spatial layout, and cultural ambiance. The survey was distributed on January 10–11, 2025. A total of 135 questionnaires were collected. After data cleaning, 124 valid responses were retained. Among the valid respondents, 63 were male and 61 were female. Fifty-five had a landscape-related background, and 69 did not. Most respondents were between 15 and 30 years old.



Figure 5 Example of the questionnaire survey

2.5 Data Analysis

First, frequency statistics and descriptive analysis were conducted on the coded features of all rockery groups (N = 60) and plant groups (N = 95) in the 23 samples. The goal was to identify the overall distribution of stone types, techniques, plant types, and other features (see Section 3.1). Next, using the initial rockery group identified by eye tracking as the reference point, the planar and vertical relationships of the non-initial rockery groups (N = 37) and plant groups (N = 95) were counted. This was used to identify high-frequency spatial patterns (see Section 3.2).

For questionnaire data, the mean of the four aesthetic dimensions was used as the overall score. A linear mixed-effects model was then built. Planar position, vertical height, and their interaction were used as fixed effects. Participants were treated as random intercepts. Scene was included as a variance component. This model was used to test the effect of spatial relationships on overall perceptual evaluation. In addition, a joint mixed-effects model was built with single-dimension ratings as the dependent variable. This was used to compare how different aesthetic dimensions responded to different spatial combinations.

3. Results

3.1 Structured representation of rockery and plant characteristics

3.1.1 Rockery Features

The analysis of the 60 rockery groups showed a clear preference for specific material and construction characteristics (Figure 6). Taihu stone was the dominant rockery material, accounting for 72.7% of all recorded rockery groups. Among the construction techniques, stone piecing was the most frequently observed technique (35.0%), followed by horizontal linking and arched support (both 20.0%) and flat placement (18.3%). In terms of height, S3 rockeries (0.8–1.7 m) represented the largest proportion (31.7%), followed by lower categories including S1 and S2.

These results indicate that courtyard-scale rockery groups showed relatively consistent material and structural characteristics, characterized by the frequent use of Taihu stone, moderate vertical scales, and integrated construction techniques. Compared with large-scale rockeries that emphasize dramatic spatial transformation, courtyard rockeries tended to maintain a restrained relationship with surrounding plants and architectural spaces. The frequent occurrence of stone piecing and flat placement further suggests that structural integration and visual stability were important characteristics of small-scale rockery construction.

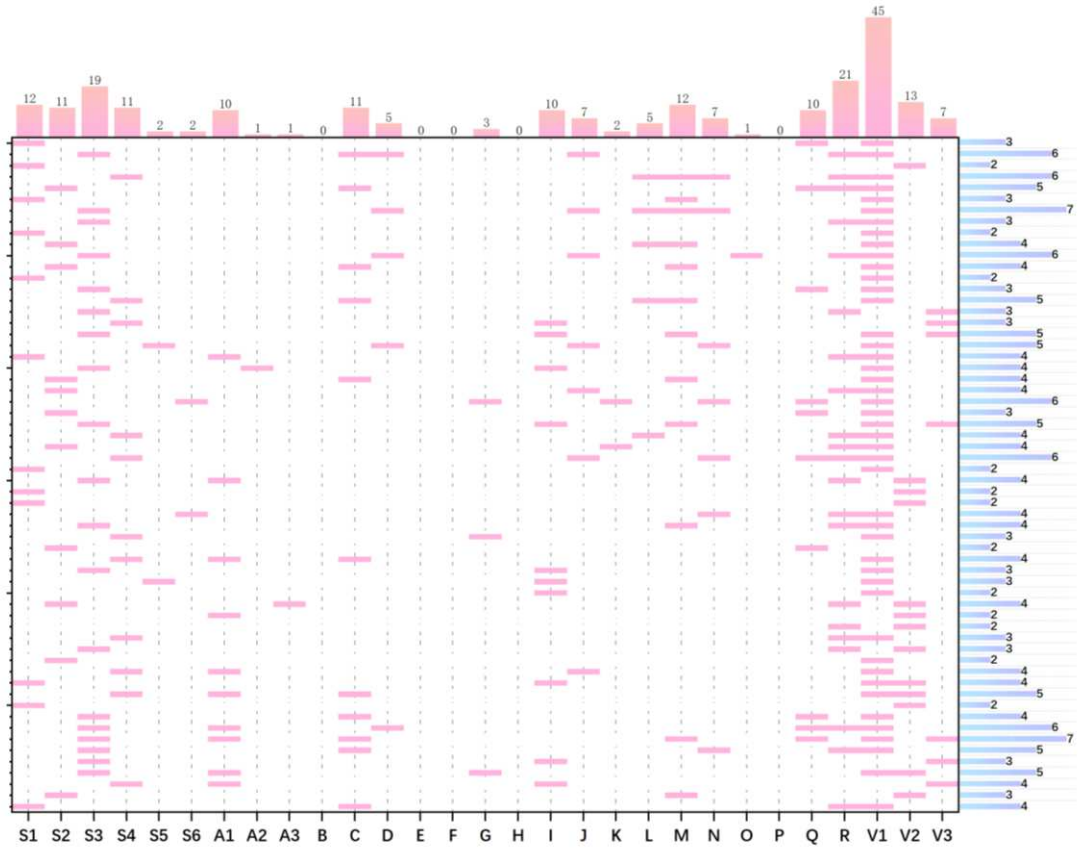


Figure 6 Heat map of rockery feature coding

High-frequency feature combinations further revealed several recurring rockery construction patterns. The dominant pattern combined Taihu stone with stone piecing, flat placement, and horizontal linking techniques, representing a relatively stable construction logic in courtyard environments. Other combinations involved yellow stone-based compositions and mixed-material configurations, reflecting variation within the overall traditional framework.

3.1.2 Plant Features

Plant coding results demonstrated that vegetation in the sampled gardens mainly contributed to vertical layering and spatial enclosure (Figure 7). Among the recorded plant groups, low shrubs or herbaceous plants (B2, 35.8%) and tall shrubs or trees (B5, 26.3%) were the most common plant types. Regarding botanical categories, timber or shade trees (H4, 35.8%) and ornamental foliage plants (H3, 24.2%) accounted for the largest proportions.

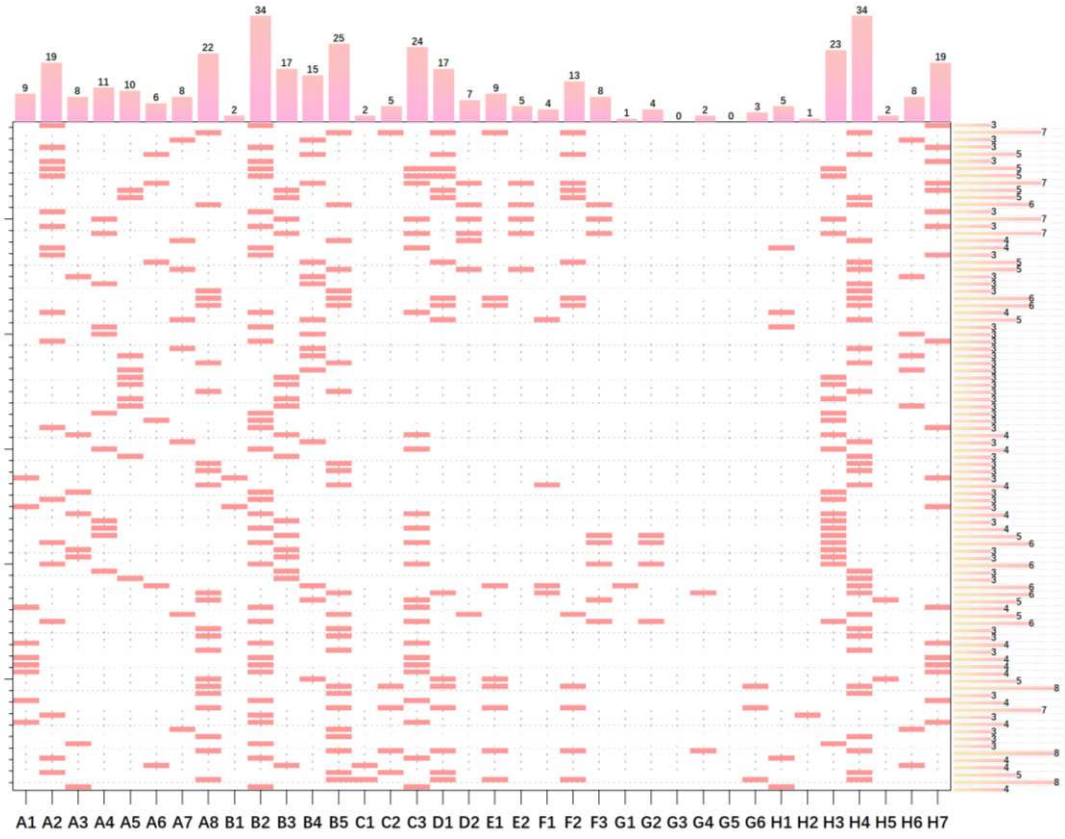


Figure 7 Heat map of plant feature coding

The distribution of plant characteristics suggests that vegetation was not randomly arranged but functioned as a spatial framework. Lower plants were frequently associated with foreground and transitional areas, whereas taller plants contributed to background enclosure and vertical extension. In terms of morphology, clumped growth forms (C3) were most frequently observed, and evergreen plants were more common than deciduous plants.

Plant height showed a clear bimodal distribution, with A2 plants (0.1–0.3 m, 20.0%) and A8 plants (⩾4 m, 23.2%) representing the most frequent categories. This pattern indicates the coexistence of low vegetation and tall trees, which supports a layered visual structure rather than a uniform planting surface.

3.2 Recurring spatial organization patterns in rockery–plant arrangements

Beyond individual material and morphological characteristics, the spatial relationships between rockeries and plants revealed repeated organizational patterns around visual focal elements. Using the initial rockery group identified through eye tracking as the reference point, the relative positions of other rockery and plant groups were analyzed.

3.2.1 Spatial Relationships among Rockery Groups

As shown in Table 8, secondary rockery groups demonstrated a relatively concentrated spatial distribution around the initial rockery group. The most frequent planar position was type 4 (front-right), accounting for 40.5% of secondary rockery groups, followed by type 2 (rear-left, 27.0%) and type 3 (rear-right, 21.6%).

Table 8 Spatial Relationships between Secondary Rockery Groups and the Initial Rockery Group

Planar relationship	Frequency	Percentage (%)	Vertical relationship	Frequency	Percentage (%)
1	4	10.8	13	4	10.8
2	10	27.0	22	7	18.9
3	8	21.6	23	3	8.1
4	15	40.5	43	12	32.4

Considering both horizontal and vertical relationships, type 43 represented the most common combination (32.4%), indicating that secondary rockeries were frequently positioned at the front-right side of the focal rockery and at a lower height. This spatial tendency suggests that secondary rockeries generally functioned as extensions or supporting elements rather than independent visual centers. Their lower position and

directional arrangement helped maintain the dominance of the initial rockery while enriching spatial depth and visual transition.

3.2.2 Spatial Relationships between Plants and Rockery

For plant groups relative to the initial rockery (Table 9), the most common planar positions are type 1 (front-left, 34.7%) and type 2 (rear-left, 29.5%). On the vertical dimension, type 11 and type 21 are both common (23.2% each), and type 43 is also notable (12.6%). Based on these positional patterns, two typical organizational tendencies were identified: plants positioned in front-left or rear-left areas with a higher relative height, and plants positioned in front-right areas with a lower height.

Table 9 Spatial Relationships between Plant Groups and the Initial Rockery Group

Planar relationship	**Frequency**	**Percentage (%)**	**Vertical relationship**	**Frequency**	**Percentage (%)**
1	33	34.7	11	22	23.2
2	28	29.5	21	22	23.2
3	16	16.8	43	12	12.6
4	18	18.9	12	6	6.3

Looking more closely at plant types, tall shrubs and trees are mostly located behind the rockery (positions 2 and 3, 76%). They form the background. Low shrubs and herbaceous plants are mostly located in front of the rockery (positions 1 and 4, 68%). They function as foreground and transition layers. Together, the spatial positions and plant-type distributions revealed a recurring compositional structure consisting of low foreground plants, middle-layer rockery, and background trees. This pattern provides quantitative evidence of how traditional gardens achieve spatial depth through the coordinated arrangement of solid and vegetative elements.

3.3 Relationship between spatial configurations and contemporary perception

3.3.1 Results of the Mixed-Effects Model

Table 10 presents the results of the linear mixed-effects model for the overall score. The model included 124 participants and 12 scenes, giving 1488 observations in total. The variance for participants (0.677) is much larger than the variance for scenes (0.047). This indicates that score differences mainly come from individual preferences. For the overall score, planar position, vertical height, and their interaction do not show strong or stable single-factor effects. This suggests that spatial position alone was insufficient to explain aesthetic evaluation differences. Instead, contemporary perception appeared to be influenced by the combined effects of multiple spatial cues and individual interpretation.

Table 10 Results of the Linear Mixed-Effects Model (Overall Score)

Variable	Coefficient	Standard Error	z value	p value
Intercept	3.768	0.085	44.136	<0.001
Planar 1 (front-left)	-0.052	0.060	-0.867	0.386
Planar 2 (rear-left)	-0.000	0.060	-0.000	1.000
Planar 4 (front-right)	-0.075	0.060	-1.234	0.217
Height 1 (higher than the rockery)	0.046	0.060	0.767	0.443
Height 2 (similar to the rockery)	0.046	0.060	0.767	0.443
Planar 1 × Height 1	0.071	0.085	0.825	0.409
Planar 2 × Height 1	-0.018	0.085	-0.212	0.832
Planar 4 × Height 1	0.038	0.085	0.448	0.654
Planar 1 × Height 2	0.028	0.085	0.330	0.741
Planar 2 × Height 2	0.032	0.085	0.377	0.706
Planar 4 × Height 2	0.044	0.085	0.519	0.604

As shown in Figure 8, although different spatial combinations produced variation in mean scores, no clear separation between preferred and less-preferred configurations was observed. Vertical relationships showed slightly clearer directional tendencies than planar positions, suggesting that height coordination may contribute to visual

interpretation. However, these effects should be understood as part of a broader spatial configuration rather than independent determinants of preference.

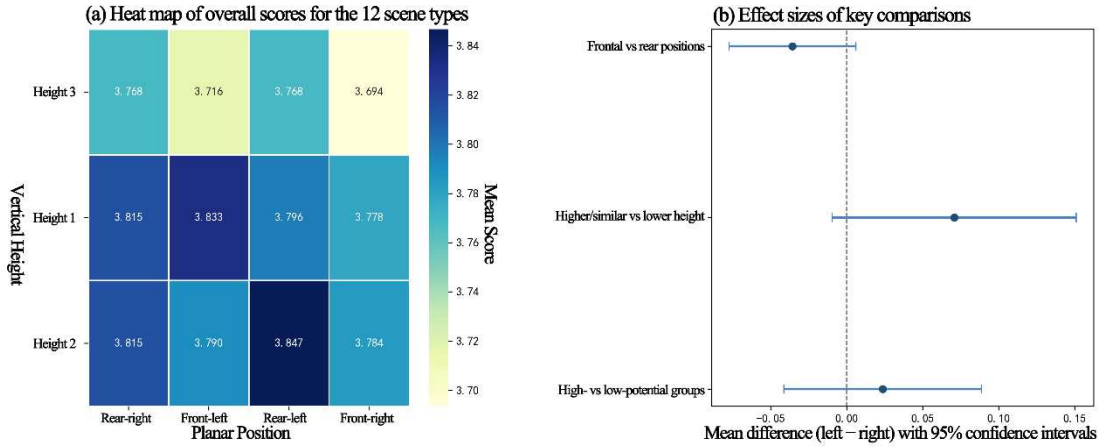


Figure 8 Combined plot of the main analysis results

3.3.2 Dimension-Specific Results, Descriptive Trends, and Consistency Comparison

The relationship between rockery–plant spatial configurations and contemporary perception was examined through a perceptual evaluation experiment. Four aesthetic dimensions, including formal beauty, artistic form, spatial layout, and cultural ambiance, were evaluated based on 12 generated scenes and 124 valid responses. The four dimensions showed good internal consistency (Cronbach's alpha = 0.8285), while their correlations ranged from 0.529 to 0.553, suggesting that they represented related but distinct perceptual aspects. A linear mixed-effects model was further applied to examine the effects of planar position, vertical relationship, and their interaction.

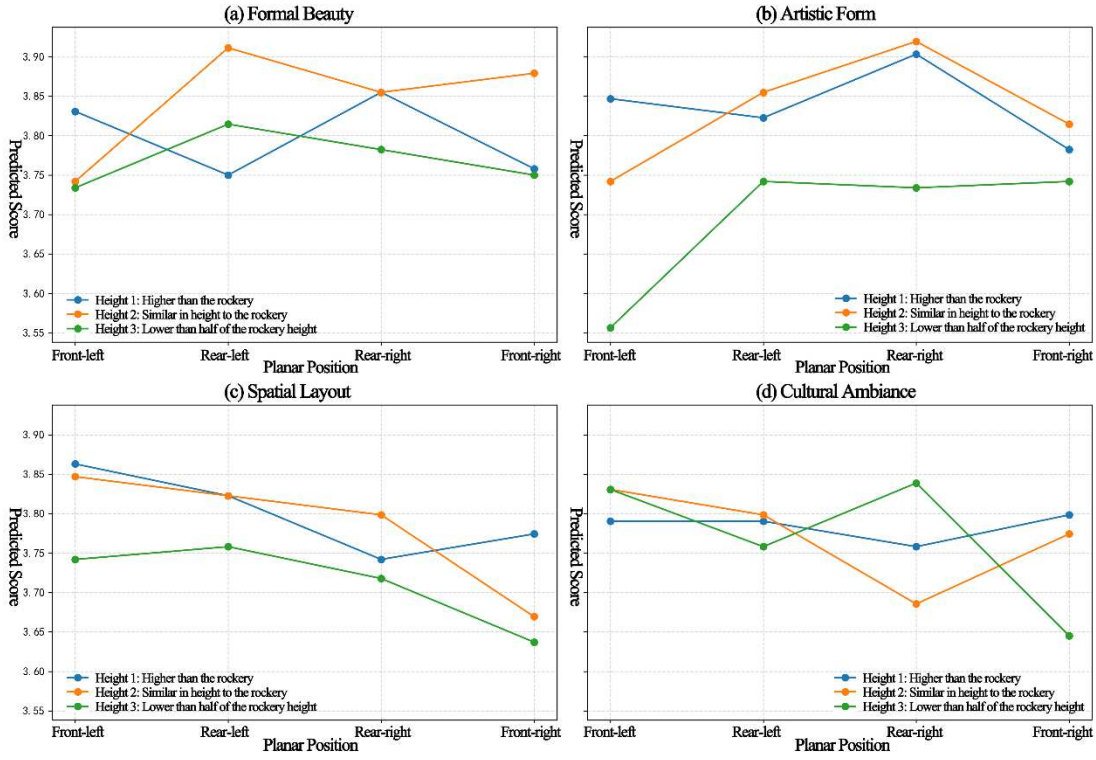


Figure 9 Response plot of the joint model for rating dimensions

The model results indicated limited overall effects of spatial position and interaction terms (Figure 9). No single rockery–plant configuration showed a consistent influence across all aesthetic dimensions. However, different perceptual dimensions exhibited different response tendencies, with relatively clearer variation observed in cultural ambiance. To compare perceptual trends with actual garden compositions, the frequency distribution of plant spatial relationships in real samples was analyzed.

Table 11 Spatial Relationships between plant groups and the initial rockery group

Planar relationship	**1**			**2**			**3**			**4**		
Frequency	33			28			16			18		
Percentage (%)	34.7			29.5			16.8			18.9		
Vertical relationship	11	12	13	21	22	23	31	32	33	41	42	43
Frequency	22	6	5	22	3	3	4	6	6	3	3	12
Percentage (%)	23.2	6.3	5.3	23.2	3.2	3.2	4.2	6.3	6.3	3.2	3.2	12.6

The results showed that plant groups were mainly arranged in front or side-front positions relative to the initial rockery group, while configurations with plants higher than or like the rockery accounted for the majority of cases (Table 11). These recurring

spatial relationships were partially consistent with the perceptual trends observed in the virtual scenes.

Overall, the results suggest that contemporary perception of rockery–plant arrangements are not determined by a single spatial rule. Instead, aesthetic interpretation emerges from the interaction of multiple spatial relationships, while some frequently observed traditional configurations remain compatible with contemporary visual responses.

4. Discussion

This study shows that rockery and plants in micro-scale courtyards of Suzhou classical gardens are not arranged as isolated elements. Instead, they form layered spatial patterns around the visual focus. Real samples show that Taihu stone, the techniques of stone piecing and flat placement, and the height range of 0.8–1.7 m are the main rockery features. Plants show a combined pattern of low shrubs and herbs in the lower layer and tall trees in the upper layer. The questionnaire and the mixed-effects model further suggest that these high-frequency patterns show some directional compatibility with contemporary aesthetic perception. Still, the overall effect remains weak and mainly appears as trend-level support and dimension-specific variation. For this reason, the findings of this study are better understood as identifiable structural clues rather than directly transferable optimal rules.

4.1 From traditional garden practice to measurable spatial knowledge

From the perspective of spatial composition, the arrangement of plants and rockeries in Suzhou classical gardens reflects a coordinated organization of material, height, and relative position. Plants showed a clear layered relationship around the reference rockery, with low shrubs mainly distributed in foreground areas and taller trees frequently positioned behind rockery groups. Together, these elements formed a recurring depth structure of “foreground plants–midground rockery–background trees”.

This spatial organization is consistent with traditional Chinese garden theories emphasizing layered progression, visual transitions, and the interaction between solid and void[3,4,14,34,36,40]. Previous studies have also demonstrated that classical garden spaces are organized through relationships among multiple elements rather than independent objects[12,15].Beyond traditional interpretation, the present study contributes by transforming these experiential principles into measurable spatial variables. Previous digital documentation studies have mainly focused on recording geometric information, reconstructing physical forms, or representing individual garden elements[8,9,28,33].

4.2 Interpretation of Aesthetic Perception

From the perspective of aesthetic response, the effects of planar position, vertical relationship, and their interaction were limited in the mixed-effects model. Descriptive trends and dimension-specific responses nevertheless indicated that some spatial configurations may be interpreted differently. Configurations in which plants were positioned in front or side-front areas and were not substantially lower than the rockery showed relatively more positive evaluation tendencies in several dimensions, particularly artistic form and cultural ambiance. This tendency may be related to the role of vegetation in framing views, creating transitions, and enhancing spatial depth[5,30].In addition, the coordination between plant height and rockery form may influence the perception of enclosure and spatial immersion[41]. Previous studies on landscape preference and visual perception have suggested that relationships among openness, enclosure, and visual structure contribute to human interpretation of landscape environments[37,42,43].However, these findings should not be interpreted as evidence for a universal aesthetic rule. Instead, they suggest that rockery–plant relationships influence perception through the interaction of multiple spatial cues, including position, height, and contextual composition.

4.3 Heritage Spatial Patterns and Design Implications

Beyond direct design application, the main contribution of this study lies in the quantitative identification of spatial knowledge embedded in Suzhou classical gardens[4,14,34]. By converting rockery techniques, plant characteristics, and relative spatial relationships into structured variables, the study makes a traditionally experience-based compositional system more explicit, comparable, and open to further verification[9,28,33]. In this sense, the recurrent pattern of "foreground plants–midground rockery–background trees" should first be understood as a quantitatively identified heritage spatial pattern rather than as a ready-made design formula. From this perspective, Figure 10 presents three schematic application scenarios that illustrate how the identified pattern may be translated into contemporary micro-scale green-space design. The scenes were modelled in SketchUp Pro (Trimble Inc., USA) and rendered with D5 Render (Dimension 5 Techs, China) to visualize possible spatial interpretations of the identified configuration.

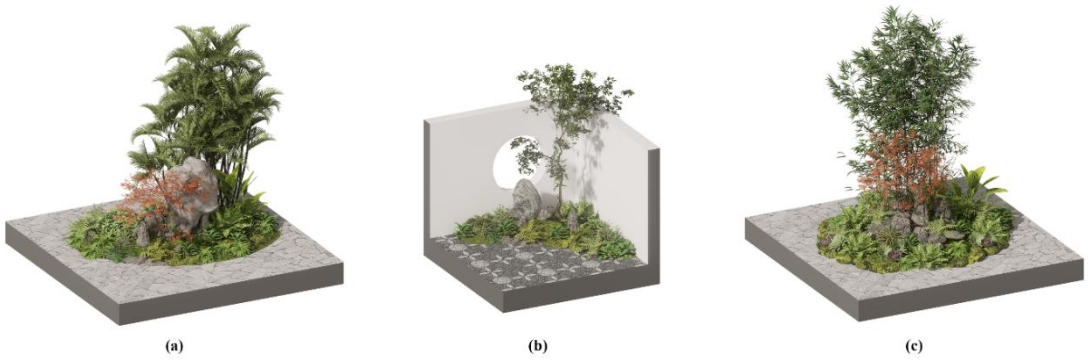


Figure 10 modern micro-scale green space design

In these scenarios, the rockery functions as the main visual anchor, low plants serve as the foreground and transition layer, and taller vegetation provides background enclosure and spatial definition. Although the three scenes differ in spatial conditions and planting arrangements, they all maintain the basic compositional sequence identified from traditional gardens. The purpose is not to reproduce historical garden scenes directly, but to reinterpret the spatial relationships between solid elements, vegetation layers, and visual depth that characterize classical garden composition[4,44].In

this sense, the identified pattern may provide references for the organization of small-scale urban green spaces with different functional orientations. Nevertheless, design translation should not rely solely on aesthetic similarity. Recent landscape performance studies have emphasized that landscape interventions should be evaluated through multiple dimensions, including aesthetic, environmental, social, and functional performance [45]. Therefore, the scenarios presented in Figure 10 should be regarded as heuristic spatial prototypes rather than fixed design solutions.

5. Conclusion

This study developed a quantitative framework for analyzing rockery–plant spatial relationships in the micro-scale courtyards of Suzhou classical gardens. By integrating rockery characteristics, plant attributes, and relative spatial positions into structured variables, the framework provides a systematic approach for describing and comparing traditional garden compositions that are often represented through experiential knowledge.

The results demonstrate that courtyard-scale rockery and plant arrangements were not organized as isolated elements but formed coordinated spatial structures. Real samples showed that Taihu stone, stone piecing and flat placement techniques, and moderate rockery height ranges were the dominant characteristics of the studied rockery groups. Plant arrangements further revealed a layered spatial pattern consisting of foreground plants, midground rockeries, and background trees. The perceptual evaluation indicated that these recurring spatial configurations showed partial compatibility with contemporary aesthetic responses, although no single configuration demonstrated a universal perceptual advantage. The findings suggest that traditional garden compositions can be understood as identifiable spatial patterns rather than fixed design rules. By transforming implicit design knowledge into measurable relationships, this study provides a potential pathway for connecting classical garden theory with quantitative analysis and contemporary landscape interpretation. The proposed

framework and design scenarios may offer references for the understanding and adaptation of traditional spatial principles in small-scale landscape design. Future studies could extend this approach by incorporating larger samples, different regional garden traditions, and additional perceptual and environmental factors to further examine the relationship between heritage spatial knowledge and contemporary landscape experience.

Abbreviations

BIM: Building information modeling
GIS: Geographic information system
UAV: Unmanned aerial vehicle

Acknowledgements

The authors thank all participants who took part in the eye-tracking experiment and questionnaire survey.

Author contributions

Conceptualization, Y.C. and Y.L.; methodology, Y.C. and D.Z.; validation, Y.L.; formal analysis, Y.C.; investigation, Y.C., D.M., and D.Z.; data curation, Y.C., D.M., and D.Z.; writing—original draft preparation, Y.C.; writing—review and editing, Y.C., Y.L., D.M., and D.Z.; All authors have read and agreed to the published version of the manuscript.

Funding

This study was supported by the National Natural Science Foundation of China (No. 42571103), and the Jiangsu University Senior Talent Fund (No. 19JDG004).

Ethics approval and consent to participate

This study was an anonymous and non-invasive perceptual study involving an eye-tracking experiment and an online questionnaire survey. In accordance with Article 32(2) of the Measures for Ethical Review of Life Science and Medical Research Involving Humans, issued jointly by the National Health Commission, the Ministry of Education, the Ministry of Science and Technology, and the National Administration of Traditional Chinese Medicine on 18 February 2023, formal ethical review was not required. This provision applies to behavioural testing and questionnaire-based research that does not involve sensitive personal information or cause physical harm to participants[1].

---

[1] Measures for Ethical Review of Life Science and Medical Research Involving Humans, Article 32(2), 18 February 2023. Available at: https://www.gov.cn/zhengce/zhengceku/2023-02/28/content_5743658.htm

All research was performed in accordance with the Declaration of Helsinki, the Measures for Ethical Review of Life Science and Medical Research Involving Humans, and other relevant institutional and national guidelines and regulations. Informed consent was obtained from all adult participants before participation. For questionnaire participants younger than 18 years of age, informed consent was obtained from their parents or legal guardians before participation.

Consent for publication

Not applicable. This manuscript does not contain any individual person's identifiable data.

Availability of data and materials

The coded rockery and plant data, coding schemes and variable definitions, sample and image identifiers, anonymized raw and processed questionnaire data, questionnaire instruments and protocols, standardized virtual-scene images, eye-tracking protocols, heat-map results, reference-rockery results, and the Python scripts and output files used for data processing and linear mixed-effects modelling are provided as supplementary files submitted with this manuscript. The anonymized native Tobii Pro Lab project underlying the eye-tracking component has been uploaded as a related file for access by the editors and referees during peer review.

Competing interests

The authors declare that they have no competing interests.

References

1. Li, X., He, X., Xiao, Y., Jia, S. & Qin, K. A multi-level quantitative analysis method on the scale, shape and quantity of rockeries in Chinese classical gardens: taking Wanfang Anhe rockery in the Old Summer Palace as an example. *Herit Sci* **12**, 101 (2024).

2. Ding, M. *et al.* Fractal dimension-based analysis of rockery contour morphological characteristics for chinese classical gardens south of the Yangtze River. *J. Asian Archit. Build. Eng.* **22**, 2490–2505 (2023).

3. Ji C., Liu Y. & Ji C. *The Garden Manual*. (Jiangsu Phoenix Literature and Art Publishing House, 2015).

4. Chen C. *On Chinese Gardens*. (Tongji University Press, 2007).

5. Wu, W., Zhou, K., Li, T. & Dai, X. Spatial configuration analysis of a traditional garden in Yangzhou city: a comparative case study of three typical gardens. *Journal of Asian Architecture and Building Engineering* **24**, 593–604 (2025).

6. Chen, Y., Gu, Y., Liu, Y. & Cao, L. Unveiling the dynamics of 'scenes changing as steps move' in a Chinese classical garden: a case study of Jingxinzhai Garden. *Heritage Sci.* **12**, 131 (2024).

7. Jia, S. *et al.* Conservation and management of chinese classical royal garden heritages based on 3D digitalization - a case study of jianxin courtyard in jingyi garden in fragrant hills. *J. Cult. Heritage* **58**, 102–111 (2022).

8. Liang, H. *et al.* The integration of terrestrial laser scanning and terrestrial and unmanned aerial vehicle digital photogrammetry for the documentation of chinese classical gardens – a case study of huanxiu shanzhuang, suzhou, china. *J. Cult. Heritage* **33**, 222–230 (2018).

9. Liang, H., Li, W. & Zhang, Q. Semantic-based 3D information modelling and documentation of rockeries in chinese classical gardens: a case study on the rockery at huanxiu shanzhuang, suzhou, china. *J. Cult. Heritage* **37**, 247–258 (2019).

10. Sun, J., Mi, S., Olsson, P., Paulsson, J. & Harrie, L. Utilizing BIM and GIS for Representation and Visualization of 3D Cadastre. *ISPRS International Journal of Geo-Information* **8**, 503 (2019).

11. Dao, J., Ng, S. T. & Kwok, C. Y. Interlinking BIM and GIS data for a semantic pedestrian network and applications in high-density cities. *Developments in the Built Environment* **17**, 100367 (2024).

12. Chen, H. & Yang, L. Analysis of Narrative Space in the Chinese Classical Garden Based on Narratology and Space Syntax—Taking the Humble Administrator's Garden as an Example. *Sustainability* **15**, 12232 (2023).

13. Zhai, Z. *et al.* Research on the healing effect of the waterscapes in chinese classical gardens in audiovisual interaction. *Buildings* **15**, 2310 (2025).

14. Peng Yigang. *Analysis of Classical Chinese Gardens*. (China Architecture & Building Press, 1986).

15. Zhang, T., Tang, G. & Lian, Z. The Mathematics of Spatial Structure Evolution: Using Syntactical Data to Compare the Humble Administrator's Garden in the Sixteenth and Nineteenth Centuries. *Nexus Netw J* **25**, 387–407 (2023).

16. Wang, Y., Pan, B. & Zhang, Q. Rockery morphology based on quantitative analysis of shading. *Heritage Sci.* **12**, 379 (2024).

17. Hao, S. *et al.* Visual behavior characteristics of historical landscapes based on eye-tracking technology. *J. Asian Archit. Build. Eng.* **24**, 487–506 (2025).

18. Dong, Q., Wei, T., Wang, Y. & Zhang, Q. Intangible cultural heritage based on finite element analysis: force analysis of chinese traditional garden rockery construction. *Heritage Sci.* **12**, 241 (2024).

19. Dong, Q., Wei, T., Zhang, Q., Jia, X. & Pan, B. The texture of chinese garden rockery stones: based on 3D point cloud and 3D printing technology. *npj Herit. Sci.* **13**, 47 (2025).

20. Wartmann, F. M., Acheson, E. & Purves, R. S. Describing and comparing landscapes using tags, texts, and free lists: an interdisciplinary approach. *Int. J. Geogr. Inf. Sci.* **32**, 1572–1592 (2018).

21. Means, B. M. & Rohwer, W. D. Attribute dominance in memory development. *Dev. Psychol.* **12**, 411–417 (1976).

22. McNamara, T. P. & Miller, D. L. Attributes of theories of meaning. *Psychol. Bull.* **106**, 355–376 (1989).

23. Amer, A. Teaching/developing vocabulary using semantic feature analysis. in *The TESOL encyclopedia of english language teaching* 1–7 (John Wiley & Sons, Ltd, 2018). doi:10.1002/9781118784235.eelt0743.

24. Kivisaari, S. L. *et al.* Reconstructing meaning from bits of information. *Nat. Commun.* **10**, 927 (2019).

25. Zhang, R. *et al.* Intelligent recognition method of decorative openwork windows with sustainable application for suzhou traditional private gardens in China. *Sustainability* **13**, 8439 (2021).

26. Hong, S. *et al.* Aesthetic style transferring method based on deep neural network between chinese landscape painting and classical private garden's virtual scenario. *Int. J. Digital Earth* **16**, 1491–1509 (2023).

27. Weng, F. *et al.* Study on multidimensional perception of national forest village landscape based on digital footprint support—anhui xidi village as an example. *Forests* **14**, 2345 (2023).

28. Peng, Y., Zhang, G., Nijhuis, S., Agugiaro, G. & Stoter, J. E. Towards a framework for point-cloud-based visual analysis of historic gardens: jichang garden as a case study. *Urban For. Urban Greening* **91**, 128159 (2024).

29. Choi, H. S. (Sunny), Bruyns, G., Cheng, T., Zhang, W. & Sharma, S. Human cognition and emotions for human-centred design in vertical interior urban spaces. *J. Urban Des.* **30**, 114–137 (2025).

30. Shen, C. & Yu, C. The virtual-real measurement of Chinese garden impression: A quantitative analysis of cognitive experience of Jiangnan gardens with virtual reality experiments. *Frontiers of Architectural Research* **13**, 895–911 (2024).

31. Yang, C. *et al.* Digital characterization of the surface texture of chinese classical garden rockery based on point cloud visualization: small-rock mountain retreat. *Herit Sci* **11**, 13 (2023).

32. Wang, Z., Song, P., Zhang, Q., Wei, T. & Pan, B. Digital improvements in the design and construction process of classical Chinese garden rockeries: a study based on material digitization. *Herit Sci* **12**, 327 (2024).

33. Jia, S. *et al.* Methods of Conserving and Managing Cultural Heritage in Classical Chinese Royal Gardens Based on 3D Digitalization. *Sustainability* **14**, 4108 (2022).

34. Liu Dunzhen. *Suzhou Classical Gardens*. (China Architecture & Building Press, 1979).

35. Ho, L.-C. LaDeco: A tool to analyze visual landscape elements. *Ecological Informatics* **78**, 102289 (2023).

36. Yang, Z. *et al.* A study on visual impact assessment of the enclosing wall entourage of Chinese traditional private garden. *Environmental Impact Assessment Review* **105**, 107427 (2024).

37. Shi, Y. *et al.* Designing Perennial Landscapes: Plant Form and Species Richness Influence the Gaze Perception Associated with Aesthetic Preference. *Land* **11**, 1860 (2022).

38. Jia, J. & Zhu, Y. Plant Landscapes in the Private Gardens in Beijing. *Chinese Landscape Architecture* 61–69 (2010) doi:10.3969/j.issn.1000-6664.2010.10.016.

39. Li, Y. *et al.* Entropy-weighted fuzzy and user perception-based framework for riverside greenway landscape quality assessment. *Landscape Ecol. Eng.* **22**, 153–172 (2026).

40. Antrop, M. Why landscapes of the past are important for the future. *Landscape Urban Plann.* **70**, 21–34 (2005).

41. Quantifying urban environments: Aesthetic preference through the lens of prospect-refuge theory. *Journal of Environmental Psychology* **97**, 102344 (2024).

42. Appleton, J. Landscape Evaluation: The Theoretical Vacuum. *Transactions of the Institute of British Geographers* 120–123 (1975) doi:10.2307/621625.

43. Remondino, F. Heritage recording and 3D modeling with photogrammetry and 3D scanning. *Remote Sens.* **3**, 1104–1138 (2011).

44. Zhang L. Research on Relation between Chinese Landscape Paintingand Planting Design in Chinese Classical Gardens. (ZheJiang University, 2004).

45. Li, Y. *et al.* An integrated framework for evaluating landscape performance in tourism-oriented rural areas. *Sci. Rep.* **15**, 45794 (2025).

Appendix A

Table A1 Coding Statistics of Features and Spatial Positions in the Image Samples

Sample	No.	Rockery spatial code	Rockery feature code	No.	Plant spatial code	Plant feature code
L-ENT	1	1-E	S1CRV1	4	2-E-43	4-A3B2C3H1
				5	2-E-31	5-A8B5C1D1E1F2G6H4
	2	1-E43	S2MV1V2	6	2-E43-21	6-A2B5C2D1H4
	3	1-E22	S4IV3	7	2-E22-21	7-A6B3C1H6
L-MD-SE	1	1-G	S3A1QV1V2	3	2-G-23	3-A2B2C3H1
				6	2-G-11	6-A8B5C2D1E1F2G

						4H4
				7	2-G-22	7-A3B2H3
	2	1-G22	S3IV3	4	2-G22-41	4-A8B5H4
				5	2-G22-11	5-A7B5H6
L-JG	1	1-H	S3CNRV1	3	2-H-43	3-A1B2C3H7
				4	2-H-13	4-A2B2H3
	2	1-H22	S3A1CMQV1 V3	5	2-H22-11	5-A8B5C2D1E1F2G6H4
L-HW-NW	1	1-G	S3ADQRV1	4	2-G-43	4-A1B2C3H7
	2	1-G22	S3CQV1	5	2-G22-11	5-A8B5H4
				6	2-G22-42	6-A8B5C2D1E1F2G6H4
	3	1-G43	S1V2			
L-DYLD	1	1-A	S4A1CV1V2	3	2-A-11	3-A8B4D1E1H5
	2	1-A43	S1IV1V2			
L-MD-T-E	1	1-G	S4A1JS4V1	3	2-G-23	3-A1B2C3H7
	2	1-G23	S2V1	4	2-G23-32	4-A1B2C3H7
L-WFX-E	1	1-H	S3RV2	3	2-H-43	3-A1B2C3H7
				4	2-H-11	4-A8B5H4
				6	2-H-12	6-A1B2C3H7
	2	1-H22	S4RV1	5	2-H22-31	5-A8B5H4
L-RH-E-R	3	1-D	SRV2	5	2-D-11	5-A8B5H4
	1	1-D41	S1A1V2			
	2	1-D22	S2A3RV2	4	2-D22-21	4-A8B5H4
L-PJ-N-W	1	1-H	S6IV1	4	2-H-33	4-A2B2C3F3G2H3
				5	2-H-42	5-A7B5D2F2H4
				9	2-H-13	9-A1B2C3H7
	2	1-H22	SS5IV1	6	2-H22-11	6-A8B4C3F3H5
				7	2-H22-21	7-A8B5D1F1G4H4
				8	2-H22-32	8-A4B3H3
	3	1-H13	S3IV1			
L-L-W	3	1-B	S4A1CV1	6	2-B-11	8-A6B4E1F1G1H4
				7	2-B-22	7-A5B3H4
	1	1-B31	S2Q			
	2	1-B32	S4GV1	5	2-B32-12	5-A4B3H4
	4	1-B42	S3MRV1	8	2-B42-13	8-A2B2C3F3G2H3

L-GY	1	1-B	S6NRV1	4	2-B-33	4-A3B3H3
				5	2-B-43	5-A3B3H3
	2	1-B33	S1V2	7	2-B33-21	7-A2B2C3F3G2H3
	3	1-B43	S1V2	6	2-B43-11	6-A4B3H3
SZL-ZB-SE	1	1-D	S3A1RV1V2	4	2-D-12	4-A4B2C3H3
				5	2-D-11	5-A4B3H3
				6	2-D-23	6-A3B2C3H3
	2	1-D43	S1V1	3	2-D43-12	3-A1B1H7
				8	2-D43-11	8-A2B2H3
				9	2-D43-21	9-A3B2H3
				7	2-D-43-11	7-A8B5F1H4
SZL-GWS-SE	1	1-E	S4JNQRV1	3	2-E-33	3-A1B1H7
				5	2-E-11	5-A8B5H4
				6	2-E-43	6-A8B5H4
				7	2-E-21	7-A5B34H4
	2	1-E13	S2KRV1	4	2-E13-21	4-A4B2C3H3
SZL-GWS-W	3	1-A	S4LRV1	5	2-A-21	5-A7B4H4
	1	1-A43	S3IMV1V3	4	2-A43-21	4-A3B3C3H3
	2	1-A23	S2QV1	6	2-A23-43	6-A2B2H7
				7	2-A23-11	7-A6B2H3
SZL-JJ-E	1	1-B	S6GKNQV1	5	2-B-33	5-A4B2H3
				6	2-B-43	6-A5B3H6
	2	1-B33	S2JRV1	8	2-B33-42	8-A5B3H3
				9	2-B33-21	9-A8B5H4
	3	1-B43	S2CMV1	4	2-B43-32	4-A5B3H3
				7	2-B43-43	7-A5B3H3
SZL-LX-W	1	1-G	S3A2IV1	3	2-G-21	3-A5B4H6
				5	2-G-21	5-A8B5H4
	2	1-G23	S1A1RV1	4	2-G23-11	4-A5B4H6
				6	2-G23-21	6-A7B4H4
				7	2-G23-43	7-A2B2H7
				8	2-G23-21	8-A4B4H6
SZL-YY-S	3	1-B	S5DJNV1	5	2-B-43	5-A4B2H1
				9	2-B-11	9-A7B4D1F1H4
	1	1-B43	S3IMV1V3	6	2-B43-33	6-A2B2C3H1
	2	1-B31	S4IV3	7	2-B32-11	7-A8B5D1E1F2H4
	4	1-B42	S3ORV1	8	2-B42-21	8-A8B5D1E1F2H4
SZL-S-SW	1	1-C	S4CLMV1	2	2-C-13	2-A8B5H4
				3	2-C-41	3-A4B4H6
SZL-OUT-	1	1-B	S3QV1	4	2-B-32	4-A3B4H6

W				6	2-B-41	6-A7B5D2E2H4
	2	1-B33	S1V1	5	2-B33-11	5-A6B4D1F2H4
	3	1-B43	S2CMV1	7	2-B43-33	7-A2B2H7
SZL-XF	1	1-D	S3DJORV1	5	2-D-43	5-A2B2C3H1
				6	2-D-21	6-6-A7B5D2H4
	2	1-D33	S2LMV1	7	2-D33-11	7-A4B3C3D2E2F3H3
	3	1-D43	S1V1	8	2-D43-21	8-A2B2H7
	4	1-D13	S3RV1			
SZL-GWS-E	1	1-B	S3DJLMNV1			
	2	1-B43	S1MV1	6	2-B43-21	6-A4B3C3D2E2F3H3
	3	1-B32	S2CRQV1	4	2-B32-33	4-A2B2H7
				5	2-B32-31	5-A8B5D2E2F3H4
CZL-ZB-NE	1	1-I	S4LMNRV1	6	2-I-12	6-A5B3D1F2H4
				7	2-I-21	7-A5B3D1F2H4
				8	2-I-21	8-A6B4C3D2E2F2H7
				9	2-I-23	9-A2B2C3D1H3
				10	2-I-13	10-A2B2C3D1H3
	2	1-I13	S1V2	3	2-I13-32	3-A2B2H7
				4	2-I13-31	4-A6B4D1F2H4
				5	2-I13-22	5-A2B2H7
SZL-OUT-E	1	1-B	S3CDJRV1	4	2-B-11	4-A7B4H6
				5	2-B-21	5-A8B5C2D1E1F2H4
	2	1-B43	S1QV1	3	2-B43-12	3-A2B2H7

Appendix B

Survey Instrument for Perceptual evaluation

The questionnaire title was " Perceptual evaluation of the Spatial Relationship between Rockery and Plant Arrangement." A total of 124 valid responses were

collected. Respondents first provided basic background information. They then rated each image on four dimensions by using a five-point scale.

Table B1 Respondent Profile

Item	Category	Count	Percentage (%)
Gender	Male	63	50.81
Gender	Female	61	49.19
Landscape-related background	Yes	55	44.35
Landscape-related background	No	59	55.65
Age	Under 15	11	8.21
Age	15-20	29	21.64
Age	21-25	46	34.33
Age	26-30	26	19.40
Age	31-40	6	4.48
Age	41-50	4	2.99
Age	51-60	9	6.72
Age	Over 60	3	2.24

Table B2 Rating Dimensions and Scale Descriptions

Dimension	Description
Formal beauty	Evaluation of the visible qualities of the rock, including form, texture, color, and surface pattern.
Artistic form	Evaluation of the artistic handling of rock arrangement, such as contrast and unity, balance and stability, and the expression of artistic beauty.
Spatial layout	Evaluation of planar layout or spatial organization, and of how the arrangement affects spatial aesthetic perception.
Cultural ambiance	Evaluation of conceptual meaning, the expression of rock culture, and the extent to which the scene evokes association and aesthetic imagination.

Rating scale: 1 = lowest, 5 = highest.

Appendix C

Table C1 Summary Statistics of Questionnaire Results

Sample name	Formal beauty	Artistic form	Spatial layout	Cultural ambiance	Final score
Height 1-1	3.886145	4.076818	3.847737	3.654321	3.866255
Height 1-2	3.770919	3.614540	3.576132	3.692730	3.663580
Height 1-3	3.655693	3.537723	3.423868	3.539095	3.539095
Height 1-4	3.923182	3.692730	3.729767	3.423868	3.692387
Height 2-1	3.691358	3.422497	3.537723	3.308642	3.490055

Height 2-2	3.576132	3.422497	3.462277	3.539095	3.500000
Height 2-3	3.731139	3.731139	3.578875	3.769547	3.702675
Height 2-4	3.694102	3.807956	3.694102	3.731139	3.731824
Height 3-1	3.423868	3.268861	2.962963	3.270233	3.231481
Height 3-2	3.423868	3.308642	3.537723	3.193416	3.365912
Height 3-3	3.308642	3.308642	2.962963	3.193416	3.193416
Height 3-4	3.347051	3.230453	3.153635	3.153635	3.221193

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.zip