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Do different types of VR influence pedestrian route choice behaviour? A comparison study of Desktop VR and HMD VR

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Virtual Reality (VR) is a valuable tool for studying pedestrian behaviour in complex and realistic scenarios. However, it has remained unknown how different VR technology would influence pedestrian behaviour. This paper presents VR experiments that were conducted with 70 participants using a desktop VR or a HMD VR to perform four different wayfinding tasks in a multi-story building. Quantitative analysis of pedestrian behaviour data and user experience data were performed in order to investigate the impact of the technological differences between the two VR techniques. It was found that participants had better wayfinding task performance in the desktop group. However, the route and exit choice and user experience were overall similar between the two groups. The findings suggest that one could adopt more 'simple' VR technologies for studies featuring 'simple' wayfinding tasks.

CCS CONCEPTS • Human-centered computing → Virtual Reality • Human-centered computing → Empirical studies in HCI

Additional Keywords and Phrases: Route choice, exit choice, wayfinding behaviour, desktop VR, HMD VR

1 INTRODUCTION

It is a daily activity for people choosing route and exit in large-scale and multilevel buildings, such as train stations, hospitals, shopping malls. It can be difficult because of the complexity of the three-dimensional environment [21]. That is the complexity of finding one's route and exit in multi-level buildings increases by the multiple floor layouts and moving along vertical distances [2,28].

Two traditional data collection methods have been widely applied to investigate pedestrian route and exit choice, namely field experiments and surveys (e.g., [17,18,20,27,31,32]). Although studies have shown the usefulness of these methods, there are restrictions concerning in terms of experimental control, cost, and data accuracy for studying pedestrian behaviour [15,30]. Moreover, most experimental conditions featured in traditional data collection methods differ greatly from actual reality because most pedestrian studies focused on simplified or two-dimensional environment (e.g., [17,18,20,27,31,32]). Furthermore, it is difficult to collect pedestrian behaviour data in dangerous and realistic situations due to ethical concerns.

To overcome the existing constraints of traditional data collection methods, the use of Virtual Reality (VR) for pedestrian behaviour study has become increasingly popular. With VR, it is possible to place participants in complex, or hazardous situations that are costly, dangerous or even impossible to simulate in the real world [15]. Additionally, it provides the possibilities of accurate recording a large variety of data pertaining to pedestrian's movement and choice behaviour, such as timestamp, pedestrian movement trajectory, head rotation, eye movement.

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Different VR technologies have been used to study pedestrian route and exit choice. According to the different level of immersion, VR technologies can be categorized to the head-mounted-display (HMD) VR (e.g., [8–10,14,26,34,42,44,47]), the desktop VR (e.g., [4,5,39,43]), and the cave automatic virtual environment (CAVE) (e.g., [2,3,24,25,35]). Using HMD VR, participants normally interact with the virtual environment through specialist simulator control device and motion tracking hardware. In desktop VR, the virtual environment is displayed on a monitor [13]. Different VR technologies have different characteristics and may cause people to interact and perceive the virtual environment differently [41]. However, only a few studies have directly compared the presentation of the same virtual environment using different VR technologies on pedestrian behaviour (i.e., [19,35,41]) and the experimental environments were relatively simple. Consequently, there is a strong need to compare VR technologies regarding their impact on pedestrian behaviour and user experience. This comparison will allow us to identify best practices regarding the usage of VR technologies for pedestrian behaviour research.

This paper aims to determine the impact of the technological difference between a HMD VR and a desktop VR on pedestrian behaviour and user experience of participants. The current study builds on a VR research tool that was specifically designed to collect pedestrian route and exit choice behaviour data in a complex multilevel virtual building (see [12]). In the current study, we conducted VR experiments in which participants used an HMD or a desktop display to perform the same set of wayfinding tasks with this VR tool. Pedestrian behaviour data (e.g., three-dimensional movement trajectories) and participant's experience using VR (e.g., perceived realism, usability, feeling of presence, simulation sickness) were collected synthetically. Based on the theories and previous findings from pedestrian studies (e.g., [19,29,33,36,37,41]) and human-computer interaction studies (e.g., [1,6,33,38,40]), these data were analysed qualitatively and quantitatively to test two main hypotheses, namely (H1) there are differences in the pedestrian route and exit behaviour between the participants that used the desktop VR and the HMD VR, and (H2) there are differences in the user experience between the participants that used desktop VR and the HMD VR.

There are three major contributions of this study, namely, we (1) investigate pedestrian route and exit choice behaviour in a complex and multilevel building, (2) provide a direct comparison of pedestrian behaviour and user experience between two different VR technologies and (3) recommend which VR technology to use to perform pedestrian route and exit choice behaviour studies.

2 MATERIALS AND METHOD

The goal of this study is to investigate the impact of technological differences between two VR techniques on pedestrian's behaviour and user experience. To this end, empirical, comparative VR experiments with the HMD VR and the desktop VR were carried out. The VR experiment was approved by the Human Research Ethics Committee of the Delft University of Technology.

2.1 Participant characterization

In total, 70 participants joined the experiment in which 36 participants took part in the HMD group and 34 took part in the desktop group. The participants were between 22 and 64 years old ($M = 27.85$) in the desktop group, and between 17 to 41 years old ($M = 28.66$) in the HMD group. There were no significant differences found between the two groups regarding gender, familiarity with the faculty building, the highest level of education, experience with VR and familiarity with computer gaming (all $p > 0.05$).

2.2 The virtual environment

The virtual environment featured a virtual building that comprises four floors, each floor features two parallel hallways, multiple intersections, four staircases and four elevators. There are five major exits located on the ground floor (see Figure 1). This virtual environment was originally developed as a VR research tool to study pedestrian route and exit choice behaviour in a multi-level building (see [12]). The VR tool supports free navigation and collects pedestrian walking trajectories automatically. In the virtual environment, the participants have a first-person perspective. Participants could move in the virtual environment at a maximum constant speed of 140 cm/s.

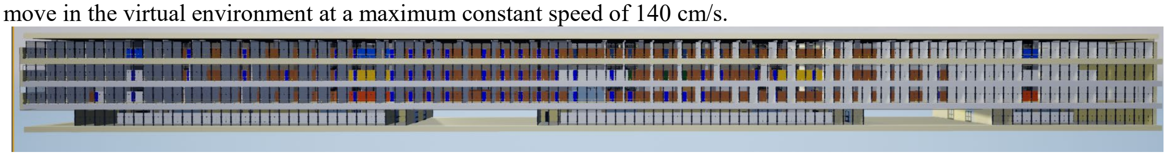


Figure 1: The overview of the virtual building.

The virtual environment resembles the building of the Faculty of Civil Engineering and Geoscience of the Delft University of Technology. In addition to the overarching geometry, detailed environmental elements were also included in the virtual environment in order to improve the accuracy of the building's representation and increase its realism. These elements include, amongst other things, glass windows, furniture, evacuation signs, room numbers, and floor plans (see Figure 2). Besides that, the colour and texture of objects in the virtual environment were modelled realistically to represent the real-world experience.

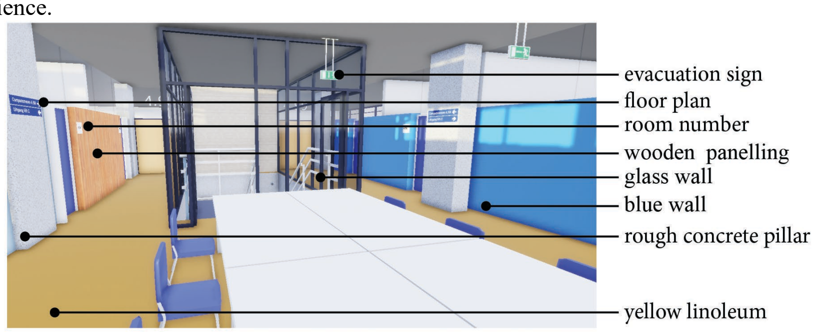


Figure 2: The screenshots of details of the virtual building.

2.3 Experimental setup

The versions of HMD VR and desktop VR of the VR research tool were developed for this study. A HTC Vive system was employed for the HMD group. By holding the home pad of the controller, the participant moves forward; by releasing the home pad, the participant stops moving. The direction of the movement is controlled by the participant's head orientation.

The participants of the desktop group view the virtual environment via a 24-inch desktop monitor (AOC G2460PF). The participant moves forward using the keyboard key 'w', and changes the direction of view by rotating the mouse.

2.4 Experiment design

A single-factor between-subjects experimental design was used for this study to reduce the learning effects due to repetitive exposure. The VR experiments featured two different experiment settings but the only difference between both setups is the HMD VR versus the desktop VR. Each participant can only take part in the experiment once in order to prevent learning effects.

Figure 3: The layout of the virtual environment.

Figure 3 shows the abstract layout of the experimental environment. Participants of both groups were asked to complete four wayfinding tasks during the experiment in the following orders. First, pedestrian route choice behaviour across the horizontal level is investigated. Participants are initially positioned in front of Room 4.02 and are asked to find their way from Room 4.02 to Room 4.99 (see Figure 3). Second, pedestrian route choice behaviour (including staircase choice) at the vertical level is investigated. Participants are asked to find their way from Room 4.99 to Room 2.01. Third, pedestrian route and exit choice across both the horizontal and vertical level are investigated. Participants are asked to find their way from Room 2.01 to Room 4.64. The fourth task of the experiment is to investigate pedestrian route and exit choice during an evacuation scenario. When participants arrive at Room 4.64, the evacuation alarm triggers and participants are asked to evacuate and find an exit.

2.5 Data collection

Two types of data were collected during the experiment, namely the behavioural data pertaining to the participant's movement in the VR environment and questionnaire data pertaining to user experience with the VR system.

First, participant's behaviour in the virtual environment was recorded. Participant's positions were recorded in milliseconds within UE4. Second, the personal features and experiences of each participant regarding the virtual experiment were collected via the questionnaire. The questionnaire contained five sections: (1) participant's information (2) the face validity questionnaire[22], (3) the Simulator Sickness Questionnaire [23], (4) the System Usability Scale [7] and (5) the Presence Questionnaire [45].

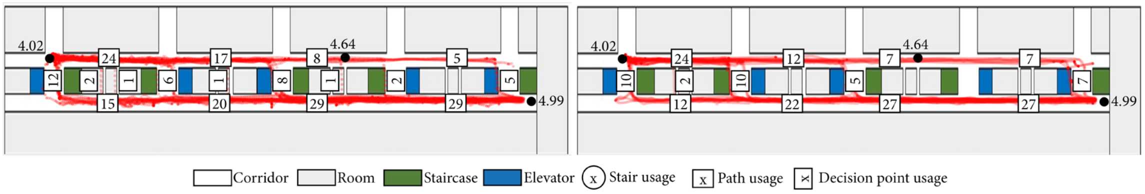
2.6 Experimental procedure

A consistent experimental procedure was used for the HMD group and the desktop group. This procedure included five major stages, namely (1) participants are introduced to the purpose of the experiment, (2) participants familiarize themselves with the HMD device, (3) conduct the formal experiment, (4) fill in the post-experiment questionnaire and (5) health check to make sure participants experience no symptoms before they leave.

3 RESULTS

3.1 Pedestrian route and exit choice

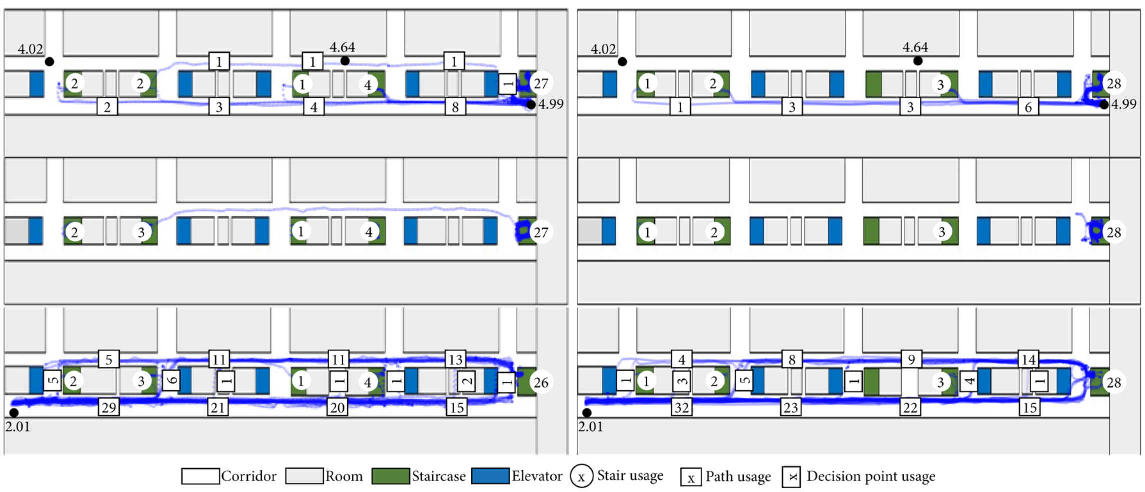
Figure 4 shows the movement trajectories of all participants during the first task, including the usage of paths and decision points. There are no significant differences in the usage of paths (X^2 (7, N= 286) = 1.56, p = 0.98)) and usage of decision points (p = 0.63).



a. HMD group b. desktop group

Figure 4: Participants' movement trajectories during task 1.

Figure 5 shows the movement trajectories of all participants during the second task. Fisher exact test revealed that there were no significant differences in the usage of paths (p = 0.99), usage of decision points (p = 0.12) and usage of staircases (p = 0.99).



a. HMD group b. desktop group

Figure 5: Participants' movement trajectories during task 2.

Figure 6 illustrates the distribution of the usage of paths, decision points and staircases during task 3. The Fisher exact test revealed that there was no significant difference in the usage of paths (p = 0.12) between the desktop group and the HMD group during task 3. However, there were significant differences in the usage of decision points (p = 0.02) and staircases (p = 0.002) between the two groups during task 3. It indicated that although the usage of paths was similar, the usage of decision points and staircases were significantly different.

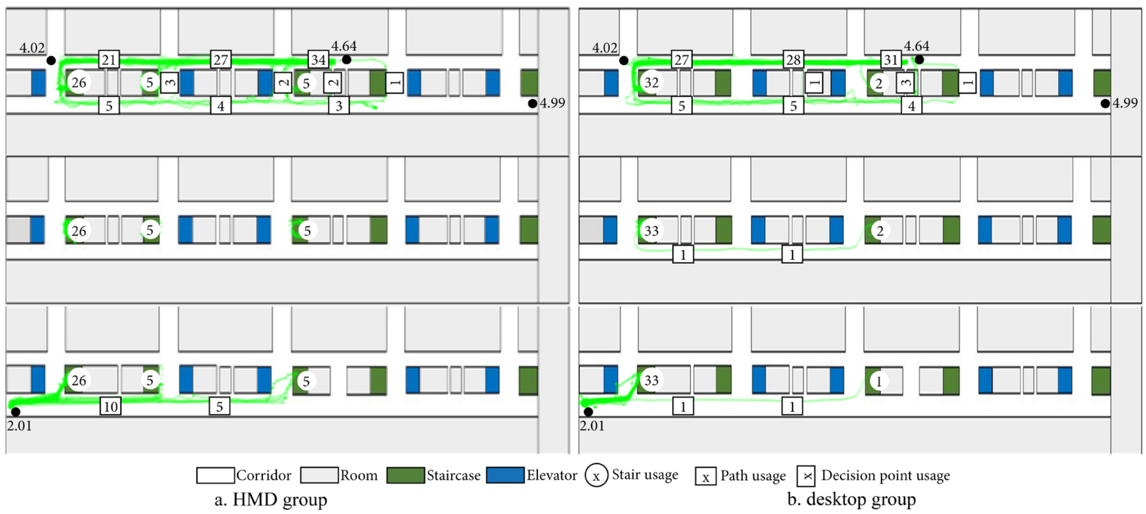


Figure 6: Participants' movement trajectories during task 3.

Figure 7 shows the movement trajectories of all participants during the evacuation task. The Chi-square test showed there was no significant differences in the usage of paths, X^2 (1, N = 70) = 0.35, p = 0.55, and the usage of staircases, X^2 (1, N = 210) = 0.69, p = 0.98. Even though five exits were available, only the two exits near elevator C and D were chosen, which are the nearest two exits for the participants. There was no significant difference in the exit usage between two groups using Chi-square test, X^2 (1, N = 70) = 0.24, p = 0.62.

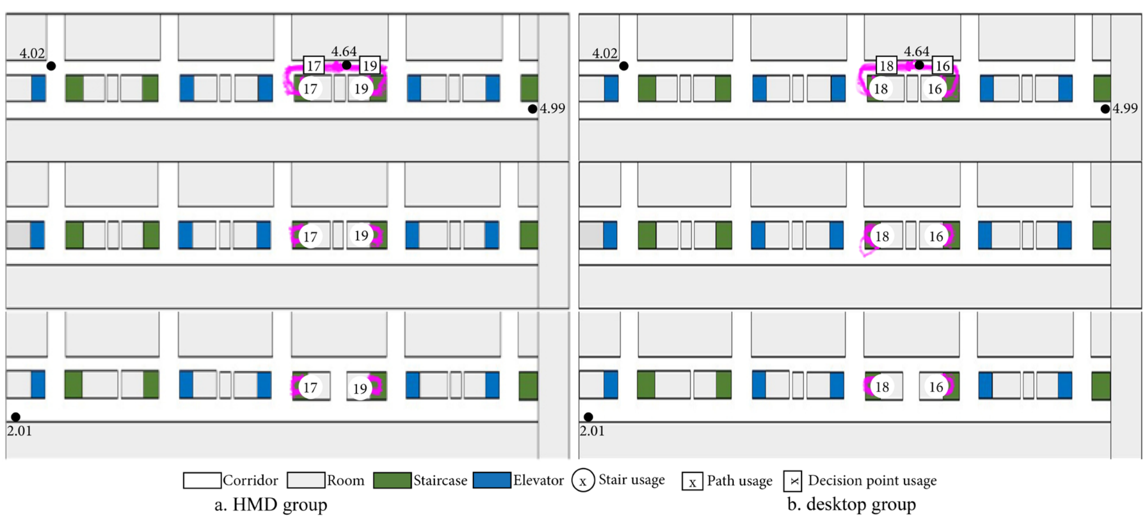


Figure 7: Participants' movement trajectories during task 4.

Besides pedestrian route and exit choice behaviour, task performance is measured. The Mann-Whitney U test was conducted which showed significant differences in total travel time (U = 185, p < 0.001), travel time of task 1 (U = 215, p < 0.01), travel time of task 2 (U = 203, p < 0.001), travel time of task 3 (U = 164, p < 0.001), and travel time for evacuation task ($U = 316$, $p < 0.001$). The results showed that participants from the HMD group spent significantly more time on each task than in the desktop group. Besides, the Mann-Whitney U test showed that there was a significant difference in travel distance between the HMD and the desktop group ($U = 185.0$, $p < 0.01$), which indicated that participants in the HMD group travelled significantly longer distance than the desktop group. Furthermore, the result of the Mann-Whitney U test indicated that there was a significant difference in average travel speed between the two groups ($U = 217.0$, $p < 0.01$). That is, the participants in the HMD group had significantly slower average speed than the desktop group.

3.2 Questionnaire data

Overall, the average total score of face validity in the HMD group and the desktop group was above 4 out of 5, which suggested the virtual environment had a high level of realism. Mann-Whitney U test showed that there was no significant difference in the average total score of face validity between the two groups ($U = 587.5$, $p = 0.39$).

The Mann-Whitney U test showed that there was no significant difference in total SSQ score between two groups ($U = 559.5$, $p = 0.27$). Moreover, no significant differences in the scales of Nausea ($U = 591$, $p = 0.40$), Oculomotor ($U = 536.0$, $p = 0.18$) and Disorientation ($U = 603.5$, $p = 0.46$) were found between two groups.

The mean score of PQ was 146.00 ($SD = 13.63$) for the HMD group and 148.50 ($SD = 17.86$) for the desktop group. The desktop group presented a higher average presence score than the HMD group. T-test showed there was no significant difference in the total score of PQ between the HMD group and the desktop group ($t = 0.66$, $p = 0.51$). Meanwhile, there were also no significant differences in the four subscales between the two groups.

The average total score of SUS is 83.75 ($SD = 11.92$) in the desktop group and 82.01 ($SD = 11.10$) in the HMD group, which indicated the effective usability of both systems. The Mann-Whitney U test that there was no significant difference in the usability score between the two groups ($U = 511.50$, $p = 0.12$) .

4 DISCUSSION AND CONCLUSION

This study examined how the differences of VR technology impact participant's route and exit choice behaviour in a complex multi-level building and the user experience of the VR technology. Pedestrian behaviour (i.e., pedestrian route and exit choice, task performance) and user experience (i.e., realism, simulation sickness, presence, usability) were compared between two groups of participants, where one group used the HMD VR and another group used the desktop VR.

This study found a limited significant difference in terms of route and exit choice behaviour. Only slight differences pertaining to the detailed behaviour (i.e., usage of staircase and decisions points in task 3) were recorded. Yet, the task performance significantly differed between the two groups. Ultimately, the first hypothesis that there are differences in pedestrian behaviour between the desktop VR and the HMD VR, is only partially confirmed. In particular, the task performance during four tasks, the distribution of the number of decision points and distribution of used staircases were significantly different in the case where the destination was not clear-cut. Regarding the questionnaire data, there were no significant differences in terms of realism, simulation sickness, the feeling of presence and usability between the two groups. Thus, the second hypothesis that there are differences in user experience between desktop VR and HMD VR, is rejected in this study.

This study provides the first direct comparison of VR technologies regarding the differences in pedestrian behaviour and user experience in a complex multilevel building. This study determines that the technological differences between the two VR technologies did significantly impact task performance. In particular, the adoption of HMD technology decreased pedestrians' task performance during all tasks, increased the number of decision points, and altered staircase usage in the task where the location of destination was not clear-cut. Furthermore, this study concludes that the technological difference between VR technologies does not have a significant impact on the user's experience. The results featuring the user experience imply that both VR technologies effectively collect and investigate pedestrian behaviour. These conclusions imply that one could adopt more 'simple' VR technologies for studies featuring 'simple' wayfinding tasks, for instance, to study learning effects, the impact of environmental characteristics and route choice behaviour. However, in cases where the experience of the environment and searching behaviour are important impacts on the resulting pedestrian behaviour, one is advised to consider carefully the differences in behaviour between both VR technologies.

Which of these two technologies is preferred for the more complex wayfinding tasks is difficult to say based on the results of this study, as there are no validation studies featuring the comparison of the pedestrian behaviour in real-life and in VR. In order to clarify which of the two technologies should be preferred, future studies should directly compare pedestrian behaviour in real and virtual environments.

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