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Touring Pattern of Chinese Classical Gardens Based on VR and Eye Tracking Experiment: A Case Study of Canglang Pavilion Garden in Suzhou City

GAO Yiming, CUI Shuangyi, REN Sihan, ZHANG Yimeng*
(School of Architecture and Art, North China University of Technology, Beijing 100144, China)

Abstract Classical Chinese gardens, with their intricate interplay of architectural landscapes featuring narrow corridors and expansive courtyards, are designed to surprise and captivate visitors at every turn. Unraveling the connection between visual perception, walking behaviors, and the spatial elements of these garden compounds is essential to grasping the essence of traditional Chinese garden design. This study employs Virtual Reality (VR) and eye-tracking technologies to evaluate the touring patterns within Chinese classical gardens, with a case study focusing on the Canglang Pavilion Garden in Suzhou. A total of 68 participants were enlisted to engage in a VR experiment simulating a visit to a courtyard space within this garden. The study analyzed route choices between 2 distinct spatial types: corridor-architecture and courtyard-wall. Eye movement indicators within the Areas of Interest (AOIs) for frame-of-view and depth-of-view spatial elements were monitored, and visitors' spatial-temporal trajectory maps were documented. This research offers valuable insights into the intricate dynamics between visual attention, spatial elements, and visitor behavior within garden environments. The methodology applied in this study has broad implications for environmental psychology, landscape architecture, and the study of cultural heritage sites, providing a deeper understanding of the interactions and perceptions of visitors within garden spaces.

Keywords Classical Chinese Gardens, Garden spatial creation techniques, Canglang Pavilion Garden in Suzhou, VR, Tour pattern

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1 Introduction

Classical Chinese gardens are composed of a series of architectural landscape, with narrow corridors and broad courtyards, continually generating surprises for the walkers, thus making people feel attracted. People also often feel lost in such kind of maze landscape which aims at guiding people on their tour behavior. The difficulty in explaining its spatial structure often makes Chinese garden something mysterious and intricate, which hinders on its spread world widely. The structure of "buildings, corridors, and walls combined to form a courtyard" is common on the spatial creation of Chinese classical gardens[1]. Through the spatial sequences of layered courtyards made up of buildings, walls and corridors, traditional Chinese gardens lead to a rich variety of touring behaviors and psychological activities to achieve the aesthetic effect of shifting views. Therefore, to find the association between subjective visual and walking behaviors and the spatial elements of garden compounds is the key to interpret the essence of traditional Chinese garden landscape.

By studying the path selection and tour patterns of visitors on courtyards of traditional gardens, it is possible to analyze the attractiveness of garden space, and further analyze the mysteries of the garden spatial creation. In previous studies, diagram method has been widely used to analyze the spatial creation of Chinese classical gardens, but this approach has certain disadvantages on its static perspective, that it cannot intuitively respond to the continuous reaction of garden visitors. Chinese garden research mostly emphasizes the step-by-step changes with time, and the changes in the feelings they trigger as well[2]. The diagrammatic medium is static, which cannot reflect the real-time walking choice of visitors[3]. A recent study uses recorded video analysis and quantitative research method to study visitors' tour behaviors and spatial distributions in Chinese Garden to establish the composition of charming space in classical gardens[4]. But video analysis is time-consuming and is not conducive to eliminating the influence of unfavorable factors like human traffic and noise in the experiment. Nowadays, the development of VR (Virtual Reality) and eye tracking technologies have brought a new direction to the Chinese garden research aiming at evaluating on its touring pattern.

1.1 Use of eye tracking on evaluating touring behavior of Chinese classical gardens

The VR experiment method applied in tour behavior research utilizes immersive virtual environments to simulate the experience of physically being in a garden. VR technology offers an immersive experience that closely mimics the real-world exploration of a Chinese garden, allowing for a more natural and intuitive response from participants. This method allows researchers to study visitors' behavior and spatial cognition without the constraints and limitations of physical space. Participants can experience the garden without the physical constraints of the actual space, making the experiment safer and more accessible. It can also eliminate the impact of unfavorable factors such as human traffic and noise, providing a more controlled setting for the experiment. VR experiments are less time-consuming compared to video analysis in real settings, as they allow for rapid setup and modification of experimental conditions.

Moreover, instead of being a viewer in designer's narrative mode as in traditional media, VR technology allows the user to be not only a receiver but also a transmitter of information. The VR platform allows for precise tracking and recording of participant movements and choices, providing a rich dataset for analysis. By analyzing the route choices and VR roadmaps of participants, researchers can gain insights into wayfinding and walking behaviors, which can enhance the understanding and interpretation of the spatial structure of Chinese gardens.

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* Corresponding Author.

1.2 Use of eye tracking on evaluating touring behavior of Chinese classical gardens

Eye tracking is another emerging technology used to measure either the point of gaze (where one is looking) or the motion of the eyes, relative to changes in the visual scene. It involves the use of various devices or software that can detect where a person is looking, the duration of the gaze, and the sequence of eye movements. In previous studies, the association between garden landscape elements and visual perception has been analyzed using landscape picture stimulus materials combined with eye-tracking, and the results show that the total number of gaze counts index in eye-tracking can objectively reflect the interest in visual gaze and the pattern of gaze in the garden space[5]. The eye-tracking experimental study of garden depth of field and frame variable photographs shows that "the richness of the depth of field brings longer gaze time, and the framing technique makes the distribution of gaze points more concentrated"[6]. However, 2D landscape material can only assess static gaze interest, and cannot reflect the subject's visual behavior that changes in real time as it moves through space. By using VR technology with immersion, interaction and imagination features for the study of touring experience of Chinese classical gardens, a high-resolution virtual image without the influence of other factors can allow users to be completely immersed in the virtual world, where they can observe the details of the garden more clearly and enhance the visual experience. VR tour perception evaluation, when combined with eye tracking, enable the measurement of physiological indicators related to visual behavior and cognitive processes. These metrics are crucial for gauging the visual attentions of users within the virtual garden setting.

1.3 Combination of VR and eye tracking on evaluating touring pattern of Chinese classical gardens

Touring pattern of Chinese garden consists of 3 parts: "touring", "viewing" and "perceiving". "Touring" is a dynamic behavioral process of visiting the garden. "Viewing" mainly refers to the visual experience of observation. "Perceiving" is a comprehensive feeling of "touring" and "viewing"[7]. Following this logic, we made an analysis on the possibilities of applying VR and eye-tracking techniques for the evaluation of touring patterns. In the context of Chinese gardens, which are known for their complex and intricate spatial layouts, the VR experiment method provides a controlled and flexible platform to observe and analyze visitors' path selection and tour tracking within the garden setting. Eye-tracking technology, on the other hand, measures visitors' visual attention and viewing behavior. By combining eye-tracking with VR, researchers can gain a deeper understanding of the tour pattern involved in the garden experience. To illustrate this analytical process, a representative Chinese classical garden named Canglang Pavilion Garden in Suzhou was selected as a case study to interpret the process of evaluating "touring (VR)" and "viewing (eye tracking)" behavior, thus resulting in the exploration on comprehensive touring experience of Chinese classical gardens. The significance of this study is to help garden managers to better plan paths, set up attractions, and improve signage to enhance the overall experience of visitors and the attractiveness of the garden.

2 Materials and methods

The courtyard space adjacent to Cui-Ling-Long Pavilion in the Chinese classical garden Canglang Pavilion in Suzhou was chosen as the subject of the experiment. This courtyard space is enclosed by a single corridor, the Cui-Ling-Long building, a wall with a moon gate, and a folding corridor. According to its spatial sequence, it can be divided into a single corridor-architecture route (Group A) and a courtyard-wall route (Group B), which represent 2 types of spatial elements of the enclosing courtyard (Fig. 1). Group A of corridor-architecture space type is a single-sided colonnade with one side facing the courtyard. The corridor ends in 3 doorways, connecting more architectural levels. The courtyard-wall space of Group B consists of an open courtyard space and a wall that serves as an enclosing interface with a circular moon gate. The corridor-architecture type of space is more narrow and closed, while the courtyard-wall space is relatively open, and these two types of space play the role of connecting the whole garden spatial sequence, bringing people a very different psychological feeling.

The experiment took the moment of ending the tour of the folded corridor and entering the open courtyard space as the starting point, and the single corridor-architecture route and the courtyard-wall route as the control of the spatial structure sequences of the 2 different types of gardens. The aim of the study was to investigate whether the corridor-architecture space type (Group A) or the courtyard-wall space type (Group B) was more visually attractive in the garden courtyard space structure sequence. In the experiment, the subjects were not guided by a specific task, and were only instructed to freely choose the path to visit the garden space, and the spatio-temporal behavioral trajectory map was collected through the software background to analyze the subjects' choice of the type of space to visit.

According to existing research, "depth of view" and "frame of view" elements are visually appealing to step-in behavior in gardens[6]. View depth elements refer to transportation paths like roads and steps that guide the way of visitors. View frame elements refer to windows, doorways, or other openings in buildings that frame views of the garden to create picture-like composition. In order to further understand whether the frame of view or depth of view elements cause more influence on path selection when making pathfinding decisions in garden space, the experiment delineated the doorway that attracted vision as the eye movement interest area (AOI) of the view frame category, and the paths as the eye movement interest area of the view depth category, and collected eye tracking data including First Fixation Duration, Total Fixation Duration, Fixation Count (Fig.2).

The eye is the first sense to acquire external information, and the physiological signals produced by eye movements are the most objective source of data to express the psychological state. In eye tracking experiments, Area of Interest (AOI) is often used to understand how users interact with and perceive different parts of a visual layout. An AOI is a specific region within a visual scene or display that is predefined by the researcher or analyst as being of particular interest for analysis. Time to First Fixation (TTFF) refers to the time it takes from the onset of stimulus presentation to the observer's first fixation within the AOI. First Fixation Duration (FFD) refers how long the eyes are fixated on the area of interest during the initial encounter with that area. Total Fixation Duration (TFD) indicates the cumulative time the user's gaze spends on a specific AOI across all fixations. Fixation Count (FC) means the total number of times the user's gaze fixates on an AOI. Usually a higher total number and duration of gaze indicates that the content of the area of interest is more attractive and the viewer is more interested in the area of interest[8]. These eye-movement indicators have important scientific value for understanding the visual cognitive process in garden space (Table 1).

Based on the site research and shooting pictures of Canglang Pavilion Garden in Suzhou, the virtual simulation of the experimental scene was carried out by using Google Sketchup and Unity software. Long-pressing the handle was set as the interactive action to trigger the continuous walking behavior, and the walking speed was preset as the normal walking speed of 1.5 m/s for adults. The collection and analysis of the eye movement and walking behavior data were carried out by using ErgoLAB platform from Kingfar Corporation. The spatial and temporal behavior module of the software can collect real-time movement trajectory coordinates in the experiment, and the VR eye tracking data can be collected simultaneously by using HTC VIVE PRO Eye, a VR head-mounted display device with eye tracking function.

A total of 68 people were recruited for the experiment, with the ratio of men and women basically the same in the experiment, all of whom were students ranging from 20 to 28 years old without 3D vertigo syndrome, with normal spatial perception and normal corrected visual acuity in both eyes, and the VR experiment was carried out without interfering factors in a VR lab room of 40 km^2. In the experiment, subjects were not familiar with the specific map before the start, and this was their first time to participate in the experiment. After clarifying how to use the VR experimental equipment, participants wore the VR head mounted device (HMD) to roam in the garden. Then, they first got familiarized themselves with the VR experimental environment through a tour of the folded corridor space and learned to operate the VR equipment. The experiment started at the exit of a folded corridor, and the subjects were told by voice command that they could choose the path freely and start the tour of the garden space. The subjects could trigger the walking experience through the control handle when sitting on a backless swivel chair, rotating the head and body to independently control the direction of the tour, and the system would automatically and synchronously record the eye movement data and spatial-temporal behavioral trajectory of the subjects. VR and other equipment wearing process is cumbersome, and long-time wearing may cause vertigo and other errors that affect the experimental results. Therefore, each subject's experimental time was controlled within 30 minutes. A total of 68 sets of valid experimental data were collected. The data were analyzed using SPSS statistical software to derive the experimental results.

3 Results

In the study of path selection, an analysis of 68 spatiotemporal behavioral trajectories revealed a significant preference for courtyard spaces over corridor spaces. The spatial-temporal trajectory map provided a visual representation of how

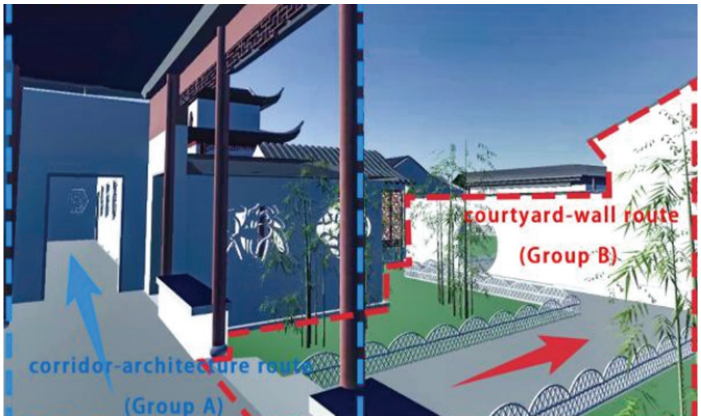

Fig.1 Grouping of corridor-architecture spatial type and courtyard-wall spatial type in a courtyard space in Canglang Pavilion Garden in Suzhou

Fig.2 Areas of interest (AOI) of depth-of-view and frame-of-view type in in a courtyard space in Canglang Pavilion Garden in Suzhou

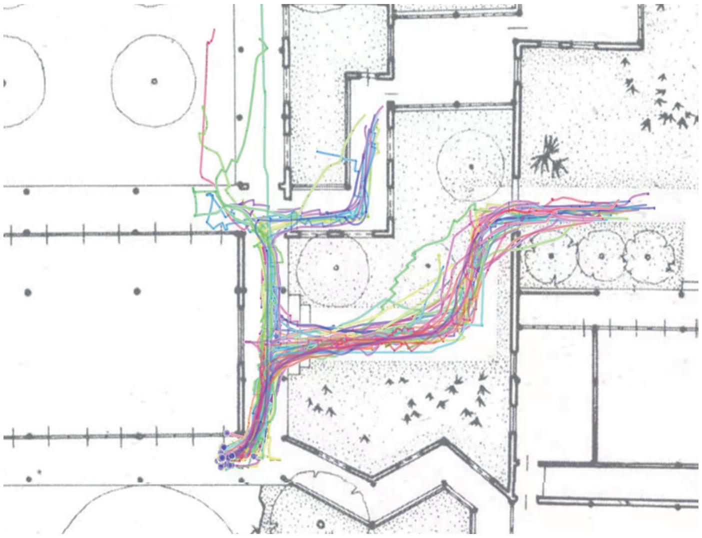

Fig.3 Spatial-temporal trajectory map of touring behaviour in a courtyard space in Canglang Pavilion Garden in Suzhou

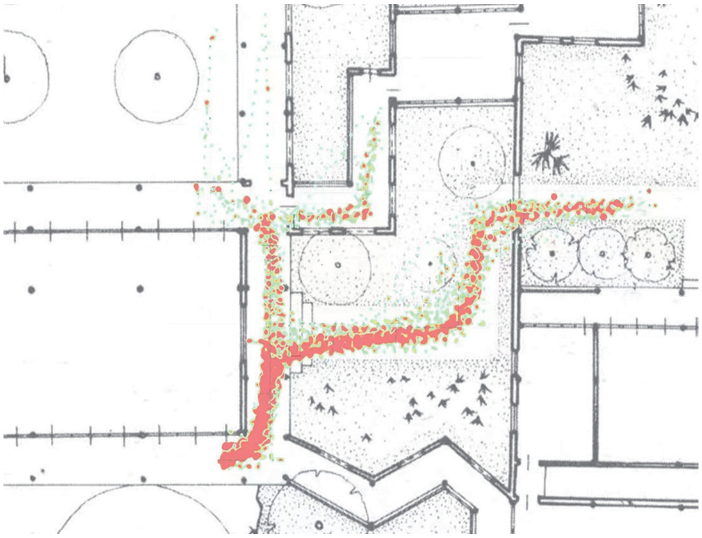

Fig.4 Spatial-temporal heat map of touring behaviour in a courtyard space in Canglang Pavilion Garden in Suzhou

visitors moved through the garden (Fig.3 & 4). Specifically, 47 participants opted to explore the courtyard areas, while only 28 chose the corridor spaces. This initial observation suggests that spaces characterized by courtyards and walls are more appealing than those defined by corridors and buildings. However, the question arises: which spatial visual elements predominantly influence decision-making during the path selection process?

To delve deeper into this question, we analyzed the eye-tracking data of the 47 participants who chose to enter the courtyard spaces. The results indicated that the TTFF in the depth-of-view AOI was shorter than in the frame-of-view AOI, suggesting that participants in the depth-of-view AOI took less time to first fixate on the area of interest. However, the difference was not statistically significant (P>0.05). The FFD in the depth-of-view AOI (13.42 s) was longer than in the frame-of-view AOI (15.86 s), indicating that participants in the depth-of-view AOI spent more time on their first fixation, which in turn suggested that the depth-of-view elements might have more engaging or complex content on the initial gaze. However, the total duration and number of fixations on the frame of interest areas (4.52 s, 23 times) was slightly higher than that on the depth of field interest areas (2.70 s, 19 times) (Table 2), suggesting that while visitors first noticed elements associated with the depth of the space, such as pathways, their visual interest shifts towards elements that constituted the depth as they progressed through the garden, particularly those formed by doorways and other frame-like structures. This is also evident in the gaze heat map (Fig.5), where areas with higher intensity or color saturation indicate more frequent and longer fixations. And the gaze path map (Fig.6) suggests visitors' gaze shifting drawn between 2 types of spatial elements.

4 Discussion

These findings provide valuable insights into the visual attention patterns of individuals in garden environments, which are crucial for understanding the behavioral and psychological tendencies of people as they navigate and visually perceive courtyard spaces in gardens. The initial fixation on depth elements like pathways could be attributed to the natural human inclination to follow paths and seek out navigable routes, which serve as the primary means of exploration and movement within space.

As the visitors continue their journey, the increased interest in frame elements like doorways could be due to several factors. These elements not only serve as visual markers that guide visitors through the space but also offer glimpses into other areas of the garden, creating a sense of mystery and inviting further exploration. The frame elements also play a role in creating a dynamic visual experience, as they frame views and scenes, much like a picture frame in traditional art. This framing effect can enhance the aesthetic appeal of the garden, drawing visitors' attention and influencing their path selection.

Furthermore, the interaction between visitors' and the garden's spatial elements is a dynamic process that involves continuous adjustments and reassessments, as seen in the spatial-temporal trajectory map of touring behavior (Fig.3 & 4). As the visitors move through the garden, their visual attention is drawn to different elements, and their path selection is influenced by a combination of factors, including the layout of the garden, the visual cues provided by the environment, and their personal preferences and expectations.

5 Conclusion

The courtyard space technique of creating walls and corridors in classical gardens has an impact on the path-choice decisions of garden visitors. In the spatial sequence of the Canglang Pavilion Garden, after having visited a section of space-defining folded corridor space, people are more inclined to turn into the open courtyard space rather than visiting another section of similar corridor-type space. The sudden change of space type brings rich and instantaneous changes in perception, which drives the visitors to have the desire to explore further. Further analysis on the subject's visual behavior when visiting the garden courtyard space shows that it is the depth-of-view and frame-of-view spatial elements that first guide the line of sight and the line of motion, but the distant frame-type elements also continue to attract the line of sight, further guiding the line of motion. The control of line of sight and line of movement plays a crucial role in the creation of the courtyard space of Canglang Pavilion Garden. By constantly changing the spatial type of the courtyard and wall, and cleverly setting a series of depth of field and frame elements, it can effectively guide the visual spatial feeling of the visitors, drive the secondary visual spatial behavior, so that the visitors in the changing walking behavior can be able to view different landscapes, which greatly enriches the spatial hierarchy and three-dimensionality, and brings a unique experience of shifting scenery for the visitors.

The study used the method of VR eye movement experiment to explore the landscape behavior of the subject during the dynamic tour in the garden compound space of Canglang Pavilion, revealing the correlation mechanism between the subject's perceptual behavior and the spatial sequence type and spatial elements of the garden, which provides new ideas and methods for the study of garden space creation, and also helps to better satisfy the needs of the visitors, and enhances the ornamental value of the heritage of classical gardens and the sense of experience during the tour.

Although VR technology has certain advantages in simulating the dynamic experience of gardens, there is still a non-negligible difference between the virtual simulation scene and the actual visiting environment. With the continuous development of VR technology and the continuous optimization of its presentation equipment, it is possible to simulate the garden visit

Table 1 Indicators of eye movement data

Norm	Description
Area of interest (AOI)	Specific regions within a visual scene that are predefined by the researcher as being of particular importance or relevance to the study
Time to First Fixation (TTFF)	The time spent from the onset of stimulus presentation to the first fixation at the AOI
First fixation duration (FFD)	How long the eyes are fixated on the AOI during the initial encounter
Total Fixation Duration (TFD)	The total time spent looking at the AOI
Fixation count (FC)	The total number of times the subject looked at the AOI

Table 2 Mean values of eye-movement area-of-interest gaze data for selected courtyard spaces

Term	Frame-of-view AOI	Depth-of-view AOI	Sig
Time to First Fixation (TTFF)	15.86 s	13.42 s	0.322
First fixation duration (FFD)	0.206 s	0.232 s	0.000*
Total Fixation Duration (TFD)	4.52 s	2.70 s	0.042*
Fixation count (FC)	23 times	19 times	0.001*

Note: *The difference is concerned statistically significant when P<0.05.

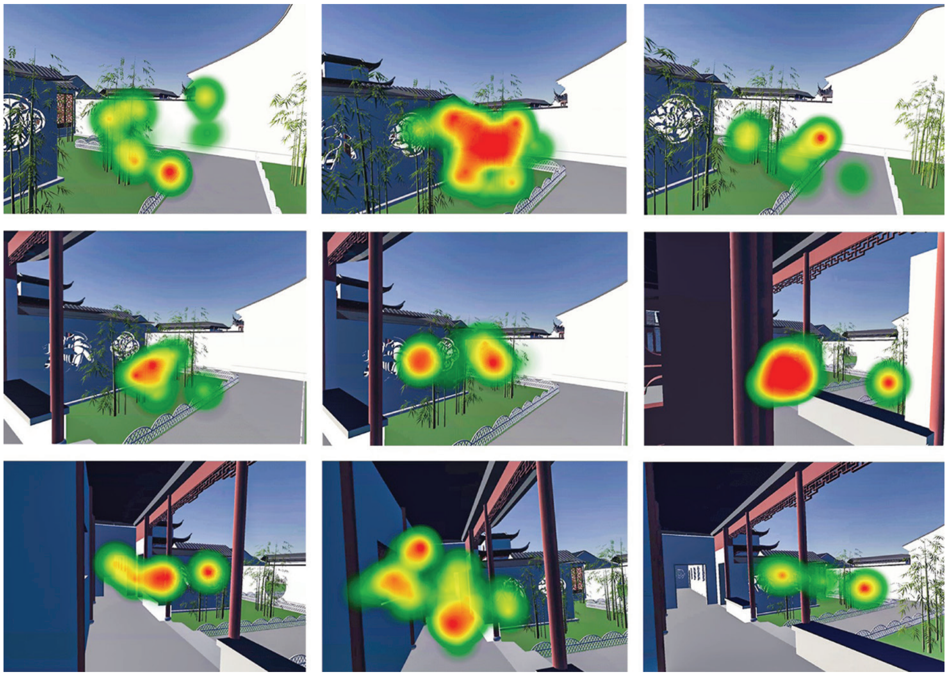

Fig.5 Gaze heat map

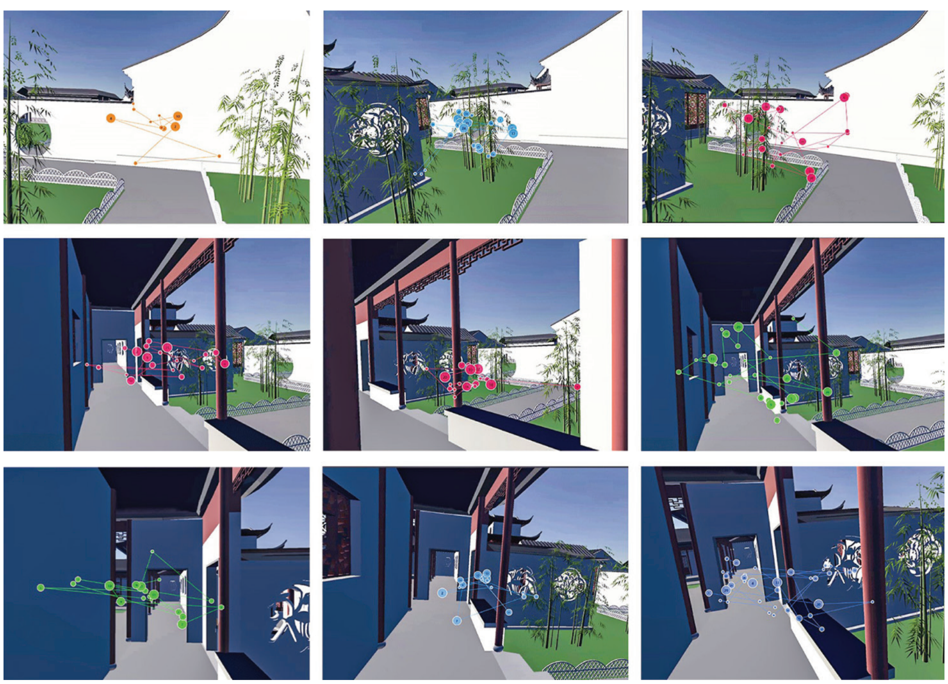

Fig.6 Gaze path map

environment more realistically, which helps to improve the accuracy and reliability of the research results, and the iteration of VR eye-tracking equipment can also capture users' eyemovement information more accurately and reduce the errors and delays. However, this study only selected a local area of Canglang Pavilion Garden as the object of analysis, and the generality of the results needs to be verified by further research on more gardens. Future research can expand and deepen the basis of this study, such as adding physiological data on the basis of eye movement data to further measure the perception of garden space, which can provide a more scientific basis for the design and protection of gardens.

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