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Characteristics of a stroll-style Japanese Garden in Unreal Engine Based Virtual Reality: A Comparison with On-Site Investigation

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Abstract

This study investigates how a stroll-style Japanese garden is perceived within a freely explorable virtual reality (VR) environment created using Unreal Engine, and how these impressions compare with experiences in the actual garden. A VR model of Kyu-Shiba-rikyu Gardens was developed and evaluated through a VR experience survey (N = 73) and a follow-up on-site survey (N = 20). Participants photographed locations perceived as beautiful, comfortable, or historically/culturally valuable and provided evaluative ratings and open-ended responses. Photo data, textual responses, and spatial distributions were analyzed using chi-square tests, adjusted residual analysis, and kernel density estimation. Results indicate that VR preserves core perceptual structures of garden appreciation, with Beauty, Comfort, and History/Culture guided by distinct cues. While most landscape elements showed similar selection patterns across VR and on-site conditions, VR selectively enhanced the salience of spatially distinctive features such as islands and stone bridges. These findings suggest that such purposefully constructed VR environments have significant potential to broaden and redefine future approaches to the appreciation of Japanese gardens.

Keywords

Japanese garden, Stroll style, 3D models, VR experience, Actual Garden experience, Hotspots, Unreal Engine

1. Introduction

1.1 Japanese garden

In recent years, interest in landscapes and environmental quality has increased across a wide range of fields. Among these, landscapes play an essential role as spaces that provide viewers with a sense of enrichment and tranquility. Japanese gardens have long incorporated visual elements and design techniques aimed at creating aesthetically pleasing views. Even within urban areas, Japanese gardens remain important sites where people can experience a sense of nature [1].

A Japanese garden is a designed landscape that expresses natural scenery in an idealized, symbolic, and highly controlled form. It emphasizes harmony between human-made elements and nature using rocks, water, plants, and spatial composition. Traditional design principles such as asymmetry, borrowed scenery, and seasonal change are employed to create spaces that evoke tranquility, contemplation, and aesthetic refinement [2].

Japanese gardens are completed through the two principal styles of miniaturized landscape style and stroll garden style. The primary characteristic of the miniaturized landscape style is its composition based on the miniaturization and symbolic representation of various natural and cultural landscapes. In the case of the stroll style, where viewers walk through the garden,

the sense of miniaturization becomes slightly less pronounced compared with fixed-viewpoint styles. However, when the garden is juxtaposed with large-scale contemporary architecture in the background, the contrast becomes visually striking even to untrained observers The stroll style is defined as a garden form in which visitors experience sequentially changing scenery by walking along the designed pathways. A wide range of elements contribute to this spatial variety, including the pathways themselves, vegetation especially trees bridges, pavilions, other man-made structures, and the garden's topography. Research has shown that Japanese people tend to prefer naturalistic and familiar landscapes, and that the presence of water further enhances the desirability of such settings. Water constitutes the core of the basic spatial composition of many Japanese garden styles, and together with bridges represents a highly significant design element. Previous studies indicate that gardens incorporating water features are highly valued and are strongly associated with restorative effects; therefore, pond-centered stroll gardens are regarded as particularly important [3]. In this study we will concentrate on stroll style gardens.

In research on Japanese gardens, the perspectives and methodologies employed have become increasingly diversified. Among these, three notable tendencies can be identified:(1) a shift in perspectives for evaluating the value of gardens; (2) growing attention to conservation, maintenance, and operational management; and (3) the advancement of visualization and quantification techniques through the application of new technologies [4]. Studies utilizing new technologies are particularly closely connected to the third perspective. For example, research has demonstrated the usefulness of three-dimensional landscape simulations generated by terrestrial laser scanning [5], as well as attempts to analyze planting spaces and landscape structures using high-precision 3D laser survey data [6]. These efforts have contributed to the visualization and quantification of garden management techniques. Also, there is The Garden Archives Project (GAP), launched in 2019 under Hara Rurihiko, reinterprets Japanese gardens as dynamic, living environments. Through its digital platform "Incomplete Niwa Archives," GAP uses 3D scanning, high-resolution photography, ambisonics audio, and DNA analysis to document the spatial, ecological, acoustic, and biological layers of historic gardens. The open-access archive enables users to explore 3D point-cloud models, examine features such as stones, plant species, and fauna, and observe landscape changes over time [7].

However, 3D models of gardens generated from laser-scanned point clouds, while suitable for large-scale verification, cannot provide sufficient detail for examining elements such as tree trunks or branching structures, making them inadequate for full visualization or practical use in virtual environments. Point cloud data also involve extremely large file sizes and complex processing requirements, making smooth operation and utilization difficult. Consequently, practical examples that enable free walkthroughs within VR environments using such models remain limited. To adequately evaluate stroll gardens, assessing static scenes extracted from photographs or similar media is insufficient. Instead, an evaluation approach is required that captures perceptions of the garden based on actual patterns of use, particularly the experiential and sequential nature of movement through the garden, which is fundamental to the concept of stroll style garden.

In recent years, computer based three-dimensional visualization has advanced significantly, particularly through the development and practical application of 3D Computer Graphics (3DCG) technologies. With improvements in computational processing power, there has been a notable shift from traditional pre-rendering methods where static CG images are generated over extended processing times to real-time rendering techniques. As a result, the use of Virtual Reality (VR) has become increasingly common even at the personal computer level.[8]

Currently, various game engines, such as Unreal Engine and Unity, are popular. Recent advancements in Unreal Engine and Unity have made an increased interest in virtual VR, engaging users with artificial environments [9]. Unreal Engine 5.3 is regarded as the preferred choice for creating these simulated environments. It has lots of advanced technologies, including Nanite, the intricate polygonal graphics technology. In UE5.3's VR templates, instance stereoscopic rendering is default enabled, it is a beneficial feature that significantly reduces the performance impact of VR. Without instance stereo, the computer would do the entire rendering twice, once for each eye in the VR headset. This would result in a significant performance hit, especially in complex VR environments [10]. Another aspect that makes Unreal Engine stand out: its accessibility to individual users, enabling them to unlock its full potential without any costs [11].

The provision of virtual reality (VR) experiences at gardens, historical sites, and cultural heritage locations has increased in recent years, driven by advances in real-time rendering and game-engine technologies [12]. Previous studies have demonstrated that VR is an effective tool for reproducing historical environments with high visual fidelity, enabling users to freely explore sites that are otherwise difficult to access due to preservation constraints or spatial limitations [13]. For example, photorealistic VR reconstructions of historical sites in Kyoto

using game engines have shown that immersive environments can enhance users' sense of authenticity and spatial understanding while maintaining real-time interactivity. Similarly, landscape simulation systems developed for historical and cultural heritage contexts have emphasized the value of walkthrough-style experiences, allowing users to move freely through reconstructed townscapes and to perceive sequential changes in scenery, including variations in time, season, and weather [14].

Beyond cultural heritage applications, VR has been widely adopted in fields such as education, simulation, and training, where its primary strength lies in providing users with a high degree of behavioral freedom and immersive engagement [12]. These characteristics suggest that VR is particularly well suited to the experiential evaluation of spatial environments. However, most existing studies on VR-based representations of historical landscapes and gardens have focused primarily on technological workflows, visual realism, or system performance, rather than on how users' impressions and experiences change when they are allowed to move freely within a virtual environment [13].

Moreover, previous VR research has paid limited attention to natural landscapes and to users' perceptual and emotional responses to vegetation represented in three-dimensional virtual environments [15]. Much of the existing literature has concentrated on historical reconstruction, with a particular emphasis on architectural elements and buildings, while landscape components such as plants, water features, and spatial sequences have received comparatively less attention [13]. In the context of Japanese gardens particularly stroll-style gardens, where sequential movement and changing viewpoints are fundamental design principles there remains a lack of empirical research examining how impressions such as beauty, comfort, and historical or cultural perception differ between VR-based experiences and conventional modes of appreciation [16].

Despite the growing availability of VR content for gardens and historical sites, it remains unclear how the increased freedom of movement afforded by VR influences the way Japanese gardens are experienced and interpreted. Addressing this gap, the present study investigates how impressions of a stroll-style Japanese garden change within a VR environment that allows users to explore the space freely, compared with conventional on-site or static visual evaluations.

Therefore, this study aims to examine the characteristics of 3D models created using Unreal Engine. To achieve this objective, a comparative analysis is conducted between the actual garden space and its corresponding VR environment. The study investigates the types of landscape experiences that occur within a VR environment that allows free viewpoint selection and clarifies the similarities and differences between these experiences and those in the real garden.

2. Methods

2.1 Target site

The study site, Kyu-Shiba-Riku Garden, is in Kaigan 1-chome, Minato Ward, Tokyo, in the coastal area of Tokyo Bay. Constructed in the early Edo period, it is a pond-centered stroll garden distinguished by its incorporation of seawater to create a tidal landscape. During the Meiji period, a Western-style residence was built on the grounds, and the garden was used to receive numerous foreign dignitaries as part of the Imperial Household's property. In 1924, it was opened to the public as a municipal garden of Tokyo City. Situated adjacent to JR Hamamatsu Cho Station, the garden was designated as a Place of Scenic Beauty by the Japanese government in 1979 [20] (Figure 1).

2.2 3D modeling of Japanese garden

In this study, Unreal Engine (ver. 5.3.2) was used as the primary platform for constructing the VR environment, and the Megascans (now Fab) library was employed to create natural elements such as trees, rocks, and water. Garden-specific components including lanterns, a pavilion, pine trees, and wooden and stone bridges were modeled in Blender (ver. 4.1) and imported into Unreal Engine. By utilizing Nanite, which enables real-time rendering of ultra–high-resolution 3D models, the system efficiently displays highly detailed and complex geometry while maintaining real-time performance [21].

The 3D model was developed based on on-site data collection, including photographs, video recordings, and 360-degree images. The model was further refined through multiple review sessions and consultations with university faculty members, industry professionals, and

garden staff, allowing for iterative improvements in accuracy and realism (Figure 2).

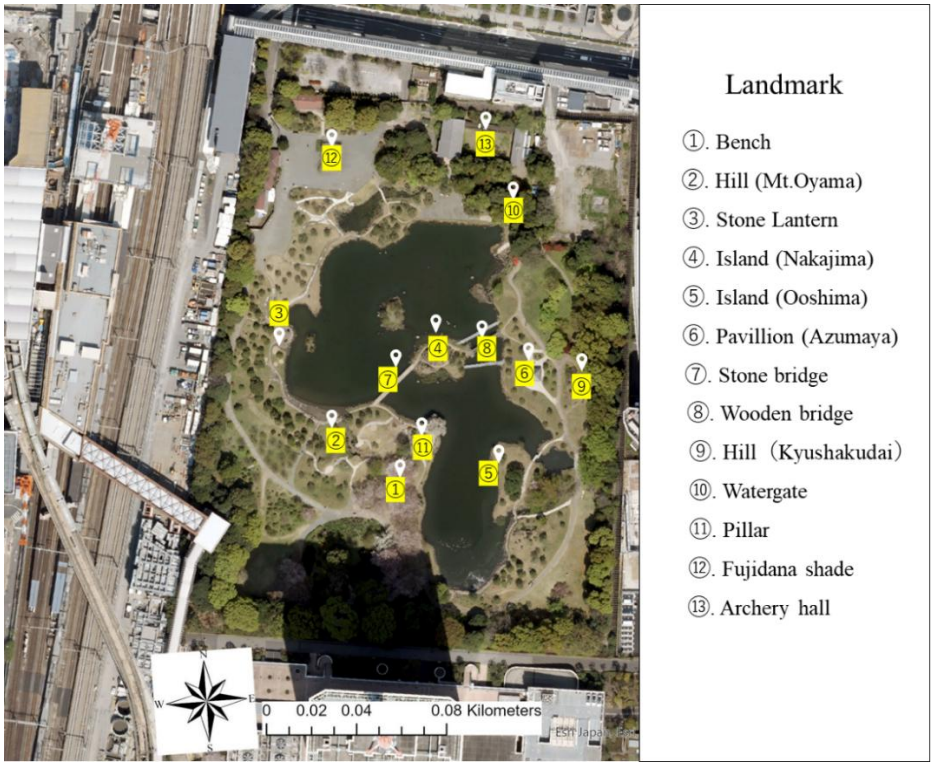

Figure 1 Kyu-Shiba-rikyu gardens map and Landmarks

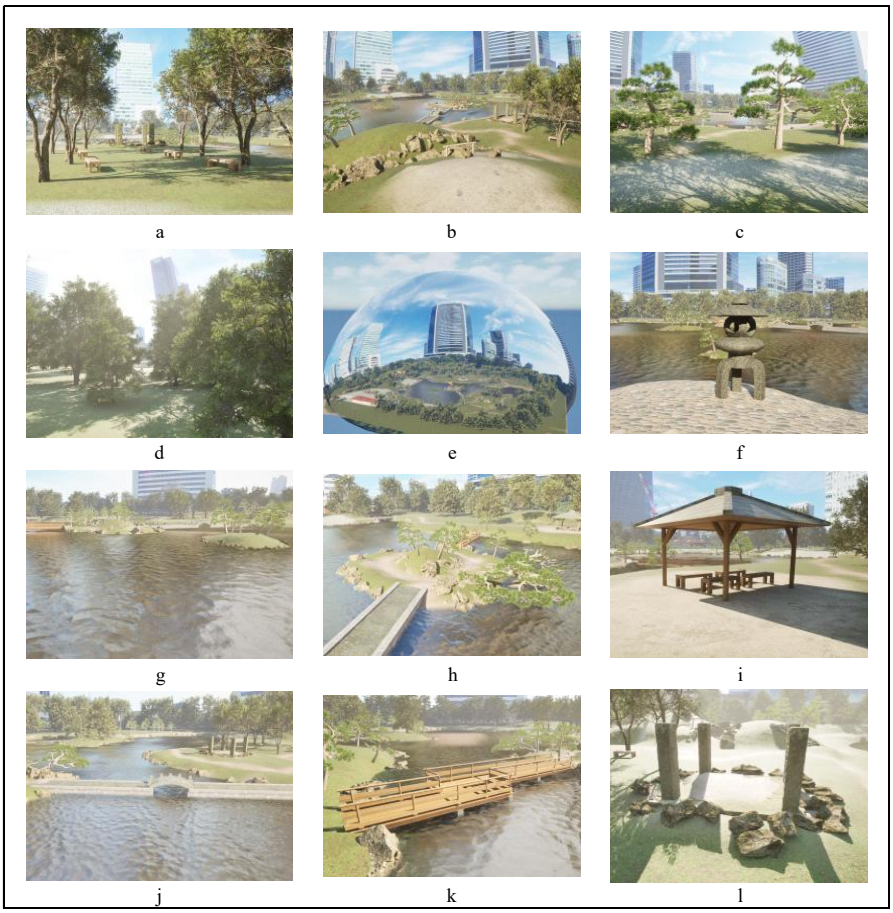

Figure 2 Unreal Engine based Kyu-Shiba-rikyu 3D model. a) bench, b) hill (Oyama), c) pine tree, d) trees, e) building (360-degree photo), f) stone lantern, g) pond, h) Island, i) pavilion and bench (azumaya), j) stone bridge, k) wooden bridge, l) Pillar

For system development and VR implementation, the hardware setup included a Mouse-brand desktop PC (Intel Core i7 CPU, 32 GB RAM, NVIDIA GeForce RTX 3060 Ti), an ASUS laptop (Intel Core i9 CPU, 16 GB RAM, NVIDIA GeForce RTX 4060 Ti), and a Meta Quest 2 VR headset.

2.3 Data collection

2.3.1. VR Experience Survey

For the implementation of the VR experience survey, two types of 3D model environments were developed in Unreal Engine: VR Mode and First-Person View Mode. In the VR Mode setup, SteamVR was first installed on the PC, and the Meta Quest 2 headset was connected to the computer using Oculus Link or Air Link. After enabling the VR plugins within c and preparing the application in a SteamVR-compatible format, participants were able to experience the 3D model by launching SteamVR and connecting the Meta Quest 2. The First-Person View Mode was used after the VR session, enabling participants to take screenshots of the viewing spots they selected during the experience (Figure 3).

The VR experience survey was conducted in a classroom at the Faculty of Horticulture, Chiba University, with a total of 73 individuals (36 male, 37 female) participants. Each participant wore a VR headset and spent approximately 10–15 minutes walking through the 3D model of Kyu-Shiba-rikyu Gardens. During the experience, they were instructed to take several photographs of locations where they perceived “beautiful scenery,” “comfort,” or “historical/cultural value,” and subsequently completed a questionnaire based on their impressions.

Figure 3 Environment set up for VR experience survey

Figure 4 Onsite experience survey

2.3.2. On-Site Garden Experience Survey

From the 73 participants who took part in the prior VR experience survey, 20 individuals (11 male, 9 female) individuals who agreed to further cooperation visited Kyu-Shiba-rikyu Gardens in person. While walking through the garden, each participant photographed locations where they perceived "beautiful scenery," "comfort," or "historical/cultural value," and subsequently completed a questionnaire based on their impressions (Figure 4).

2.3.3. Survey Overview

Using the photo projection method and the rating scale method, a comparative analysis was conducted between the VR experience and the actual garden experience. Participants were instructed to take photographs and record locations within each environment according to three pre-specified keywords, and to provide open-ended explanations of their reasons and impressions. In addition, participants evaluated both the VR space and the real garden space using six assessment criteria. A survey on participant attributes was also conducted. All survey instruments were administered using ArcGIS Survey123.

2.3.3.1. Evaluation of the VR and Actual garden

For the VR environment, six evaluation criteria were established: naturalness, reality, beauty, comfort, historical/cultural value, and satisfaction. For the real environment, four items were used: the extent to which the 3D model accurately represented Kyu-Shiba-Riku Garden, beauty, comfort, and historical/cultural value. All items were assessed using a five-point Likert scale.

2.3.3.2. Photography Based on Specified Keywords

Based on the relevance of the evaluation items, three keywords were designated: beauty, comfort, and historical/cultural value. Participants photographed locations in both environments where they perceived these qualities. If a participant did not identify a location corresponding to a given keyword, they were not required to take a photograph.

2.3.3.3. Open-Ended Responses

In the open-ended section, participants described the reasons for selecting the photographed locations corresponding to the three specified keywords. They were also asked to comment on the most memorable elements of both the VR and real garden experiences, as well as to provide additional impressions or opinions.

In the VR environment, a total of 193 photographs and 188 open-ended textual responses were collected, together with spatial distribution data. In the actual garden, 113 photographs

and 113 textual responses were obtained. All photographed locations were recorded, enabling a comparative analysis of participants' perceptual tendencies and spatial behaviors across the two settings.

2.4 Data handling and Analysis

2.4.1. Establishing the evaluation criteria

In this study, the evaluation criteria were established based on previous research and include naturalness, beauty, comfort, historical/cultural value, satisfaction, and reality. The selection of beauty, comfort, and naturalness is grounded in findings shared across both referenced studies. Impression-analysis research demonstrates that viewers assess Japanese gardens primarily through visual harmony, balance, and coherent spatial composition, which form the basis of perceived beauty. Elements such as stone placement, water reflections, depth cues, and coordinated vegetation contribute directly to aesthetic judgment. Comfort was selected because both studies show that psychological ease is shaped by openness, low visual pressure, gentle spatial transitions, and clear sightlines; gardens with calm water surfaces and stable spatial structure consistently evoke relaxation and emotional stability. The criterion of naturalness reflects repeated findings that viewers value ecological coherence and the organic integration of stones, plants, and terrain, with naturalistic spatial continuity enhancing familiarity and positive impressions. Together, these three criteria capture the core perceptual dimensions through which Japanese gardens are evaluated [17], [18].

The criterion of historical/cultural value was included because Japanese gardens represent one of the most distinctive expressions of Japanese cultural tradition, integrating scientific–philosophical, historical, architectural, artistic, and religious dimensions. Gardens have historically functioned as urban art forms, created to reintroduce valued elements of nature into increasingly urbanized environments [19]. Finally, satisfaction and reality were selected as general criteria relevant to evaluating and improving the quality and experiential authenticity of the 3D models.

2.4.2. Rating scale method

The results of the VR experience survey and the on-site garden experience survey, which were conducted using a rating-scale method, were analyzed based on descriptive statistics to identify overall trends. Following [22] guidelines on the use of Likert scales in research data analysis, scores on the five-point scale were interpreted as follows: 1.00–1.80 = "strongly negative," 1.81–2.60 = "negative," 2.61–3.40 = "neutral or slightly negative," 3.41–4.20 = "positive," and 4.21–5.00 = "strongly positive".

In evaluating the VR environment, it was assumed that participants' prior experience visiting the study site Kyu-Shiba-rikyu Gardens as well as their prior VR experience, might influence their ratings. Therefore, independent samples t-tests were conducted for the six evaluation items to examine differences based on garden-visitation experience and VR experience. The significance level was set at $p < 0.05$, and all statistical analyses were performed using IBM SPSS (version 30.0.0.0 (172))

2.4.3. Photo data

To understand the visual representations of Kyu-Shiba-rikyu Gardens, visual content analysis, a standard method for photo analysis, was conducted [14]. The photographs were classified into 18 categories based on their primary subjects, and the frequency and shooting rates of each category were calculated to examine the spatial distribution of visual representations. In addition, crosstabulation analysis was performed to compare category selection patterns between the VR environment and the actual garden. Chi-square tests were applied to assess the statistical significance of differences in selection frequencies, and standardized residual analysis was used to identify categories that contributed most strongly to these differences. [23],[24].

2.4.4. Text data

Content analysis of the textual data was conducted to examine how Kyu-Shiba-rikyu Gardens is perceived. Written responses were classified into eight thematic categories nature, garden elements, urban elements, comfort/emotion, viewpoint/scenery, history/culture, 3D models, and shadow/light and the frequency and proportional distribution of each category were calculated. In addition, crosstabulation analysis was performed to compare thematic

patterns between the VR environment and the actual garden. Chi-square tests were applied to evaluate statistically significant differences in category distributions, and standardized residual analysis was used to identify themes that contributed most strongly to these differences. The results reveal clear thematic tendencies in how participants verbally express their impressions of Japanese garden experiences across the two settings.

2.4.5. Spatial distribution data

Photos were geocoded by referencing collected photos and google street view. Kernel density estimation was performed to analyze the spatial distribution of the shooting locations using ArcGIS Pro for visualization. For analytical purposes, areas within the upper 25% of density values (≥ third quartile) were identified as high-density zones, while the density surface was visualized using five classes for display.

3. Result

3.1 VR experience

3.1.1 Evaluation results

The evaluations of the 3D models were positive overall, with no negative assessments observed. The mean values of the descriptive statistics for the six items indicated that the categories “comfort” and “history/culture” were rated as “positive (somewhat agree),” while the remaining four items received ratings of “highly positive (strongly agree)” (Table 1). These evaluation results suggest that elements such as trees, stones, and water created using 3D software and game engines can effectively represent natural and garden environments in an appealing manner.

Table 1 Descriptive statistics for VR

Category	Range	Minimum	Maximum	Mean	Std. Deviation
Nature	3	2	5	4.26	0.8
Beauty	3	2	5	4.44	0.687
Comfort	3	2	5	4.12	0.849
History and culture	4	1	5	3.59	1.116
Reality	3	2	5	4.29	0.677
Satisfaction	4	1	5	4.6	0.702

Table 2 t-test results by garden experience (experienced vs. inexperienced)

Category	**t-value**	**Degrees of Freedom**	**p-value**
Nature	0.07	0.09	0.9468
Reality	-0.87	0.77	0.3873
Beauty	0.29	1.24	0.7717
Comfort	1.71	0.67	0.0912
History and Culture	-1.23	8.33	0.2221
Satisfaction	-1.1	3.09	0.2739

Table 3 t-test results by VR experience (experienced vs. inexperienced)

Category	t-value	Degrees of Freedom	p-value
Nature	2.93	0.56	0.0046**
Reality	0.88	1.6	0.3837
Beauty	1.36	1.89	0.1778
Comfort	0.21	0.19	0.8322
History and Culture	0.9	0	0.3692
Satisfaction	2.76	10.09	0.0074**

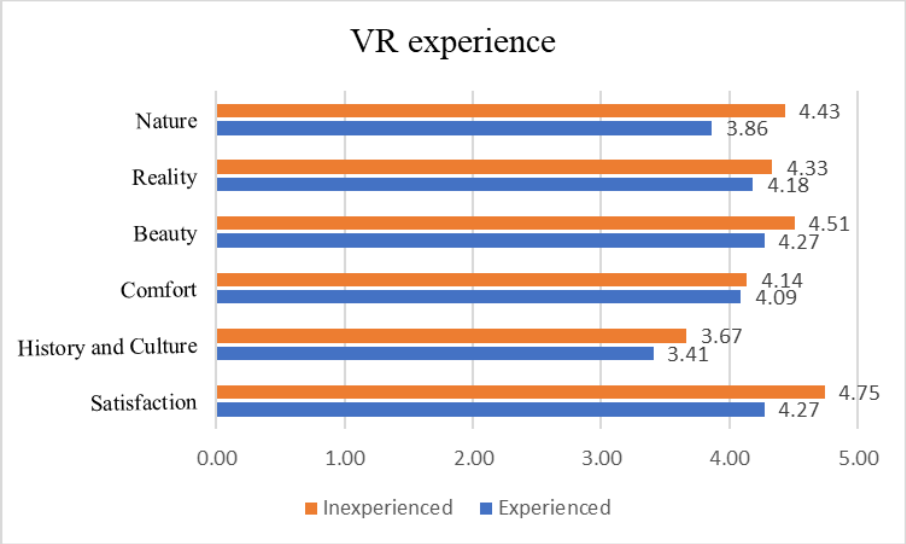

Figure 5 Mean evaluation scores by VR experience

To examine whether the evaluations on the six items differed according to prior experience, t-tests were conducted for two groups: 20 participants who had previously visited the Kyu-Shiba-rikyu Gardens and 53 who had not, as well as 22 participants with VR experience and 51 without such experience. The results indicated that, for all six items, the p-values for garden-visit experience exceeded 0.05, suggesting that prior garden experience did not produce significant differences in the evaluations (Table 2). In contrast, the comparison based on VR experience revealed statistically significant differences in two items “nature” and “satisfaction” with p-values below 0.05 (Table 3). The mean scores for each of the six items by VR experience are shown in (Figure 5).

3.1.2 How people perceive from photo

Overall, the adjusted residual analysis indicates that participants’ photo-taking behavior in the VR environment was structured by distinct perceptual cues for Beauty, Comfort, and History/Culture, rather than by landscape elements in general. Each category was characterized by a small number of elements that were selected significantly more or less frequently than expected, while most elements played a neutral background role.

For Beauty, selections were primarily guided by visually open and expansive features. Ponds were significantly over-selected (adjusted residual = +2.0), whereas shadowed areas were strongly under-selected (−3.8), indicating that brightness and openness were critical for aesthetic evaluation. Other elements showed no meaningful deviations.

For Comfort, moderated environmental conditions dominated selection behavior. Shadow exhibited an exceptionally strong positive deviation (+7.1), while stone lanterns (−3.5), ponds (−3.8), rocks (−2.9), and pillars (−2.6) were significantly under-selected, suggesting that hard or symbolic features reduced comfort perception.

For History and Culture, selections were clearly structured by symbolic and traditional elements. Stone lanterns showed the strongest positive deviation (+4.4), followed by rocks (+2.7), ponds (+1.8), stone bridges (+1.6), and pillars (+1.4), confirming the importance of culturally coded garden features in historical interpretation (Table 4).

3.1.3 How people perceive from text

We collected 188 textual responses regarding participants' reasons for choosing each spot and categorized them into eight thematic groups: nature, garden elements, urban elements, comfort/emotion, viewpoint/scenery, history/culture, 3D models, and shadow/light. (Table 5)

Overall, the adjusted residual analysis indicates that participants' photo-taking behavior in the VR environment was structured by distinct perceptual cues for Beauty, Comfort, and History/Culture, rather than by garden elements in general. Each evaluation category was characterized by a limited number of elements that were selected significantly more or less frequently than expected, while most elements functioned as a perceptual background (Table 6).

Table 4 Crosstabulation, Chi-square and Residual result (N=73) total of 193 photos

Category	Beauty N=72			Comfort N=65			History&Culture N=56			Chi-
	Selected	%	Residual	Selected	%	Residual	Selected	%	Residual	square
Bench	7	9.7%	-	8	12.3%	-	2	3.6%	-	-
Hill	4	5.6%	-	6	9.2%	-	8	14.3%	-	-
Pine tree	35	48.6%	-	31	47.7%	-	22	39.3%	-	-
Trees	65	90.3%	-	58	89.2%	-	50	89.3%	-	-
Buildings	55	76.4%	0.1	43	67.2%	-2	48	85.7%	2	0.06
Stone lantern	8	11.1%	-0.7	1	1.5%	-3.5	17	30.4%	4.4	<.001
Pond	61	84.7%	2	39	60.9%	-3.8	48	85.7%	1.8	<.001
Island	30	41.7%	0.8	18	27.7%	-2.1	25	44.6%	1.2	0.111
Pavilion	9	12.5%	-	8	12.3%	-	3	5.4%	-	-
Stone bridge	24	33.3%	0.9	12	18.5%	-2.4	21	37.5%	1.6	0.049
Wooden bridge	11	15.3%	-	9	13.8%	-	4	7.1%	-	-
Rock	37	51.4%	0.3	23	35.4%	-2.9	36	65.5%	2.7	0.004
Water gate	1	1.4%	-	1	1.5%	-	0	0.0%	-	-
Pillar	14	19.4%	1.2	4	6.2%	-2.6	12	21.4%	1.4	0.035
Shadow	3	4.2%	-3.8	29	45.3%	7.1	2	3.6%	-3.3	<.001
Fujidana shade	0	0.0%	-	3	4.6%	-	0	0.0%	-	-
Archery hall	0	0.0%	-	0	0.0%	-	1	1.8%	-	-
Sky	4	5.6%	-	5	7.7%	-	3	5.4%	-	-

Table 5 Textual response categorization

Category	Description
Nature	Water, trees, pine, greenery, and the richness of nature
Garden Elements	Bridges, pavilions, stone lanterns, islands, rocks, and other landscape design components
Urban	Buildings, urban scenery, and the contrast between the city and the garden
Comfort / Emotion	A sense of calmness, comfort, security, and pleasant feelings
Viewpoint / Landscape	Panoramic views, elevated vantage points, openness, and scenic outlooks
History / Culture	A sense of history, Japanese identity, tradition, and cultural heritage
3D Model	High-quality textures, beautiful water rendering, and the ability to explore freely
Shadow / Light	Dappled sunlight through trees, reflections of sunlight on water, relaxing shade, and the pleasantness of tree shadows

Table 6 Crosstabulation, Chi-square and Residual result (N=73) total of 188 text response

Category	Beauty(N=71)			Comfort (N=64)			History and culture (N=53)			Chi square
	Selected	%	Residual	Selected	%	Residual	Selected	%	Residual	
Nature	21	30%	2.7	15	23%	-	1	2%	-3.8	< .001
Garden elements	11	15%	-	5	8%	-3.1	23	43%	4.8	< .001
City	13	18%	3.8	0	0%	-3	3	6%	-	< .001
Comfort and emotion	8	11%	-	17	27%	3.8	0	0%	-3.4	< .001
Viewpoint and scenery	10	14%	2.4	4	6%	-	1	2%	-	0.038
History and culture	2	3%	-3.5	0	0%	-4	25	47%	8	< .001
Shadow and light	2	3%	-2.6	17	27%	5.4	0	0%	-	< .001
3D model	4	6%	-	6	9%	-	0	0%	-	-

For Beauty, selections were primarily guided by visually open and legible spatial features. Nature (adjusted residual = +2.7), City elements (+3.8), and Viewpoint and Scenery (+2.4) were significantly over-selected, indicating that openness, contrast, and panoramic visibility played a central role in aesthetic judgment. In contrast, History and Culture (−3.5) and Shadow and Light (−2.6) were significantly under-selected, suggesting that symbolic meaning and shaded conditions contributed less to perceived beauty in the VR environment.

For Comfort, selection behavior was dominated by environmental moderation and atmospheric qualities. Comfort and Emotion (+3.8) and Shadow and Light (+5.4) showed strong positive deviations, highlighting the importance of shade and emotional calmness for comfort perception. Conversely, Garden Elements (−3.1), City (−3.0), and History and Culture (−4.0) were significantly under-selected, indicating that hard, symbolic, or urban features tended to reduce comfort-related evaluations.

For History and Culture, selections were clearly structured by symbolic and traditional garden components. History and Culture itself showed an exceptionally strong positive deviation (+8.0), followed by Garden Elements (+4.8), confirming that participants relied heavily on culturally coded objects and spatial markers when interpreting historical value. In contrast, Nature (−3.8) and Comfort and Emotion (−3.4) were significantly under-selected, suggesting that experiential comfort and natural richness played a limited role in historical interpretation (Table 6).

3.1.4 Spatial distribution on VR

The results indicate that participants' photo-taking locations in the VR environment were spatially clustered rather than evenly distributed. Kernel density analysis further identified upper 25% density zones that revealed clear category-specific spatial tendencies. Beauty-related photo spots were concentrated along pond edges and near central islands, indicating that scenic openness and water surfaces strongly guided visual attention. In contrast, Comfort-related locations formed broader and more diffuse upper-density areas, primarily along shaded peripheral paths, suggesting that comfort was associated more with atmospheric conditions than with specific landmarks. History and Culture photo spots exhibited tightly clustered upper-density zones around symbolic elements such as stone bridges, lanterns, and island connections, reflecting focused cultural attention (Figure 6).

Overall, the upper 25% density patterns demonstrate distinct spatial differentiation in photo-taking behavior, with Beauty driven by visual composition, Comfort by environmental moderation, and History and Culture by symbolic garden features (Figure 7).

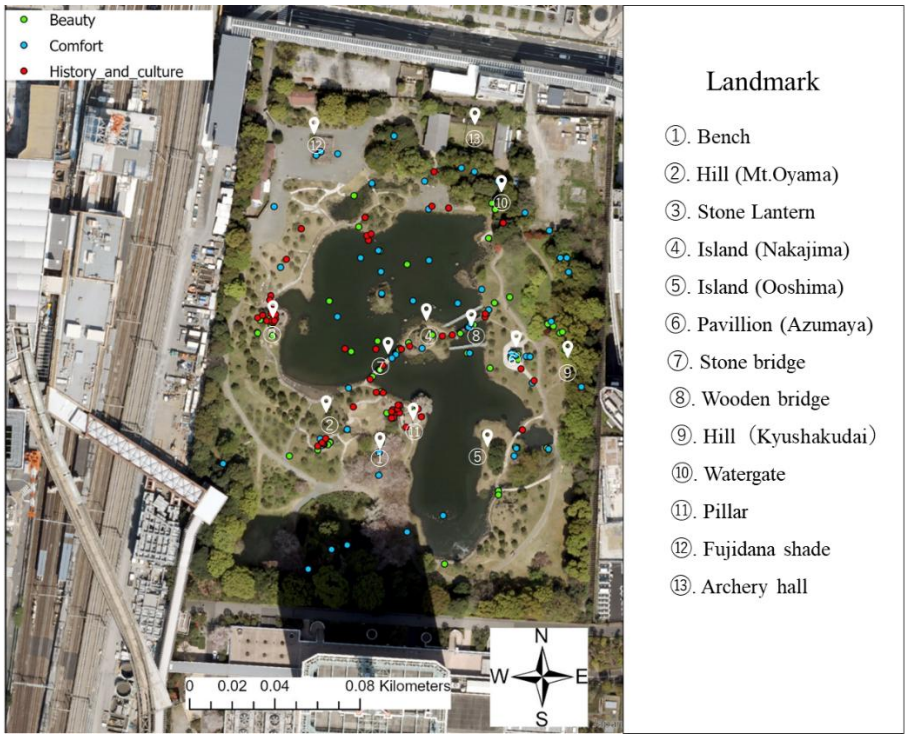

Figure 6 XY point distribution for VR

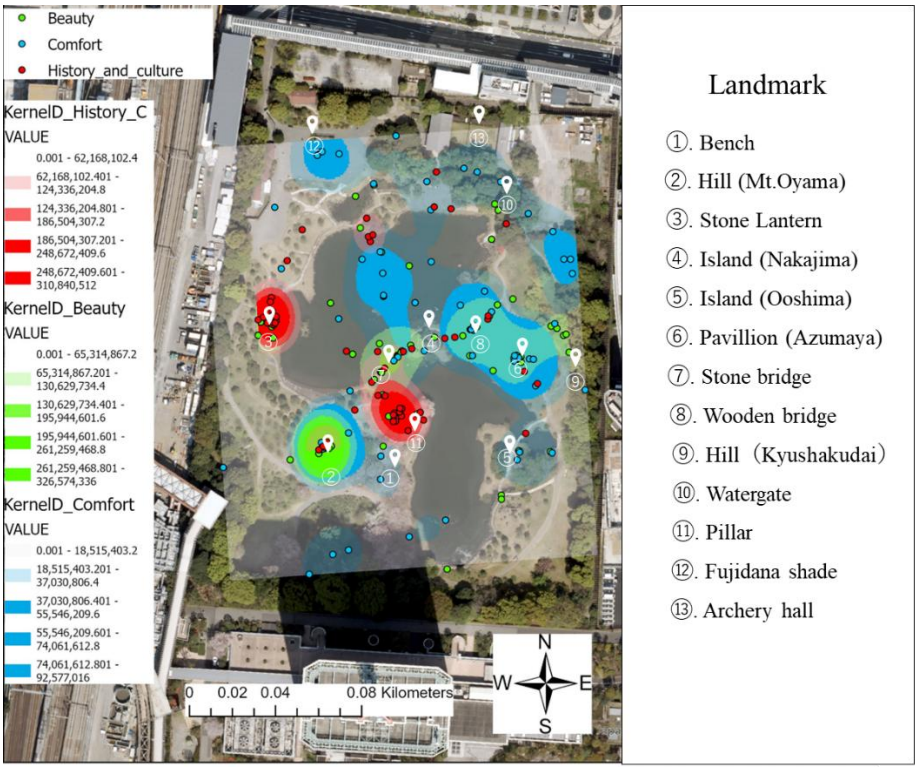

Figure 7 Kernel Density estimation for all categories on VR

3.2 Comparison of VR and Actual Garden

3.2.1 Evaluation of both spaces

The descriptive statistics indicate consistently higher ratings for the on-site garden compared to the VR environment across all categories. On-site evaluations of Beauty (M = 4.80) and Comfort (M = 4.70) were particularly high and showed low variability (SD = 0.41 and 0.47), suggesting stable and shared perceptions among participants. In contrast, VR evaluations exhibited lower mean scores and substantially greater variability, especially for Comfort (M = 3.55, SD = 1.50) and History and Culture (M = 3.50, SD = 1.32), indicating more diverse individual responses. The wider ranges in VR ratings (1–5) further suggest that immersive virtual experiences produced less consistent impressions than direct on-site experiences. (Table 7)

3.2.2 How people perceive from photo for VR and Onsite

Adjusted residual analysis showed that landscape element selection patterns were largely consistent between the VR and onsite conditions across the Beauty, Comfort, and History/Culture categories, with most elements exhibiting no meaningful deviations from expected frequencies.

Within the Beauty category, buildings, ponds, rocks, and stone lanterns showed neutral residuals ($|AR| < 1.96$), indicating similar selection tendencies across environments. Trees and pine trees displayed marginal onsite tendencies but did not reach meaningful thresholds. In contrast, islands (VR: AR = +2.1; onsite: AR = −2.1) and stone bridges (VR: AR = +2.4; onsite: AR = −2.4) exhibited clear residual deviations, indicating increased selection under VR conditions (Table 8).

For the Comfort and History/Culture categories, adjusted residuals for most elements remained within the neutral range, suggesting stable perceptual patterns across environments. Overall, the results indicate that while VR preserves general perceptual tendencies observed onsite, it selectively enhances attention to spatially distinctive features that benefit from freer movement and flexible viewpoints (Table 9, 10).

3.2.3 How people perceive from text for VR and Onsite

Adjusted residual analysis revealed clear differences between the VR and on-site conditions across the Beauty, Comfort, and History/Culture categories, indicating that each evaluative category was structured by a distinct pattern of element selection rather than by uniform emphasis across landscape components. Several elements exhibited meaningful residual deviations, confirming category-specific effects associated with the VR environment.

For Beauty, Nature showed a significant positive residual and History/Culture a corresponding negative residual, suggesting that aesthetic evaluations in VR were primarily grounded in natural qualities rather than symbolic or historical elements. In the Comfort category, Comfort/emotion and Shadow/Light displayed strong positive residuals, indicating that affective states and moderated environmental conditions were central to comfort perception in VR, while Garden elements showed negative residuals and were selected less frequently than expected. In contrast, History/Culture evaluations were strongly characterized by positive residuals for culturally symbolic elements and negative residuals for Nature, indicating a clear shift toward explicitly cultural cues in VR-based interpretation. City did not exhibit meaningful residual deviations, suggesting that urban references were not strongly associated with any single evaluative category (Table 11), (Figure 8).

Table 7 Descriptive statistics for VR and Onsite

Category	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
On site beauty	1	4	5	96	4.8	0.41
VR beauty	4	1	5	83	4.15	1.226
On site comfort	1	4	5	94	4.7	0.47
VR comfort	4	1	5	71	3.55	1.504
On site History and culture	2	3	5	85	4.25	0.716
VR history and culture	4	1	5	70	3.5	1.318

Table 8 Comparison of Beauty on VR and Onsite

Category	Beauty						
	VR			Onsite			
	Selected	Percentage	Residual	Selected	Percentage	Residual	Chi square
Bench	2	10%	-	0	0%	-	-
Hill	0	0%	-	3	15%	-	-
Pine tree	11	55%	0.3	10	50%	-0.3	0.752
Trees	17	85%	-1.8	20	100%	1.8	0.072
Buildings	16	80%	-0.4	17	85%	0.4	0.677
Stone lantern	3	15%	-	4	20%	-	-
Pond	19	95%	1.4	16	80%	-1.4	0.151
Island	9	45%	-	6	30%	-	-
Pavilion	2	10%	-	1	5%	-	-
Stone bridge	7	35%	-	3	15%	-	-
Wooden bridge	3	15%	-	1	5%	-	-
Rock	14	70%	0.7	12	60%	-0.7	0.507
Water gate	0	0%	-	0	0%	-	-
Pillar	7	35%	-	1	5%	-	-
Shadow	1	5%	-	0	0%	-	-
Fujidana shade	0	0%	-	0	0%	-	-
Archery hall	0	0%	-	0	0%	-	-
Sky	1	5%	-	1	5%	-	-

Table 9 Comparison of Comfort on VR and Onsite

Category	Comfort						
	VR			Onsite			
	Selected	Percentage	Residual	Selected	Percentage	Residual	Chi square
Bench	3	15%	-	4	20%	-	-
Hill	1	5%	-	5	25%	-	-
Pine tree	8	40%	-	8	40%	-	-
Trees	16	80%	-1.4	19	95%	1.4	0.151
Buildings	14	70%	-1.1	17	85%	1.1	0.256
Stone lantern	0	0%	-	0	0%	-	-
Pond	10	50%	-1.6	15	75%	1.6	0.102
Island	6	30%	2.1	1	5%	-2.1	0.037
Pavilion	1	5%	-	3	15%	-	-
Stone bridge	3	15%	-	0	0%	-	-
Wooden bridge	1	5%	-	0	0%	-	-
Rock	5	25%	-	5	25%	-	-
Water gate	0	0%	-	0	0%	-	-
Pillar	2	10%	-	4	20%	-	-
Shadow	9	45%	-0.9	12	60%	0.9	0.342
Fujidana shade	1	5%	-	2	10%	-	-
Archery hall	0	0%	-	0	0%	-	-
Sky	2	10%	-	1	5%	-	-

Table 10 Comparison of History and Culture on VR and Onsite

Category	History and Culture						
	VR			Onsite			
	Selected	Percentage	Residual	Selected	Percentage	Residual	Chi square
Bench	1	5%	-	1	5%	-	-
Hill	2	10%	-	2	10%	-	-
Pine tree	7	35%	-1.9	13	65%	19	0.058
Trees	16	80%	-	16	80%	-	-
Buildings	16	80%	-	17	85%	-	-
Stone lantern	3	15%	-1.1	6	30%	1.1	0.256
Pond	14	70%	0.7	12	60%	-0.7	0.507
Island	7	35%	1.9	2	10%	-1.9	0.058
Pavilion	0	0%	-	2	10%	-	-
Stone bridge	7	35%	2.4	1	5%	-2.4	0.018
Wooden bridge	1	5%	-	0	0%	-	-
Rock	10	50%	-	9	45%	-	-
Water gate	0	0%	-	0	0%	-	-
Pillar	6	30%	-1.6	2	10%	1.6	0.114
Shadow	1	5%	-	5	25%	-	-
Fujidana shade	0	0%	-	0	0%	-	-
Archery hall	1	5%	-	0	0%	-	-
Sky	1	5%	-	0	0%	-	-

Table 11 Comparison of textual response for VR and Onsite

Category	Beauty(N=20)					Comfort (N=20)					History and culture (N=20)					Chi-Square
	VR		On site		Residual	VR		On site		Residual	VR		On site		Residual	
	Selected(%)		Selected(%)		Selected	Selected(%)		Selected(%)		Selected	Selected(%)		Selected(%)		Selected	
Nature	5	25%	5	25%	3.1	4	20%	0	0%	-	0	0%	0	0%	-2.7	0.01
Garden elements	5	25%	4	20%	-	1	5%	0	0%	-3	4	20%	7	35%	2	0.01
City	0	0%	4	20%	2.2	0	0%	0	0%	-	0	0%	1	5%	-	0.169
Comfort and emotion	1	5%	0	0%	-2	2	10%	8	40%	4.1	0	0%	0	0%	-2.5	0.01
Viewpoint and scenery	3	15%	4	20%	-	2	10%	5	25%	-	1	5%	1	5%	-	0.01
History and culture	2	10%	1	5%	-3.1	0	0%	2	10%	-3.2	12	60%	11	55%	6.5	0.01
Shadow and light	1	5%	2	10%	-	6	30%	5	25%	3.8	0	0%	0	0%	-2.9	0.01
3D model	3	15%	0	0%	-	1	5%	0	0%	-	0	0%	0	0%	-	0.01

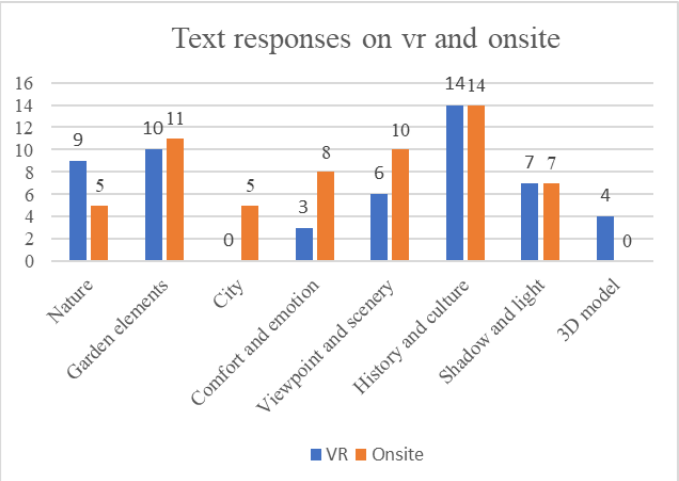

Figure 8 Textual response comparison graph

3.2.4 Spatial distribution on VR and Onsite

The results show that photo-taking locations were spatially clustered rather than randomly distributed in both VR and onsite conditions. Across both environments, Beauty, Comfort, and History/Culture points were concentrated around key landscape features, including pond edges, bridges, and island areas, indicating shared spatial focal points within the garden.

Kernel density analysis revealed differences in spatial distribution between the two conditions. In the VR environment, high-density areas were more spatially extensive and diffused, particularly around the central pond and circulation routes, reflecting freer movement and broader exploration enabled by flexible viewpoints. In contrast, onsite density patterns were more compact and strongly concentrated around specific landmarks, such as stone bridges and island connections, suggesting more constrained movement and focused attention.

Overall, while core focal locations were consistent, VR altered the intensity and spatial spread of photo-taking behavior, especially by expanding areas associated with Comfort (Figure 9, 10, 11).

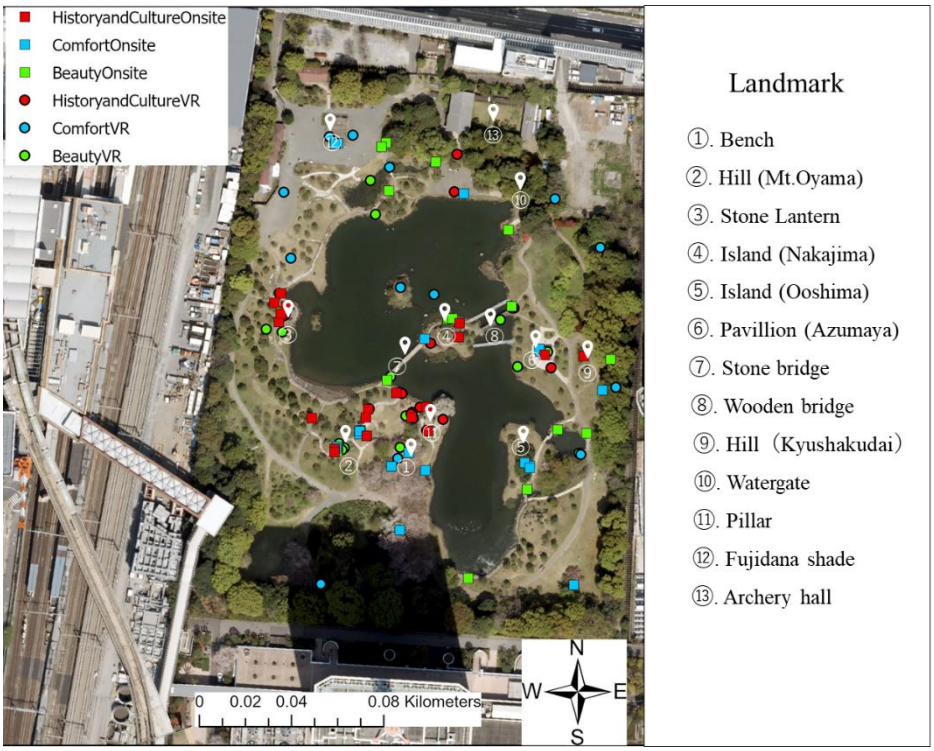

Figure 9 XY point distribution for VR and Actual Garden

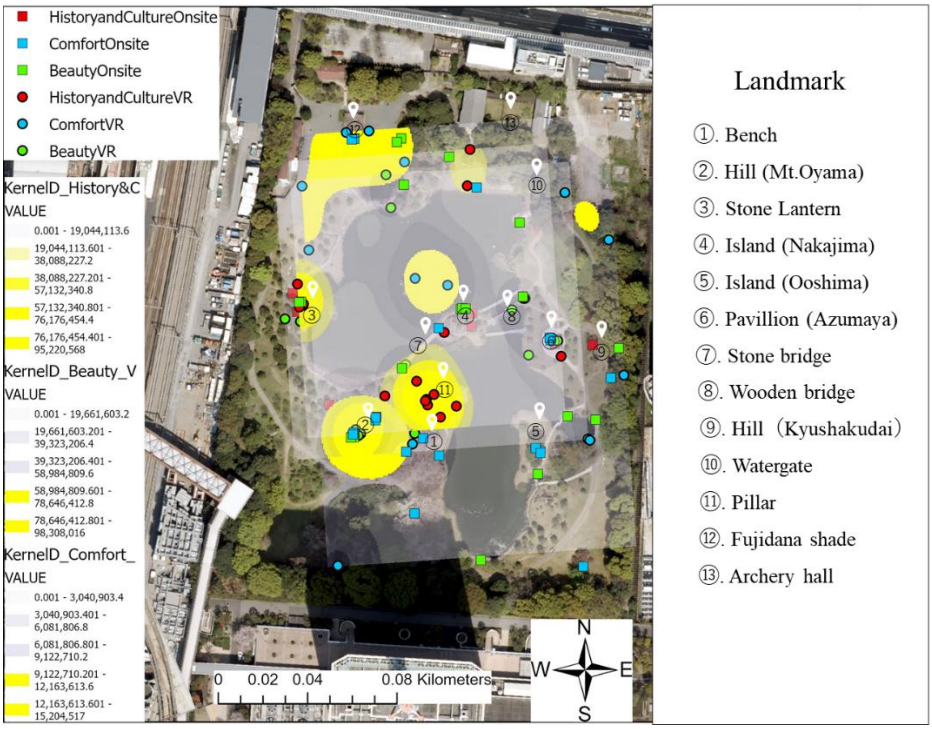

Figure 10 Kernel density estimation for VR

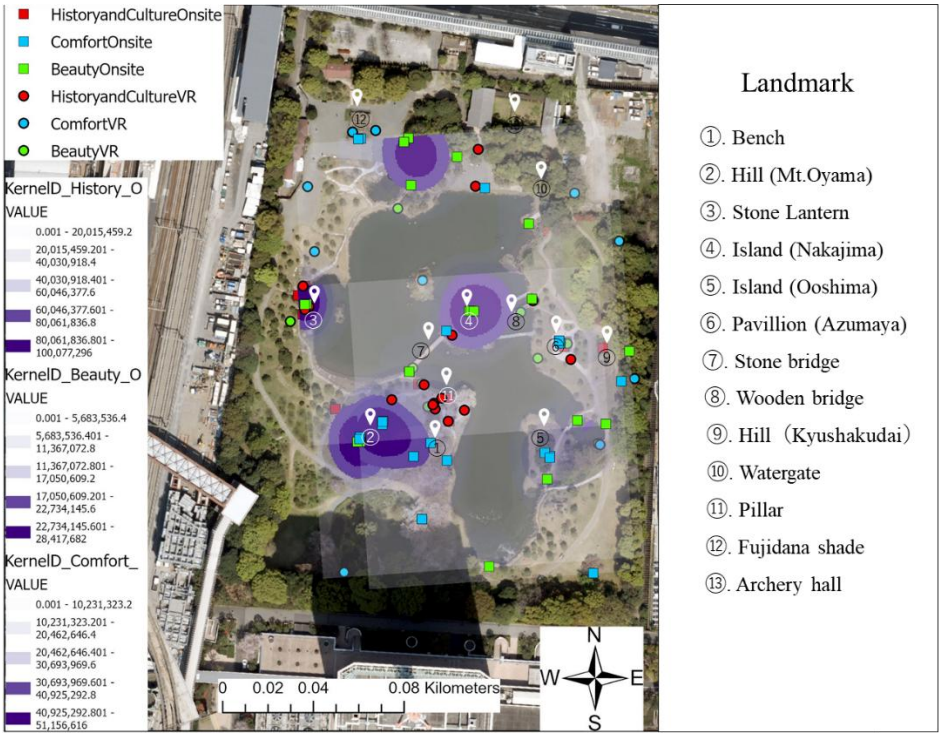

Figure 11 Kernel density estimation for Onsite

4. Discussion

This study aimed to examine the characteristics of a stroll-style Japanese garden 3D model created with Unreal Engine and to clarify how experiences in a freely explorable VR environment compare with those in the actual garden. Overall, the results show that the VR model successfully preserved the main perceptual structure of garden appreciation beauty, comfort, and historical/cultural value were consistently associated with distinct cues while also introducing specific shifts linked to VR's freedom of movement, viewpoint flexibility, and rendering conditions.

VR as a valid medium for evaluating stroll-garden experience: The key objective of this study was to examine whether a VR environment can support the evaluation of stroll gardens, in which sequential movement and changing viewpoints are essential. The VR results indicate that participants' impressions were not random: photo-taking locations showed clear spatial clustering, and both photographic and textual data revealed distinct category-specific patterns. These findings suggest that VR enables users to form structured judgments through active movement and exploration, which is consistent with the fundamental design logic of stroll gardens, such as sequential scenery along paths, pond-centered compositions, and the use of bridges and islands as experiential nodes. It can therefore be inferred that the landscape experience expanded beyond the viewpoints originally intended by the garden designers, allowing visitors to perceive the garden from multiple and diverse perspectives.

Category-specific cues were preserved in VR: The residual-based analyses show that the three evaluation categories were organized by different cues rather than by landscape elements in general. In the VR-only analysis, Beauty was linked to openness, nature-related descriptions, and panoramic viewpoints, Comfort to emotional ease and shadow/light, and History/Culture to culturally coded structures and garden elements. These patterns suggest that the VR model reproduced key interpretive pathways through which Japanese gardens are typically appreciated: scenic composition for beauty, environmental moderation for comfort, and symbolic objects for historical meaning. The strong positive associations for History/Culture themes further indicate that users could recognize and articulate culturally meaningful features within the virtual representation.

Similarities and differences between VR and on-site experience: A second objective was to identify similarities and differences between VR and real-garden experiences. At the element-selection level, most items did not differ meaningfully between conditions, suggesting that VR can preserve general attention patterns to major garden components. This is important because it indicates that the VR environment did not broadly distort what participants considered relevant for each category.

However, VR also produced selective enhancements. Islands and stone bridges showed clear residual deviations in the VR-on-site comparison, implying that spatially distinctive features became more salient in VR. This is consistent with the affordances of VR: users can adjust viewpoint freely, revisit locations without physical effort, and potentially access angles that are difficult or constrained on-site. These factors likely increase the visual legibility of structural connectors (bridges) and focal nodes (islands), which are central to pond-centered stroll garden composition. In contrast, on-site evaluations were consistently higher and less variable, suggesting that real environments provide richer multisensory information and more stable experiential cues, while VR produces more individualized responses depending on familiarity with VR, navigation behavior, and sensitivity to visual realism.

Implications for Unreal Engine–based garden modeling: Because the study specifically examined an Unreal Engine model, the findings also highlight practical implications for digital garden representation. The strong role of shadow/light in Comfort judgments in VR suggests that lighting simulation and shading conditions are not merely aesthetic improvements but can influence perceptual evaluation outcomes. Likewise, the selective amplification of islands and bridges implies that spatial composition and navigation design (movement constraints, viewpoint height, path guidance) directly shape what users notice and how they interpret the garden. Therefore, when Unreal Engine models are used for evaluation or public engagement, careful control of lighting, water rendering, and navigation settings is critical to ensure interpretive validity relative to on-site experience.

5. Limitations and future issues

This study has several limitations. First, the VR environment relied primarily on visual information and did not include multisensory elements such as sound, wind, temperature, or smell, which are important components of Japanese garden experiences. This limitation may have influenced the lower and more variable evaluations of Comfort and History/Culture in VR compared with the on-site condition.

Second, the number of participants in the on-site survey was smaller than in the VR survey, which may limit the robustness of the comparative analysis. Future studies should aim for more balanced sample sizes.

Third, spatial analysis was based on photo-taking behavior, which captures salient locations but may not fully represent continuous or transitional experiences inherent to stroll gardens. Incorporating movement or gaze data would provide deeper insight.

Finally, as this study focused on a single garden, future research should examine multiple garden types and design styles. In light of recent advances in immersive technologies, real-time rendering, spatial data analysis, and cloud-based delivery methods such as pixel streaming, combining VR with enhanced multisensory simulation and advanced interaction metrics is expected to offer new possibilities for scalable landscape evaluation, remote participation, design assessment, and heritage preservation.

6. Conclusion

This study investigated how a stroll-style Japanese garden is experienced in a freely explorable VR environment created with Unreal Engine, and how those experiences compare with perceptions formed in the actual garden. The results indicate that VR can reproduce the core perceptual structure of garden appreciation: Beauty, Comfort, and History/Culture were guided by distinct cues in both photo-based and text-based responses, and photo-taking locations showed clear spatial clustering rather than random selection.

At the same time, VR introduced selective differences. While most landscape elements showed broadly similar selection tendencies across VR and on-site conditions, spatially distinctive features particularly islands and stone bridges became more salient in VR, likely due to freer movement and flexible viewpoints.

Unreal Engine based VR environments are a promising tool for evaluating and communicating stroll-garden experiences, especially for analyzing viewpoint-dependent scenic composition and culturally meaningful structures, while also emphasizing the need to carefully manage VR-specific factors such as navigation and lighting to maintain comparability with on-site impressions.

Overall, the results of this study demonstrate that VR developed using Unreal Engine is effective not only for the preservation and archiving of traditional gardens but also as a tool for enhancing viewers' experiences by removing physical constraints. Crucially, to accurately evaluate the impact of intricate features such as water surface reflections and material textures, the researcher personally developed a high-fidelity VR environment, directly incorporating expert feedback from garden specialists and site administrators. This rigorous development process ensured a level of precision that meets professional standards, enabling a qualitative experience comparable to that of the actual site. These findings suggest that such purposefully constructed VR environments have significant potential to broaden and redefine future approaches to the appreciation of Japanese gardens.

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抄録

本研究は、Unreal Engine を用いて構築した自由に回遊可能な仮想現実（VR）環境において、回遊式日本庭園がどのように知覚されるのかを明らかにし、その印象を実空間での体験と比較することを目的とした。対象地である旧芝離宮恩賜庭園の VR モデルを作成し、VR 体験調査（N＝73）および現地の庭園体験調査（N＝20）を実施した。参加者は「美しさ」「心地よさ」「歴史・文化」を感じた地点を撮影し、評価尺度による評定および自由記述回答を行った。写真データ、テキストデータ、ならびに空間分布について、カイ二乗検定、調整済み残差分析、カーネル密度推定を用いて分析した。

その結果、VR 環境においても庭園鑑賞における基本的な知覚構造が保持されていることが確認され、「美しさ」「心地よさ」「歴史・文化」はそれぞれ異なる手がかりに基づいて評価される傾向が示された。また、多くの景観要素において VR と実空間で類似した選択傾向が認められた一方で、島や石橋といった空間的に特徴的な要素は、VR 環境において相対的に顕著化する傾向が明らかとなった。

これらの結果は、学術的意図に基づいて構築された VR が、将来的に庭園鑑賞のあり方を広げ、再定義するツールとして広く活用できる可能性を明らかにしたものである。