A METHOD OF VR ENHANCED POE FOR WAYFINDING EFFICIENCY IN MEGA TERMINAL OF AIRPORT

SHUYANG LI1, CHENGYU SUN2 and YINSHAN LIN3
1,2,3Tongji University.
1lishuyang1995mail@gmail.com, 0000-0002-8780-7469
2ibund@126.com, 0000-0002-5686-5957
3lilianlin003@126.com, 0000-0002-6687-6457

Abstract. The airport is one of the most essential infrastructures of cities. An important issue of the airport design is that passengers must be able to find their way efficiently. Although the designers adopt the post-evaluation after the operation, it takes a long time to conduct the on-site wayfinding experiment, and the number of participants of the experiment is also limited. Moreover, conventional post-occupancy evaluation suffers from security control and quarantine inspection that cannot be carried out in the field. We proposed a VR enhanced POE approach that carries out an online wayfinding experiment to obtain numerous and detailed data, which significantly improves the efficiency of the post-occupancy evaluation project, and is validated by an affordable small-scale on-site experiment. Meanwhile, the cause for low wayfinding efficiencies, such as the symmetric space, the ambiguous direction and the redundant information on signboards are found and corresponding optimization suggestions are presented. The following signage system optimization project conducted in the terminal is welcomed by the passengers according to monthly questionnaires.

Keywords. Transportation Building; Post-Occupancy Evaluation; Digital Twins; Signage System Design; Wayfinding; Virtual Reality; Eye-Tracking; SDG 9.

1. Introduction

With the increase of global economic cooperation and cultural exchanges, the airport has become one of the most important infrastructures of cities. Tourism will be booming if there is an airport in the developing area, and the produces export will increase at the same time, so that the income and living standard of residents will be improved. The scale of terminal buildings has been expanding gradually because the globalization and the travel on business, accompanied by the accelerating complexity of passenger paths in the terminal. As the first stop for visitors, terminal design, especially the signage system design, will greatly affect their feelings, thus the efficiency of wayfinding becomes a crucial indicator in the post-occupancy evaluation for the airport.
1.1. OBSTACLES IN WAYFINDING EFFICIENCY EVALUATION

Through the post-occupancy evaluation of wayfinding, we can accumulate knowledge about airport design and signage system design. Anthony adopted the personal survey and behaviour tracing to evaluate the signage system in O'Hare International Airport (Anthony, 1991). He found that the corridor directional signs play a more important part in wayfinding rather than you-are-here maps, then he designed an experiment to compare the signs before and after optimization, the conclusion was used to suggest specific guidelines for the effective redesign. Barbara and others conducted a post-occupancy evaluation of wayfinding in a hospital through the interviews, behaviour observation, and tracking of visitors (Barbara et al, 1997). Results reveal the problems of radial floor layouts, signs, colors, and other wayfinding cues, these conclusions can provide references for hospital design in the future.

Most wayfinding research take on-site experiment, this is a huge challenge for researchers, and it is impossible to comprehensively evaluate the whole indoor space of the large-scale buildings. Considering that the strict user control of the terminal, the number of participants is limited, especially in the post-pandemic era, organizing large numbers of people to take part in on-site experiments suffer more risks. Then, the researchers are forced to choose only some section of the building to design wayfinding experiments, which makes the post-occupancy evaluation is incomplete and less credible. Moreover, researchers spend a lot of time recording and collating data of participants’ trajectories and behaviours in on-site experiments, which results in a long period for the post-occupancy evaluation.

Compared with the on-site wayfinding experiments, the virtual wayfinding experiments are more feasible, but it also suffers from credibility. Virtual environments can be reproduced verisimilitudinous with mapping the material textures to 3D model (Kuliga et al, 2020), but the surrounding crowds, lighting, and other factors also affect the participants' wayfinding behaviour. Therefore, some researchers design the same wayfinding experiment conducted both on-site and in the virtual environments to verify the reliability of virtual wayfinding experiment (Schwarzkopf et al, 2013). Besides, the number of participants is limited because the virtual experiments need a set of VR equipment with the head-mounted display or the CAVE VR, similar to on-site wayfinding experiments.

1.2. EXPLORATION OF VIRTUAL WAYFINDING EXPERIMENT

From the perspective of influencing factors of the wayfinding process, Carpman, Grant, and other scholars summed up three elements: behaviour elements, design elements, and operational elements (Carpman and Grant, 2002). Both the conventional on-site wayfinding experiment and the virtual wayfinding experiment in recent years are based on the above theory. Then, a VR wayfinding experiment is designed to minimize the differences between the experimental scene and the real scene in the three elements. The performance and trajectory of the participants are recorded. Finally, the researchers analyze the data and make conclusions.

Helmut and others built a virtual interior environment of the main railway station of Vienna (150m × 300m, 3 levels). With the help of mobile eye-tracking, they saved lots of time in the wayfinding research because the eye-tracking data can be projected
onto the 3D model (Helmut et al, 2016). Xu and others constructed a virtual space of three subway stations of Shanghai and conducted experiments to explore how the layout of the signboards affects passengers’ wayfinding behaviour (Xu et al, 2010). Benefitting from the virtual environment can be adjusted according to the experimental requirements, this experiment was completed in 4 days with 120 participants at an affordable cost. Sun and Yang proposed a research approach to study the wayfinding process in the virtual environment based on eye-tracking technologies (Sun and Yang, 2019). Through the analysis of the trajectories (recorded by virtual wayfinding experiment platform) and cognitive map, they investigated the mechanism of how architectural characteristics impose an impact on individuals’ wayfinding behaviour.

Previous studies have shown that passengers mainly focus on the signboards and architectural environment in the wayfinding process. The above two objects can be completely reproduced in the virtual environment, so the virtual wayfinding experiment is adopted by more and more researchers.

2. Methodology

As a powerful supplement to the conventional wayfinding experiment and post-occupancy evaluation methods, this study proposes a VR enhanced post-occupancy evaluation method based on the self-developed online virtual wayfinding experiment platform (Desktop VR). This method can facilitate systematic virtual experiments with large numbers of participants in that it can avoid obstacles in the on-site experiment. It also betters the credibility of the virtual experiment that used to be only tested in a small-scale on-site wayfinding experiment. Eye-tracking technology is used in the on-site experiment so that abundant data can support the conclusion of the virtual experiment.

![Figure 1. The low-level detailed 3D model](image1)

![Figure 2. The layout of wayfinding decision points](image2)
2.1. ONLINE WAYFINDING EXPERIMENT PLATFORM

Based on Unity 3D, a virtual experiment platform is developed. First, after the field research, a low-level detailed 3D model (Fig. 1) within the scope of this evaluation is constructed according to the CAD drawings and BIM model of the PVG airport. Then, as stated by the theory of wayfinding, the walkable area and wayfinding decision points (passengers will decide to turn left, right, or go ahead at this point) are determined (Fig. 2). To make the participants have a fluent experience of wayfinding, a point is added between two wayfinding decision points if they are far away from each other, and a total of 1235 panorama images (Fig. 3) with 8K resolution are taken at each point. Based on the method of “the high-resolution panoramas + the low-level detailed 3D model”, the interior space of the Satellite Terminal of PVG airport is reproduced as a virtual reality scene.

Desktop VR wayfinding experiment has some credibility and is a suitable option for VR experiments with larger numbers of participants. Compared with HDM VR, Desktop VR is overall similar when it comes to the user experience and wayfinding decision. Some experiments provide empirical evidence supporting researchers to choose non-immersive VR when studying passengers' wayfinding behaviour (Yan, 2021).

Publishing the virtual wayfinding experiment platform as a Web-based application can attract more people to take part in this experiment. Participants can access the website (pvg.plans.run) through various browsers (Chrome, Firefox, Edge, and Safari), and the online experience requires affordable computer hardware which is beneficial for the experiment. The experiment was started by filling in personal information (gender and age) on the login interface, and a random assignment mechanism was set up for the objectivity of the experiment.

2.2. SETTING AND PARTICIPANTS

The VR enhanced post-occupancy evaluation consists of two experiments. The first is the virtual wayfinding experiment with a large number of participants, and the second is the on-site wayfinding experiment with a small number of passengers as subjects.

In the online wayfinding experiment, 175 participants performed as passengers to
complete the given wayfinding task (Fig. 4). These participants were college students, teachers, and volunteers between 18 and 46 years, with an approximately equal number of men and women. All the participants had the experience of taking the plane and knew the boarding process, but they had never been to the Satellite Terminal of PVG airport.

In the on-site wayfinding experiment, participants were equipped with a mobile eye tracking device (Dikablis Glass 3). We recruited 8 passengers (in the Satellite Terminal of PVG airport) as subjects who took part in this experiment (Fig. 5).

2.3. VIRTUAL WAYFINDING EXPERIMENT

There are 252 kinds of specific wayfinding tasks including different entrance match with different boarding gate. Participants received random tasks when they enter the virtual environment, the essential information of the task (boarding deadline, gate number, and flight number) was recorded on the virtual ticket (Fig. 6) so that participants can check it anytime.

Participants spent about 45 minutes in the virtual wayfinding experiment. In the first 5 minutes, participants had to get familiar with the operation on the online experiment platform. Then, in the next 40 minutes, participants were required to complete randomly assigned wayfinding tasks, each participant completed about 10 tasks on average in this period, a total of 1861 wayfinding experiments were completed. The same wayfinding task was assigned to at least 5 participants to avoid occasional decision errors, but no participant will receive the same task again.
The movement of participants would be recorded as points in Cartesian coordinates, and the trajectory is obtained by connecting these points in chronological order. By overlapping the paths of different participants who complete the same task on the building plan, we can quickly find the wayfinding decision points where participants make wrong decisions (Fig. 7).

2.4. ON-SITE WAYFINDING EXPERIMENT
The on-site experiment consists of 10 wayfinding decision points. We selected 8 wayfinding decision points that participants make wrong decisions frequently in the virtual experiment as a trial group. 2 wayfinding decision points without any decision error were added as a control group.

A total of 80 on-site wayfinding tasks were completed in this experiment. 8 wayfinding tasks were set up at each decision point, with 8 passengers wearing the mobile eye tracking device who need to complete a randomly selected wayfinding task.

After hearing the experimenter dictate the wayfinding task, the participants began to observe the interior space and search for the signboards. The experiment ended when the participants reached the right boarding gate. Finally, participants described the experience feeling and reviewed the most confusing moment during the wayfinding process, which are recorded by the experimenter.

Based on the data recorded in the mobile eye-tracking device, the reason for the participants to make wrong wayfinding decisions (for example: ignoring a specific signboard or being guided by incorrect information on the signboard) can be found. Moreover, the participants’ visual behaviour during the wayfinding process can be explored.

3. Results and Discussion
This is an example of the first paragraph of body text after a heading. These paragraphs do not have an indentation of the first line. Use the style ‘CAADRIA text first’ for the first paragraph after any type of heading.

All other paragraphs should be formatted using the ‘CAADRIA text’ style. These paragraphs have a 0.5 cm indentation of the first line. Please do NOT adjust any of the styles, fonts, line spacing etc., only the CAADRIA styles should be used to format your document.

3.1. VALIDATION OF VIRTUAL WAYFINDING EXPERIMENT
By comparing the trajectories of the virtual experiment and the on-site experiment in the same wayfinding tasks, we can test the credibility of the virtual wayfinding experiment.

Assessing the 8 wayfinding decision points of the on-site experiments, we find that the trajectories of the on-site experiment are highly similar to the trajectories in the virtual experiment, that is, the decision errors made by the participants being the same as those in the virtual experiment.

For instance, in the on-site experiment, passengers look for the boarding gate H138 and choose the path on the right (Fig.8 and Fig.9), which is the same choice of the
participants in the virtual experiment (Fig. 7), but the shortest path is on the left.

However, in terms of the 2 wayfinding decision points of the control group, all the participants made the right wayfinding decision which are same as the virtual experiment. Therefore, based on the results of the virtual wayfinding experiment being consistent with the results of the on-site experiment, we assume that the VR enhanced POE method is a valid technical path and we can obtain reliable evaluation results from it.

Figure 8. Trajectory of on-site experiment  Figure 9. Data visualization of eye-tracking

3.2. PROBLEMS OF WAYFINDING AND OPTIMIZATION

3.2.1. The Symmetric Space

From the layout of the trajectories, around 78% of passengers (137 participants) took a detour when they pass through the atrium. However, only 13% of passengers took a detour in the airside concourse. The starting point and some critical wayfinding decision points of the international departure are located at the intersection of the T-shaped atrium, and the spatial arc interfaces to the three directions seem extremely similar from the standing locale (Fig. 10). Reviewing the eye-tracking data, more than three quarters of passengers looked around and observed repeatedly at these wayfinding decision points, and looked back frequently at the direction they came from although there are no signboards. Oral statements also prove the above conjecture, passengers are confused when they observe, sometimes they mistakenly think they have been to this place when they first arrive, which is the main cause of the wayfinding problem.

Considering that the form of architecture space cannot be changed, it is suggested that interior designs should be used to imply the difference between different directions, such as setting unique sculptures and installations or using different colors in three directions (Fig. 11).
3.2.2. The Ambiguous Direction and The Redundant Information on Signboards

The oral statement showed that around 65% of participants were confused and feel anxious when they see excessive signboards in the observation process, especially some of which had the same wayfinding information about the boarding gates but pointing to different directions (Fig. 12). From the layout of trajectories (Fig. 13), we can see the consistent paths become to diverge in some specific wayfinding decision points, and some paths are obvious detours. Thus, designers can accurately locate the signboards with ambiguous directions and then correct them.

Besides, the eye-tracking data reflects that passengers spend more time before making a decision when they are located at a multi-directional decision point with a large number of signboards. A large number of signboards can inevitably be seen in the multi-directional wayfinding decision points, the same wayfinding information are repeated on signboards which located in different directions, and all text on signboards are the same size and color (Fig. 14). About half of the participants ignored some important information when observing the signboards because they have lost patience in the long-period wayfinding process. It can be said that information overload triggers typical brain fatigue, passengers therefore may make wrong wayfinding decisions.

In fact, certain rules of the sequence of observation have been found through analyzing eye-tracking data: the participants’ sight will be first attracted by some signboards with different background colors from a large number of signboards, and the luminous part of the signboard will also be given priority. So, it is suggested to define the priority level of the wayfinding information, and distinguish different levels of attraction via multiple visual expressions (Fig. 15). Besides, it is desirable to reduce the redundant information on signboards to avoid misleading and to improve the wayfinding experience.
4. Summary and Outlook

In architectural practices and research, post-occupancy evaluation (POE) is an effective way to understand to what extent the built environment runs as it was designed. Only with proper evidence can further optimization and improved knowledge be expected.

We proposed a VR enhanced POE method that through online VR wayfinding experiments to obtains sufficient data, which significantly improves the efficiency of the POE projects and is validated by the affordable on-site data. VR enhanced POE took only 2 weeks to complete the wayfinding evaluation, which saved nearly 3 months compared with the conventional on-site wayfinding evaluation. Meanwhile, using the VR enhanced POE method can reach the aim of the conventional POE project under the condition of limited budget and epidemic spread. So, the VR-enhanced POE approach is feasible and replicable.

Furthermore, we can quickly locate the wayfinding decision points that may have potential problems that lead to detours through the VR enhanced POE project. Then, three major reasons are summarized, such as the symmetric interior space, the ambiguous direction and the redundant information on signboards, which claims subsequent design updates in interior space and signage system. As a result, the designers accepted our suggestions and made improvements to the interior design and signage system. The following signage system optimization project conducted in the terminal is welcomed by the passengers according to monthly questionnaires, around 60% reduction of complaints compared to the previous.

It is also found that in the on-site experiment, the participants are subconsciously
influenced by passengers around, especially when they are confused, which coincides with the results of some previous studies. Therefore, we are trying to introduce avatars as background crowds into the virtual environment to improve the credibility of the virtual experiment.

**Acknowledgements**

The research was supported by a project of Natural Science Foundation of China titled "An internet-plus-based approach of crowd simulation for public buildings" (no. 51778417).

**References**


