Virtual Reality and the Interactive Design of Elevated Public Spaces: Cognitive Experience vs VR Experience

ABDELSALAM, Ehab, HEATH, Tim and BURNETT, Gary

Virtual Reality and the Interactive Design of Elevated Public Spaces: Cognitive Experience vs VR Experience

Ahmed Ehab [1][0000-0002-9752-7321] Tim Heath [2][0000-0002-5833-2097]

Gary Burnett [3][0000-0001-9945-9396]

[1,2,3] Human Factors Research Group, University of Nottingham, University Park, Nottingham, NG7 2RD, UK

ahmed.abdelsalam@nottingham.ac.uk

Abstract.VR and visualization are visual aids, but can give much more than sight, such as a wider sensation of being in the 3D world. For the past ten years, researchers and organizations have been trying to find ways to get the public more involved in social project design and execution. Technologies such as Visual Simulation (VS) and Virtual Reality (VR) could make it possible to provide final stakeholders and consumers with closer access to the design and implementation processes of social projects. This paper analyzed two recent developments in London, Sky Garden and Crossrail Place. The study investigates how technologies such as VR can enhance the design experience of elevated urban spaces. The main aim of this study is to explore the difference and similarities between human interaction in the real cognitive experience and the virtual world. The method used in this study is walk-long interviews with the visitors of both gardens and a VR exploratory experiment, followed by semi-structured interviews with the participants. This methodology brings the participant as an active element of the project, able to explore the space and propose changes.
The paper discussed (i) the design quality of elevated social spaces such as accessibility, circulation, activities, design concerns and design features, (ii) the participant's experience and behaviour during the study and (iii) the effectiveness of the design used tools. The results showed a positive impact on enhancing user involvement and allowed users to produce and test different design alternatives in real time. The research findings include a study of human activities in the physical and the virtual world, pedestrian modelling for the selected case studies, and an analysis of the potential need for new rules and regulations relating to the use of such spaces. The research also highlighted the limitations and potentials of using these new methods as a co-design approach for designing public and social spaces in the city.

Keywords: Virtual Reality; Computational design; Gamification; Participatory design; Elevated Public Spaces

1 Introduction

The integration of public participation in decision-making and design policy formation has been a fundamental aspect of urban design and the design of public spaces in democratic societies since the late 20th century [1,2]. In recent years, digital technologies, such as Virtual Reality (VR) and Visual Simulation (VS), have presented designers with new opportunities to enhance public engagement and involvement in social project design, while also presenting the need to evaluate the validity and legitimacy of these new processes [3,5]. The use of VR and VS technologies has been gaining momentum as innovative tools for public engagement and stakeholder involvement, with a growing body of literature exploring their potential benefits in various design fields [4,6].

VR is an emerging field of research that has garnered significant attention in recent years. It holds the potential to revolutionize the way we engage with physical and informational elements. The key challenge in the development of VR technology and applications lies in the creation of innovative methods for designing information, storytelling, and narratives, as the full potential of this medium has yet to be fully realized [7,8]. This challenge extends beyond the technological domain and encompasses the development of interaction dynamics with users, including gameplay, as well as the potential for applications in novel fields. The application of Virtual Reality (VR) technology in the fields of architectural and urban design has the potential to broaden the definition of what is considered "real", thereby creating opportunities for entirely new simulations and sensory experiences [9]. With this approach, participants in VR-based architectural and urban design projects are not limited to passive observation but instead become active contributors who can preview the space, propose modifications, and have a sense of ownership over the eventual interactive environment [10]. VR technology provides users with the capability to experience changes and actions in real-time, in an immersive manner. While professionals in the Architecture, Engineering, and Construction (AEC) field may be familiar with VR, it remains a novel and challenging technology for the general public [11].

1.1 Research Background

Virtual Reality (VR) is a technology that allows users to experience computer-generated simulations in a 3D environment that can range from being similar to the real world to being entirely different [9]. VR systems typically utilize VR headsets or multi-projected environments to generate realistic visuals and sounds, allowing users to immerse themselves in the virtual environment.

The exploration of the impact of Immersive Virtual Environments (ImVE) on design perception, physiology, and cognition has produced knowledge to support improved design patterns, creativity, and reasoning among multiple users [7,3]. Research has shown that ImVE can positively impact designers' cognitive processes, including working memory, design data search and access, spatial cognition, and attention allocation. Additionally, ImVE has been found to positively impact users' perception and memory. Studies have indicated that ImVE can lead to improved performance of designers,

particularly in problem finding, and can have a positive impact on both the problem and solution spaces [6,12]. Collaborative design in ImVE has also been found to be effective in increasing inspiration for new approaches to problem-solving among design collaborators.

The use of VR technology in urban design has the potential to greatly enhance the participatory design process by allowing for greater collaboration between designers, stakeholders, and the general public. By integrating VR with Building Information Modelling (BIM), urban design projects can benefit from increased engagement with end-users and a more immersive and interactive design experience [6,10,11]. There are several VR plugins, such as Revit Live and Enscape, available to architects and urban designers that enable the integration of VR into their design and collaboration processes [15].

Similarly, game engines, such as Unreal Engine and Unity 3D, have the potential to support public participation in the design process. These game engines, originally developed for gaming development, can be customized by independent developers to meet the specific needs of the architecture and urban design fields [8]. However, it is important to note that while the use of game engines in architecture and urban design has the potential to improve public participation, there are also limitations that must be considered, such as the validity and legitimacy of information obtained through VR simulations and the potential for biases [12,14].

The use of VR technology in participatory design also raises concerns about user comfort and accessibility, as well as the potential differences between people's behavior and interactions in VR environments compared with their interactions in real-life cognitive experiences [5,13]. These limitations highlight the need for further research into people's behavior and interactions in VR environments to fully understand the potential and limitations of VR technology in participatory design processes.

1.2 Purpose

The purpose of this research is to investigate the potential of Virtual Reality (VR) technology in enhancing the design experience of elevated urban spaces, through analyzing two recent developments in London, Sky Garden and Crossrail Place. The study aims to explore the differences and similarities between human interaction in the real world and the virtual world, and to examine the impact of VR technology on user involvement, design quality, and participant experience and behavior.

1.3 Case studies

The research study involved the examination of two diverse elevated urban spaces located in London. The first of these spaces was the Sky Garden, which is situated on the upper three floors of the "Walkie Talkie" skyscraper in the center of London's financial district [16]. The second was the Crossrail Place roof garden, located in North Dock, Canary Wharf, which is an elevated green park covering an area of 10,000 square meters and located above the Elizabeth Line [17].

2 Methodology

The methodology includes **walk-along interviews** with the visitors (n=33) of both gardens and a **VR exploratory experiment**, followed by semi-structured interviews with the participants (n=33), which brings the participant as an active element of the project. These methods were selected to provide insights into the effectiveness of VR technology as a co-design approach for designing public and social spaces in the city, and to explore the potential need for new rules and regulations relating to the use of such spaces.

2.1 Walk-along interviews

A total of 33 participants were recruited for walk-along interviews in each of the Sky Garden and Crossrail Place in London to understand their physical experience in elevated urban spaces. Participants, all aged 18 years and above, came from different age groups. The 20-minute interviews were conducted on-site and analyzed through qualitative data sets. The author employed a theme-based analysis, including content analysis, to examine the impact of physical experience on social interaction and activities. The analysis followed a descriptive approach, guided by a summative approach, to effectively analyze the data [18,19]. Participants provided informed consent and signed an ethics form before contributing to the study.

2.2 VR Experiment

The purpose of the VR experiment is to compare two different approaches to creating an interactive design model, one using BIM software (Autodesk Revit+ Enscape) and the other using a game engine (Unreal Engine). The experiment is followed by qualitative semi-structured interviews with the participants (n=33) to gather their views on their virtual experience and behavior during the experiment.

2.2.1 VR Experimental setup & Procedures

The VR laboratory experiment lasted for one hour, and participants had the opportunity to interact with VR models of the Sky Garden and Crossrail Place. The VR model allowed participants to see and interact with changes and actions that could be made to the environment. The experiment was divided into three stages: induction and consent, filling out a survey, and testing the VR models.

Building an interactive design model in VR involved two methods, one for constructing the Sky Garden and the other for constructing the Crossrail Place. The Sky Garden was designed and modelled on 3DS Max and then imported to Unreal Engine for further visual coding. The Crossrail Place was designed using BIM software (Autodesk Revit 2022), with an Enscape plugin for real-time design changes in VR. The study used Oculus Quest 2 and a GoPro 360-degree camera to ensure the safety of participants during the VR experience. The researcher took safety precautions such as good

ventilation, anti-nausea wristbands, and a 'guardian' feature to reduce the risk of VR-induced discomfort.

In the Sky Garden experiment, participants were guided to interact with the space design by changing materials, moving objects, and taking virtual photos. In the Crossrail Place experiment, participants were asked to add or remove design features and components and test them in real-time using the light simulation tool and the virtual camera. The semi-structured interviews focused on participants' views on their virtual experience and behavior during the study.

3 Results

The study targeted participants from different age groups and different backgrounds such as architects, urban designers, interior designers, computer engineers, academics, and public users. The interview analysis highlighted four overarching themes which are; space circulation design, design concerns, activities and interactive design,

3.1 Space circulation design

The results showed that a significant number of participants (n=20) preferred the Sky Garden's circulation design, which was described as open, welcoming, linear, and straightforward. 45% (n=15) of the participants accepted the one-way circulation system due to its necessity for safety and social distancing. The participants who had not visited Sky Garden before (n=21) appreciated the experience of going up the stairs to different levels and found it to be more adventurous and interactive. However, they also raised concerns about accessibility for wheelchair users. On the other hand, the other group of participants (n=13) preferred the Crossrail Place circulation design, which was described as an adventure, natural experience, walking and discovering, and exploratory. The participants noted that the curvy pathways in Crossrail Place were narrow and needed to be designed wider for privacy and accessibility (Figure 1).

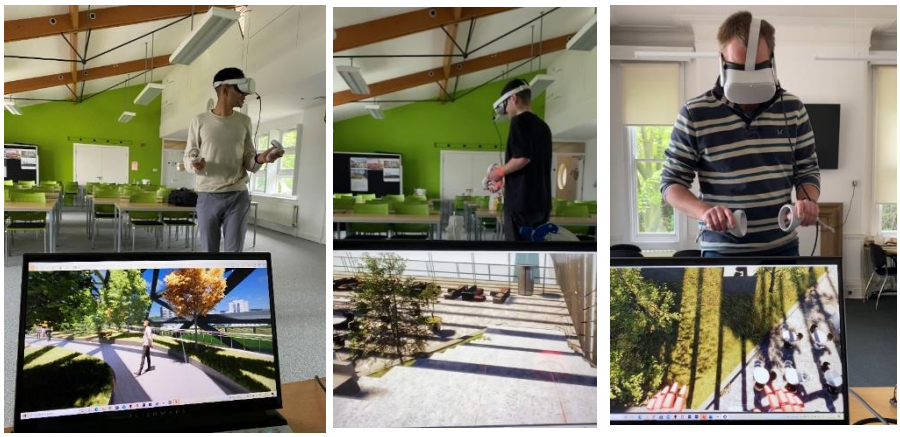

Fig. 1. Participants teleporting and testing the space design circulation, source: author.

3.2 Design Concerns

In examining the design aspects of the Sky Garden and Crossrail Place, results from the VR study showed that several limitations and concerns were identified by the participants. A significant number of participants, both those who had previously visited the Sky Garden in real life and those who had not, noted the need for more green spaces and public seating near the plants, as well as the reorganization of seating areas to accommodate for privacy, social distancing, and accessibility. Additionally, there were design concerns raised regarding the restaurant and outdoor viewing platform.

On the other hand, the elevated nature and landscape features of Crossrail Place were favored by a substantial number of participants, who viewed it as a more public space than the Sky Garden. However, they also expressed the need for comfortable and sociable seating areas, wider pathways, and an increase in plants and flowers. Further, a significant number of participants stated that the garden would benefit from additional interactive elements such as public art, statues, an outdoor viewing platform, a water fountain, a pet-friendly area, and an outdoor bar and café.

3.3 Activities

The results of the study revealed that participants had diverse preferences for the activities they would likely engage in if they visited the Sky Garden and Crossrail Place. In the Sky Garden, the most frequently cited activities were appreciating the views of the city, consuming beverages and food, socializing with friends, and capturing memories through photography. In contrast, the participants preferred to relax, immerse themselves in the natural surroundings, engage in reading, have a lunch, and take pictures in Crossrail Place. The participants also reported a high level of enjoyment while exploring the virtual models and saw potential for conducting virtual activities within the spaces. They recommended offering virtual tickets as a means of encouraging more visitors to physically visit the spaces, and a majority of participants who had not previously been to either space expressed interest in visiting after participating in the VR experiment.

The study found that exploring the virtual environment allowed participants to engage in physical and virtual activities that they may not be able to do in real life, such as jumping, flying, dancing, running, and sitting on the floor. Observing these physical motions in the virtual space highlighted the potential benefits of using VR as a social online platform in the event of future pandemics. A number of participants who shared their experience of lockdown in 2020 emphasized the importance of this as a means to support mental health for those living alone during such crises. However, the participants also acknowledged that virtual social interaction cannot completely replace the physical experience.

3.4 Interactive Design

The results of the VR laboratory experiment indicate that the participants viewed the interactive design opportunity as a critical and pleasurable aspect of the experience. All participants concurred that the utilization of advanced tools and features can enhance their understanding of the design quality of both the Sky Garden and Crossrail Place. The usage of these tools in architectural design can significantly engage users to visualize and refine the details of a project, comprehend design limitations, and test the utilization of space based on their requirements and desired activities (Figure 2). The interactive design simulation included features such as light simulation, material alteration, X-ray visualization, virtual annotations, and a virtual camera. The results indicated that light simulation and material alteration were the most favored simulation tools, while the virtual camera was perceived as an enjoyable and efficient tool for real-time changes and communication with the designer. The X-ray visualization and virtual annotations were also deemed as important interactive design tools for testing diverse design strategies and communication among project team members.

The use of the Revit BIM software with the Enscape plugin in the VR experiment allowed for real-time design changes based on participant requirements. Participants frequently identified design concerns and suggested new design scenarios and activities for Crossrail Place roof garden, such as a water element, exercise area, public art, comfortable seating, more plants, an open plaza for events, gaming areas, an outdoor café, and an outdoor space for animals.

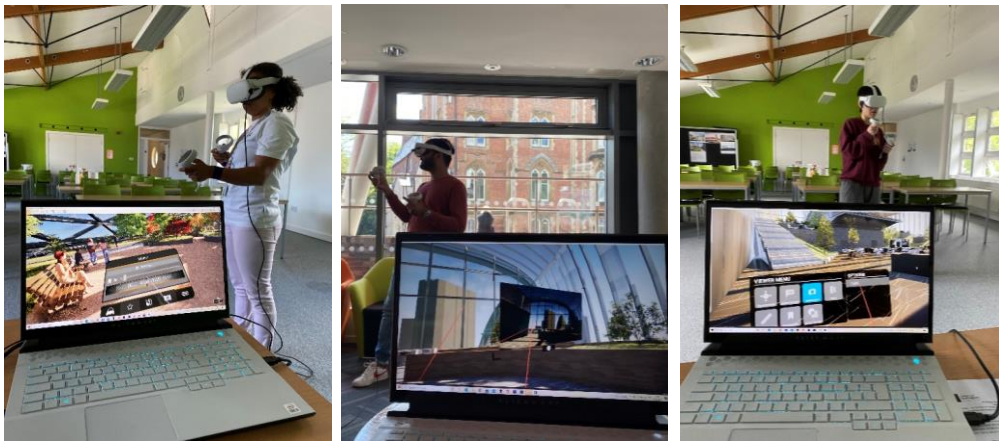

Fig.2. Participants testing the interactive design features in real-time, source: author.

3.5 Discussion & Conclusion

The present study offers evidence for the potential utilization of virtual reality (VR) technology as a co-design approach in the realm of urban and public spaces design. The combination of walk-along interviews and VR experiments allowed for a comprehensive examination of the physical and virtual experiences, revealing similarities between the two. Participants, both those with prior experience in the spaces and those without, were able to identify design limitations and propose activities and features, with many of their concerns and needs aligning with those of actual space users.

However, the study also sheds light on the limitations of VR technology in achieving a fully immersive virtual environment, such as limitations in physical space and the potential for VR sickness. The development of multimodal haptic devices is deemed crucial for creating a highly immersive VR experience.

In conclusion, the findings of this study provide valuable insights for designers and policymakers in their efforts to create public spaces that are in line with user needs and preferences. Nevertheless, further research is necessary to assess the generalizability and scalability of VR technology in larger and more complex urban design projects.

Funding

The work was supported by the Faculty of Engineering University of Nottingham Research Excellence PhD Scholarship.

References

1. Wilson, A., Tewdwr-Jones, M., & Comber, R. (2019). Urban planning, public participation and digital technology: App development as a method of generating citizen involvement in local planning processes. Environment and Planning B: Urban Analytics and City Science, 46(2), 286-302.
2. Bouzguenda, I., Alalouch, C., & Fava, N. (2019). Towards smart sustainable cities: A review of the role digital citizen participation could play in advancing social sustainability. Sustainable Cities and Society, 50, 101627.
3. Zhang, C., Zeng, W., & Liu, L. (2021). UrbanVR: An immersive analytics system for context-aware urban design. Computers & Graphics, 99, 128-138.
4. Wolf, M., Söbke, H., & Wehking, F. (2020). Mixed Reality Media-Enabled Public Participation in Urban Planning: A Literature Review. Augmented reality and virtual reality: changing realities in a dynamic world, 125-138.
5. Van Leeuwen, J. P., Hermans, K., Jylhä, A., Quanjer, A. J., & Nijman, H. (2018, November). Effectiveness of virtual reality in participatory urban planning: A case study. In Proceedings of the 4th Media Architecture Biennale Conference (pp. 128-136)
6. Safikhani, S., Keller, S., Schweiger, G., & Pirker, J. (2022). Immersive virtual reality for extending the potential of building information modeling in architecture, engineering, and construction sector: systematic review. International Journal of Digital Earth, 15(1), 503-526.
7. Yu, R., Gu, N., Lee, G., & Khan, A. (2022). A Systematic Review of Architectural Design Collaboration in Immersive Virtual Environments. Designs, 6(5), 93.

8. Panya, D. S., Kim, T., & Choo, S. (2023). An interactive design change methodology using a BIM-based Virtual Reality and Augmented Reality. Journal of Building Engineering, 106030.

9. Portman, M. E., Natapov, A., & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. Computers, Environment and Urban Systems, 54, 376-384.
10. Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). From BIM to extended reality in AEC industry. Automation in Construction, 116, 103254.
11. Zaker, R., & Coloma, E. (2018). Virtual reality-integrated workflow in BIM-enabled projects collaboration and design review: a case study. Visualization in Engineering, 6(1), 1-15.
12. Rubio-Tamayo, J. L., Gertrudix Barrio, M., & García García, F. (2017). Immersive environments and virtual reality: Systematic review and advances in communication, interaction and simulation. Multimodal Technologies and Interaction, 1(4), 21.
13. Kim, S., Kim, J., & Kim, B. (2020). Immersive virtual reality-aided conjoint analysis of urban square preference by living environment. Sustainability, 12(16), 6440.
14. Meenar, M., & Kitson, J. (2020). Using multi-sensory and multi-dimensional immersive virtual reality in participatory planning. Urban Science, 4(3), 34.
15. Huang, Y., Shakya, S., & Odeleye, T. (2019). Comparing the functionality between virtual reality and mixed reality for architecture and construction uses. Journal of Civil Engineering and Architecture, 13(1), 409-414.
16. Sky-Garden, 2015. Sky Garden Visitor Rules & Regulations. [Online] Available at: https://skygarden.london/terms-conditions/ [Accessed 4 May 2020].
17. Bosetti, N., Brown, R., Belcher, E. & Washington-Ihieme, M., 2019. Public London: the regulation, management and use of public spaces, London: Published by Centre for London
18. Schreier, M. (2014, January). Varianten qualitativer Inhaltsanalyse: ein wegweiser im dickicht der Begrifflichkeiten. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research (Vol. 15, No. 1).
19. Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.