THE VISION OF VIRTUAL REALITY

A Perspective through Eye Tracking to inform Wayfinding design

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Abstract. Recent advancements in technology have enabled virtual reality (VR) experiences to deliver high quality visualisations. Its popularity has influenced architectural practices to adopt VR for communicating architectural designs to clients and other designers. While it is not a new concept, and on its own offers significant potential, when combined with eye tracking (ET) it culminates in a powerful digital tool for understanding how one perceives space. Understanding one's perceptions of space can be particularly useful in design decision-making for wayfinding, which is the topic researched in this paper. The research investigates the utility of VR and ET for evidence-based navigation design decision making in public transport environments and proposes a framework for eye movement data collection. Action research tactics are employed to test and analyse the ET in virtual departures terminal to record where, when, how long and in what progression elements are observed. The obtained detailed data is then analysed to investigate spatial processes which assist to understand wayfinding in real-world situations. These findings can be used to determine the most effective method of signage positioning and improving overall wayfinding experience for the passenger.

Keywords. Virtual reality; eye tracking; wayfinding; user behaviour; spatial design.

1. Introduction

In recent times, architectural practices have evolved from using traditional tools to implementing digital tools (Picon 2019 p. 221). However, the traditional role of the architect has remained unchanged. It has always been to design environments for human life (Schmitt et al. 1995, p. 270). Designing for human life involves a considerable amount of decision-making to satisfy the requirements of many stakeholders involved (Criado-Perez et al. 2019, p. 2). The effectiveness of design decisions can be hardly evaluated if they have been made intuitively. To avoid lack of assumptions in the design process, evidence-based practice (EBP) is necessary to be implemented. It refers to a decision-making framework that builds on the precise, explicit and prudent use of the best available evidence from research and precedential practice (ibid).

This approach is particularly appropriate for the design and development of public transport environments where spatial navigation design is pivotal in wayfinding. Wayfinding consists of path planning and decision-making at choice points (Weiner et al. 2012, p. 713). The decision-making in wayfinding is made by the user, and understanding user behaviour contributes to creating feasible, straight-forward navigational experiences.

Informative design-decisions during the design process can be supported with the implementation of virtual environments and eye tracking (Tang & Auffrey 2018). Virtual reality (VR) has been associated with architectural visualization since the mid-20th century (Cipresso et al., 2018, p. 1). The revolutionary progression of computing power has resulted in the production of high-quality virtual reality (VR) experiences. As a result, it has been employed in architectural context as a design communication tool for clients and designers. In addition, the concept of eye tracking (ET) has been around since late 19th century. It has been vastly used for behavioural studies in psychology domains. Peter Kiefer, a geographic information systems (GIS) researcher, used ET as a tool to guide wayfinding research and understand the root cause of navigation problems.

Although VR and ET have been available for decades, they have not been integrated in the same medium until recently. The integration of ET in the VR headset can reveal one's subconscious behaviour when immersed in the virtual environment (Schrom-Feiertag et al. 2017).

This thesis will develop a virtual environment for ET data collection to assess its utility in providing wayfinding insights. To explore these insights, an action research method is employed to test and iterate and reflect on the outcomes. The results of the iterative stages then open future research explorations to adopt wayfinding practices and further develop the framework of data collection. In adopting these practices, passenger experiences will be enhanced and unnecessary cost increases in experiments and renovations will be avoided.

2. Research Aims

The digital era allows the designer to adopt new design processes which are used to create not only based on intuition, but evidence. These design processes are achievable as a result of rapid technological advancements, such as the merging of VR headset and ET glasses into one tool. This tool, based on its accuracy, uncovers unconventional possibilities for evaluating spatial navigation design in public transport spaces. This research aims to not only investigate the utility of the tool but to explore wayfinding behaviour through quantitative lens and provide foundational practices for further industry application.

3. Research Question

To begin addressing the preeminent contributions VR and ET provide for research investigation in wayfinding, the question this paper examines is: *how can eye tracking and virtual reality inform wayfinding decision making in public transport spaces?*

4. Methodology

There is a notable difference between research methodology and research methods. Research methods consist of the forms of data collection, analysis and interpretation whereas research methodology is concerned with the process researchers use to collect and analyse data (Abutabenjeh & Jaradat, 2018, p. 239). There are diverse research methodologies and action research is one of them. It is the 'informal, qualitative, formative, subjective, interpretive, reflective and experimental model of inquiry' (Hopkins, 1985).

Action research is learning by doing, where one identifies a problem, decides to do something to resolve it, assesses the success of the solution and if it is not successful, repeats the process (O'Brien, 1998). Stephen Kemmis outlined this in a diagram representing the cycles of action research and showcases the ideas of planning, action, observation and reflection (Altrichter, et al., 2002).

In technology design, action research is characterised in three ways, active participation, action- based methods and generating action (Hearn et al. 2005, p. 7). Those characteristics are effectively implemented in the process of this paper's case study provokes change in design practices to communicate designs during the development stages, as shown below.

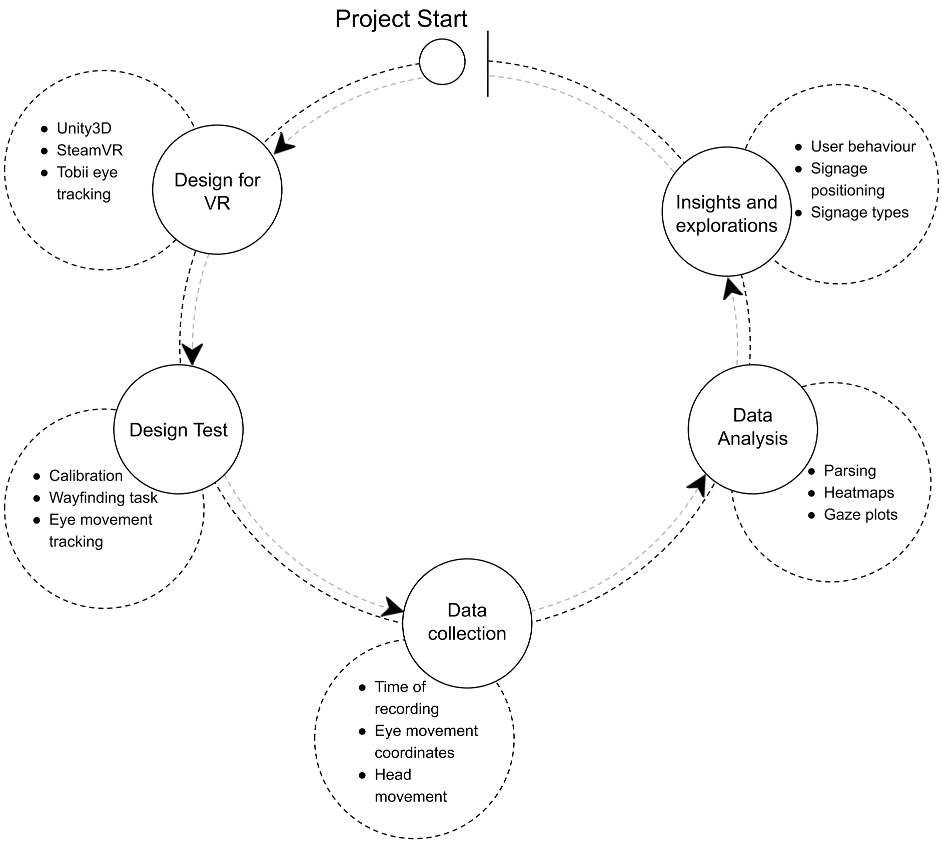

Figure 1. Process of adopting action research in project method.

At first, the user behaviour during wayfinding might seem difficult to understand. To justify the behaviour of the user in the virtual environment, an eye tracking capability is triggered as soon as the device detects eyes. The ET tool developed can extract real time eye movement data and present it in .xml format. The present data then provides points of reflection, such as choosing areas of interest in the virtual environment which later provide a direction for the second cycle testing. Furthermore, action is taken to add and adjust signage features to be then tested again. The second set of data then provides meaningful results for further research directions to gain clearer paths for the development of spatial design.

5. Literature review

This review aims to closely assess how VR can be utilised with ET to direct research on wayfinding design. Firstly, the use of virtual reality in architectural setting will be explored, then eye tracking analysis in space and finally wayfinding within the built environment.

5.1. VIRTUAL REALITY

The concept of VR has been around since the 1960s and the first commercial tool became available in 1980s (Cipresso et al., 2018, p. 1). VR is defined as a computer technology which presents sensory information and feedback with the intent of producing an illusion that the user is immersed in an artificial world (Coyne 1994, p. 65). The development of VR tools has progressed significantly in recent years and contemporary advancements allow for integration of tracking devices to be used simultaneously (Song et al. 2018, p. 2265).

The use of VR as a stimulus, replacing the real stimuli, recreates experiences that would be impossible to execute in a real environment (Cipresso, et al., 2018). While Cipresso et al. (2018) highlighted the importance of VR theoretically, Frost & Warren (2000) pioneered in articulating its practicality in collaborative design setting. The contribution of VR in such a setting assisted the users to communicate their design ideas and experiences in a way that can be formulated, analysed, tested and realised (Frost & Warren 2000, p. 568). This study is extended in the work of Song et al. (2018) which explores the user experience in virtual setting where user operations are recorded and analysed. Then the insights are applied by designers to improve the product. Although Frost & Warren (2000) have examined the use of VR in collaborative setting, there is limited material that highlights the participant's experience. Nonetheless, Song et al. (2018) provides an additional insight on the user's experience by running different simulations such as product operation, performance, structure, colour and appearance variations and activities. To further understand the user experience, a questionnaire survey was conducted before and after using the developed VR system. The analytic focus on understanding the users' requirements and demands in the development stage of products further highlights the contribution of VR in design environments (Song et al. 2018, p. 2272). However, the extent to which this study enables for another contribution is questionable due to the semi-immersive VR environment testing. The participants had the illusion of technological captivation and felt present in the virtual environment whilst having control over physical surroundings (Cipresso et al. 2018, p. 2). This limitation could be further addressed by setting up a fully immersive head mounted device (HMD) which teleports the human from reality to virtuality.

5.2. EYE TRACKING

ET measures the individual's visual attention, considering an extensive source of information on where, when, how long and in what progression certain information is looked at (Kiefer et al. 2017, p. 1). Kiefer used it as a tool to guide wayfinding research and to understand why navigation problems occur.

Seeing the surroundings using eye tracking (ET) technology provides insights in wayfinding and navigation. From the five senses, the human brain prioritises vision (Hollander, et al., 2018). Eric Kandel states that "We are intensely visual creatures and live in a world oriented to sight" (Kandel, 2012). As such, people perceive architecture by fixating momentarily on a particular area and then saccade to the next fixation (Hollander, et al., 2018).

5.3. WAYFINDING

Wayfinding consists of orientation, route choice, monitoring and goal recognition (Downs & Stea, 1977). Orientation integrates the visual signals with spatial knowledge about the environment (Gunzelmann, et al., 2004). Although there is limited research available on integrating VR and ET to inform wayfinding, Zhang et al. (2018) and Tang & Auffrey (2018) have conducted studies on using these technologies to support re-design decision making. While Zhang et al. (2018) aims to develop VR environment and outline areas for historic restoration, eye tracking data and behavioural record analysis are performed. Zhang et al. (2018) makes a key finding stating that "non-architects pay little to no attention to the second-floor features of the VR environment". This study analyses how the integration of ET and VR can be perceived differently based on human behaviour, but it has finite comprehension of research to inform re-design of space. The analytic focus of Tang & Auffrey (2018), on the other hand, aims to identify design elements to improve wayfinding and pedestrian movement, as well as understand the importance of ET and VR to influence the design process. While Zhang et al. (2018) failed to understand the similarities and differences between spatial behaviours, Tang & Auffrey (2018) have investigated VR behaviours in simulated environments and made key findings on participant's visual attentions. This study has given valuable input in using VR and ET in design practices and this paper's case study attempts to improve the effectiveness of the technologies by assessing visual attention in a fully immersive mode. Nevertheless, the study provides an effective direction to allocating wayfinding signage.

5.4. THE SYNTHESIS OF VR, ET AND WAYFINDING

Eye tracking can be used to measure not only sensory input but the wayfinder's information acquisition procedure (Kiefer, et al., 2017). A study conducted by Emo (2014) used eye tracking device to assess gaze fixation when wayfinding. The findings show that most decisions are made based on the sky area, floor area and longest line of sight where the depth of view is most available (Emo, 2014). This study contributes, to a certain extent, towards the wayfinding decision making process however the human experience and participants' individual differences are not specified. Schrom-Feiertag et al. (2017) have conducted a study which further contributes to wayfinding investigation. This study analyses the indoor guidance systems and their effectiveness in an immersive virtual environment. The approach aided by eye tracking device gives an insight of attention maps and identification objects (Schrom-Feiertag, et al., 2017). The effectiveness of this results in simple wayfinding practice since it requires minimal cognitive effort from the user. Furthermore, this method outlines the importance of achieving a high level of realism in the virtual environment to gain valuable insights. Overall, there is a need for deeper gaze examination to determine individual's visual attention and cognitive loads during navigation in immersive environment.

6. Case Study

To create the VR and ET framework, multiple scripting components were added to the Unity3D real-time development platform. The list of components enabled the hardware, VR headset with ET sensors, to work seamlessly with the software to extract data without interrupting the user's navigational task. The produced data involves extensive lines of code which are then parsed in a readable format and later visualised in form of heatmaps and gaze plots. By observing the visualisations, one can presume the user behaviour while getting from one location to another.

6.1. DETAILED INTRODUCTION OF METHOD

This section provides the detailed description of method employed, and its capabilities to collect and interpret data.

6.1.1. Real-time virtual reality development

Unity3D is a game engine platform with high quality development capabilities. The main components of the engine for VR development are Assets and Packages. Assets can be 3D objects, images, materials and other files created outside of the engine. Packages store all assets, plug-ins and other technical documents required for the VR environment. Inside the packages, Unity allows for developing or importing SDKs. Software Development Kits (SDKs) are sets of tools for programming and they have been heavily utilised in designing this paper's case study.

6.1.2. Eye tracking for data purposes

Eye tracking in wearable technology works by near-infrared illumination to create reflection patterns of the cornea and pupil of the eye. The Tobii EyeChip™ASIC sensor captures and processes the images by using an advanced algorithm to perform calculations for gaze positioning. The gaze is then classified in two categories, saccades and fixations. Saccades are the fast movement of the eyes than quickly change the point of fixation. Fixations occur when the eyes stop scanning and focus at a single point for a certain period.

Figure 2. Eye tracking sensors of VR headset.

TABLE 1. Detailed information of eye movement data collected with Tobii eye trackers.

Data	**Description**
Gaze Point X	Horizontal coordinate of the averaged left and right eye gaze point.
Gaze Point Y	Vertical coordinate of the averaged left and right eye gaze point.
Gaze point left X	Horizontal coordinate of the left eye gaze point.
Gaze point left Y	Vertical coordinate of the left eye gaze point.
Gaze point right X	Horizontal coordinate of the right eye gaze point.
Gaze point right Y	Vertical coordinate of the right eye gaze point.
Gaze direction left	Gaze direction (X, Y, Z) of the left eye.
Gaze direction Right	Gaze direction (X, Y, Z) of the right eye.
Pupil diameter left	Estimated size of the left eye pupil.
Pupil diameter right	Estimated size of the right eye pupil.
Eye movement type	Type of eye movement classified by the fixation filter.
Eye movement type index	Count is an auto-increment number starting with 1 for each eye movement type.
Fixation point X	Horizontal coordinate of the averaged gaze point for both eyes.
Fixation point Y	Vertical coordinate of the averaged gaze point for both eyes.
Head rotation	The coordinates of the participant's head rotation quaternion.

6.1.3. Data analysis

The data gathered from every recording is stored in an .xml file format. The extensive lines of code make it impossible to understand in that format. Therefore, parsing of data was executed to change the format in a readable .csv spreadsheet. This way the VR environment areas of interest (AoI) and the time of interest (ToI) can be organized and visualised in a heatmap or gaze plot visual.

Heat maps use colors to illustrate the number of fixations and their duration made by the users within certain AOIs in the VR environment. Red indicates the highest number of fixations or the longest fixation time and green indicates the opposite.

Gaze plots show the sequence and position of fixations in the selected AOI in the VR environment. The size of the dots indicates the fixation duration and the numbers inside the dots represent the order of the fixations.

6.2. DESIGN AND DEVELOPMENT OF VIRTUAL REALITY SCENES

The research design focuses on wayfinding in departure terminals. Often airport terminals are spaces where the passenger is required to arrive early or right on time to avoid unprecedented air fares and adjustment to unplanned schedules. As such, a departure's terminal has been extracted from a prefabricated airport terminal and has been imported in Unity3D. The software allows for various features to be added, such as scenes and other interactable objects compatible with the VR hardware. In a series of cases it has been stated that exploring architectural environments and effectively immersing the user in virtual dimensions calls for an almost realistic appearance. Therefore, considerable time was spent on adding materiality styles, improving interior lighting and mood of outer space.

SteamVR code snippets were imported to the VR scene to replicate a game-like environment where the user's physical actions, such as holding the controllers, are displayed as the user's hands. Then another code snippet was added to the object floor area to add teleporting features. This snippet was separated in teleportation area and teleportation point. The teleportation area allows the user to freely select where they desire to move, whereas the teleportation point restricts the user to select a single point to be moved to. The area capability is applied to the airport's exterior space and the points are placed in the interior. This way, the user is limited to look around the interior design features of the terminal which are not classified as areas of interest for eye tracking data collection.

The elements in the scene include switched off screens and no signage to test the environment by commencing the initial iteration. After the completion of the first iteration, the scene is duplicated and wayfinding signage is added, as well as simulated flight information on the screens and labelling of check-in areas. The signage is added based on the gaze data produced in the first iteration. Then this second scene iteration is tested by another user to converge the findings.

6.3. EMBEDDING EYE TRACKING CODES FOR DATA COLLECTION

To initiate the eye tracking sensors of the VR unit, code snippets from the Tobii Pro SDKs are added to the camera settings of the Unity scenes. Not every object is necessary to be tracked, and the advantage of Tobii SDK is that it can be applied to layers or objects of interest to the researcher. That way, the assigning of code snippets to the scene features produce accurate and real-time gaze data information. The eye tracking code snippets and their functionality are explained in Table 2. In addition, their functions can be presented during the testing stage in the Unity environment (Figure 3).

Figure 3. Eye tracking in action: illustration showing the functionality of VR Code snippers in Unity.

TABLE 2. VR Code attributes assigned in Unity for enabling eye tracking in the gaming engine.

Component	**Description**
VR Calibration	Adjust the device lens and position to ensure accuracy of eye tracker
VR Eye tracker	Activate the eye tracking sensors when calibration session is completed successfully
VR Gaze trail	Record and indicate, in this case using a green dot, the person’s latest gaze
VR Positioning guide	Guide collecting and showing extensive information on movement of left eye, right eye and indicate the validity of the tracking
VR Save Data	Allocating a button on when to start and stop saving gaze data

6.3.1. Participant testing

In order to test and collect user data, two users were asked to complete an identical task. The first one navigated in a virtual setting with no wayfinding cues, and the second one entered the same environment with signage indicating locations across the terminal section.

A female participant (A), aged 22, was asked to place the VR unit and experiment with the SteamVR home screen to familiarize herself with using the controllers, moving around and exploring the virtual setting. Then she was briefed on the task she is about to complete and that involved the following scenario: The taxi has dropped you off at the airport, find the check-in area. Before commencing the task, she went through short eye tracking calibration session where she was asked to look at 5 dots, appearing on the VR display consequently. The Tobii calibration code snippet indicates whether the user calibration has been successful or not. Additionally, it shows whether data is being recorded when eyes are detected. The user had 30 seconds to complete the task and her journey was recorded.

During the second iteration, a male participant (B), aged 50, went through the same preparation steps as the participant in the first iteration. He was asked to complete the same task however in his scene, signage was added, and the screens indicated plane departure times. While he was immersed for 30 seconds, Participant B verbally indicated that he completed the task few seconds earlier than Participant A.

6.4. RESULTS

The comparison of the same VR environments with and without navigational features emphasises findings on spatial decision making in wayfinding tasks. The VR study with no navigational features highlighted that participant A tend to focus more on the objects within the environment, and fixated their gaze on where they would expect to see a sign. Participant B, on the other hand, saccaded through the environment features and shifted their focus to the signage, performing the same task quicker.

6.4.1. Iteration 1 – the data

Participant A fixated on objects in horizontal line of sight in the VR environment. The number of fixations made are intensified on the screens and reduced in the design features which do not necessarily provide wayfinding information.

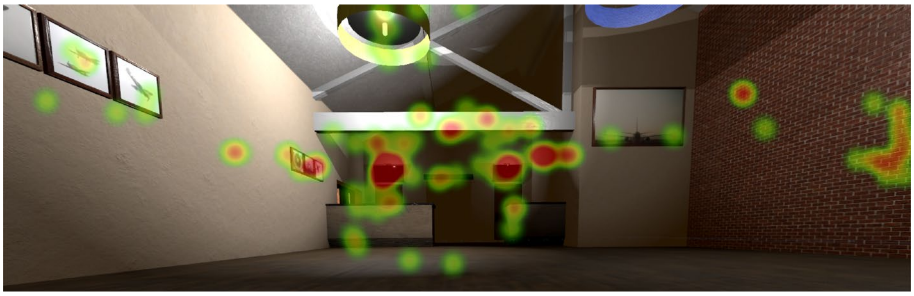

Figure 4. Participant A gaze heatmap in check in area showing fixations across the horizontal line of VR environment

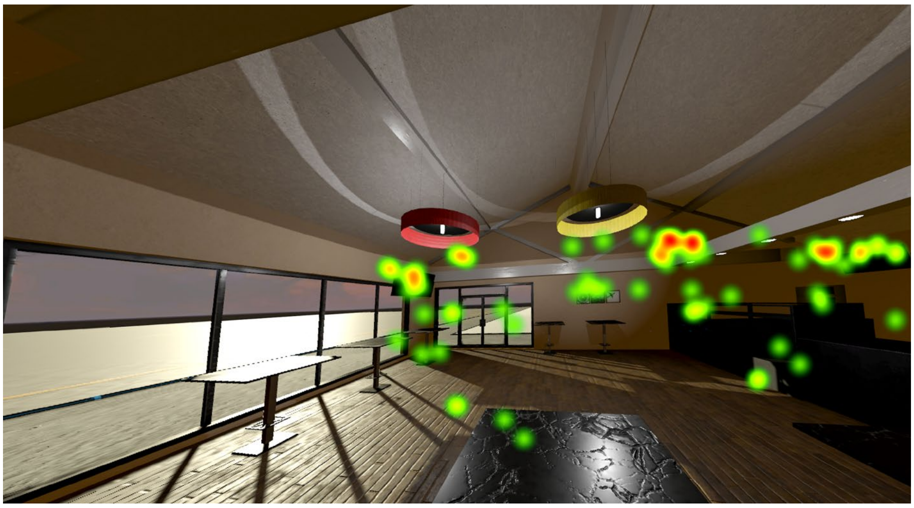

Figure 5. Participant A gaze heatmap in waiting area, focusing more on design features rather than information screens

Figure 6. Participant A gaze heatmap in departure terminal – observing check in counters

6.4.2. Iteration 2 – the data

Participant B heavily focused on the signage features of the environment. He focused on completing the task by looking for navigational cues rather than exploring the design features of the environment. As a result, he was able to complete the task quicker.

Figure 7. Participant B gaze heatmap in check in area, fixating on screens and signage

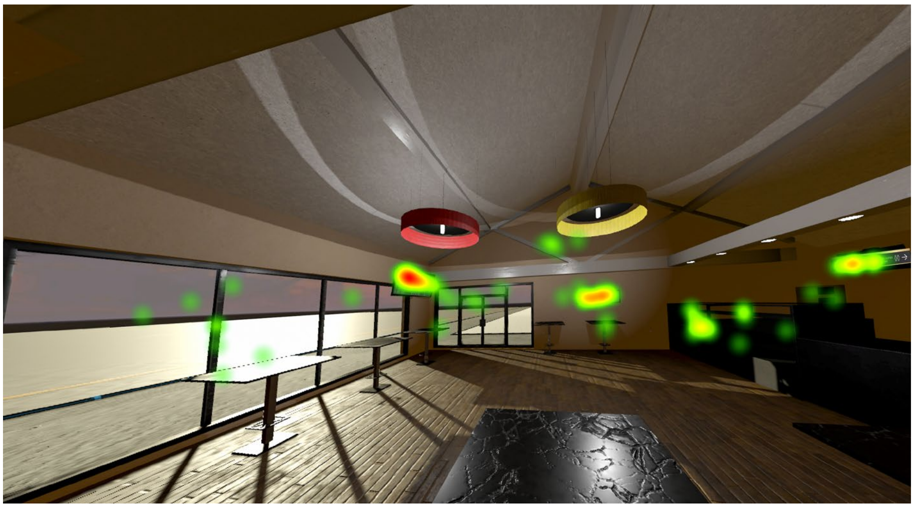

Figure 8. Participant B gaze heatmap in waiting area – duration of fixations are longer on signage and flight information screen and shorter on the environment's design features

Figure 9. Participant B gaze heatmap in departure terminal

6.4.3. Gaze plot visualisation

The gaze plot data from multiple participants can be visualised in a singular form within the AOI. The gaze plots, when hovered over with the cursor, show detailed information on the participant, the recording sequence, the duration of the fixation, number of fixation within that recording and the position in a coordinate system. This approach can be particularly useful when performing multi-user testing.

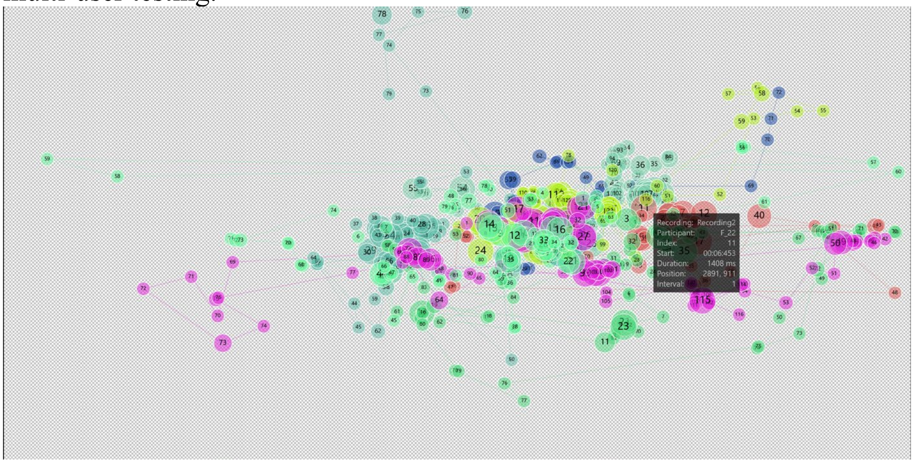

Figure 10. Combined gaze plot data from multiple recordings.

7. Discussion

Enhancing the passenger's journey through immersive interactions is a valuable approach in practice design decision-making. It opens multiple research possibilities to reduce costs in wayfinding and simultaneously create more practical, straight-forward navigation experience.

The nature of transport environments is somewhat similar for the passenger. Since this is the case, this study can be applied to discover opportunities in not only airport departure terminals but other public transport areas. Therefore, testing in other transport environments such as train stations, can extend this study's viability.

This research aimed to investigate the utility of ET in VR dimension and understand user wayfinding behaviour by applying non-traditional practices. The data extracted from the participants left eye, right eye and head movement can be analysed and provide knowledgeable perspicacity of the participant. Therefore, the researcher can discern possible advancements of signage positioning by performing extensive user tests to recognise a pattern in behaviours.

The limitations of this research open opportunities for continuation to develop further conclusions. When testing the environment on multiple users, the researcher can draw improved interpretations of data as some people are better at navigating than others. In this paper's case study, time constraints limited the longevity of research. Time constraints also limited the potential to design a larger space with multiple complex obstacles to navigation.

Performing user testing on multiple people of different demographic and extensive knowledge of VR technologies can contribute to alteration of results. Besides that, adding distracting features to fully replicate real-life situations such as simulating people and sound can alter the results since lively environments can make it more difficult for the passenger to focus and navigate. Commercial spaces, including duty-free stores are another factor of passenger distraction. The collective application of all these features can be researched to improve this study and thoroughly understand factors affecting wayfinding.

Nevertheless, there are many advantages of applying the framework to practice. The spatial features of the transport environment can be designed to enhance the passenger's experience by minimising confusion. As noted in the previous sections, architects design for the user and to do so, inclusion of the user during the iterative design process is essential (ibid). Moreover studies have explored, the wayfinding behaviour is not tested until the transport environment has been constructed (ibid). This approach leads to unnecessary cost increases in experiments and renovations. By simulating a VR environment, the designers can design for human comfort based on evidence and as a result will be rewarded with cost savings.

8. Conclusion

Informative decisions during the design process can be supported with virtual environments, eye tracking and wayfinding processes. These should not be cleaved from user experiences, and the interaction between people and the built environment should be at the very essence of any modelling or design approach.

That way, plausible navigation passenger experiences can be made possible by referring to evidenced data. The accurate collection of data and analysing its trends can be noted to indicate the creation of guides for the design of spatial architecture and signage effectiveness.

The case study in this paper has provided a preliminary data collection framework which can be improved by conducting multi-user testing to further understand user behaviour. The viability of ET data collection in VR environments has been tested, and remarks have been made on navigational signage positioning and alternatives.

Though the importance of user immersion in virtual environments and the integration of ET sensors has been documented in this paper, the constraints have opened future possibilities for investigation in the field of spatial design for public transport environments.

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References

Abutabenjeh, S. & Jaradat, R., 2018. Clarification of research design, research methods, and research methodology: A guide for public administration researchers and practitioners. Teaching Public Administration, 36(3), pp. 237-258.

Altrichter, H., Kemmis, S., McTaggart, R. & Zuber-Skerrit, O., 2002. The concept of action research. The Learning Organization, 9(3), pp. 125-131.

Cipresso, P., Giglioli, I. A. C., Raya, M. A. & Riva, G., 2018. The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature. Frontiers in Psychology, 9(2086).

Coyne, R., 1994. Heidegger and Virtual Reality: The Implications of Heidegger's Thinking for Computer Representations. Leonardo, 1 January, 27(1), pp. 65-73.

Criado-Perez, C. y otros, 2019. Beyond an 'informed opinion': evidence-based practice in the built environment. Architectural Engineering and Design Management, pp. 1-18.

Downs, R. M. & Stea, D., 1977. Maps in minds: reflections on cognitive mapping. 1st ed. New York: Harper & Row.

Emo, B., 2014. Seeing the Axial Line: Evidence from wayfinding experiments. Behavioral Sciences, 4(3), pp. 167-180.

Frost, P. & Warren, P., 2000. Virtual reality used in a collaborative architectural design process. London, An International Conference on Computer Visualizations and Graphics, pp. 568-573.

Golledge, R., 1999. Human wayfinding and cognitive maps. En: Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes. Baltimore: The Johns Hopkins University Press, pp. 5-45.

Gunzelmann, G., Anderson, J. R. & Douglass, S., 2004. Orientation Tasks with Multiple Views of Space: Strategies and Performance. Spatial Cognition & Comutation, 4(3), pp. 207-253.

Hearn, G. N. & Foth, M., 2005. Action research in the Design of New Media and ICT Systems. En: Topical Issues in Communication and Media Research. s.l.:Nova Science, pp. 79-94.

Hollander, J. B. y otros, 2018. Seeing the city: using eye-tracking technology to explore cognitive responses to the built environment. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 12(2), pp. 156-171.

Hopkins, D., 1985. A teacher's guide to classroom research. Philadelphia: Open University Press.

Huxtable, A. L., s.f.

Kandel, E., 2012. The Age of Insight: The Quest to Understand the Unconscious in Art, Mind, and Brain, From Vienna 1900 to the Present. New York: Random House.

Kiefer, P., Giannopolous, I., Raubal, M. & Duchowski, A., 2017. Eye tracking for spatial research: Cognition, computation, challenges. Spatial Cognition and Computation, 17(1), pp. 1-19.

Montello, D. R., 2005. Navigation. En: A. Miyake & P. Shah, edits. The Cambridge Handbook of visuospatial thinking. Cambridge: Cambridge University Press, pp. 257-294.

O'Brien, R., 2001. Overview of Action Research Methodology, Toronto: University of Toronto.

Picon, A., 2019. Digital Fabrication, Between Disruption and NostalgiaL Notes on the Nature of Knowledge in Digital Architecture. En: Instabilities and Potentialities. s.l.:s.n.

Schmitt, G., Wenz, F., Kurmann, D. & Mark, E. v. d., 1995. Toward Virtual Reality in Architecture: Concepts and Scenarios from the Architectural Space Laboratory. Presence: Teleoperators and Virtual Environments Summer, 4(3), pp. 267-285.

Schrom-Feiertag, H., Settgast, V. & Seer, S., 2017. Evaluation of indoor guidance systems using eye tracking in an immersive virtual environment. Spatial Cognition & Computation, 17(1-2), pp. 163-183.

Song, H. y otros, 2018. Improvement of User Experience using Virtual Reality in Open-architecture Product Design. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 232(13), pp. 2264-2275.

Tang, M. & Auffrey, C., 2018. Advanced digital tools for updating overcrowded rail stations - using eye tracking, VR, crowd simulation to support design decision making. Urban Rail Transit, 4(4), pp. 249-256.

Zhang, L.-M., Jeng, T.-S. & Zhang, R.-X., 2018. Integration of Virtual Reality, 3D eye-tracking, and protocol analysis for re-designing street space. Hong Kong, CAADRIA, pp. 431-440.