A Systematic Review of the Potential Application of Virtual Reality Within a User Pre-occupancy Evaluation

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Abstract. This research aims to discover the potential applications of virtual reality within a user pre-occupancy evaluation. The capability of the VR creates detailed observations, a feeling of immersion, an accurate behaviour measurement and systematic environmental manipulations, which can be controlled in the laboratory. However, previous studies seem to have paid little attention to specific clients when suggesting the most suitable VR approach at the evaluation stage. Moreover, few studies have investigated the use of VR in supporting designers in best practice, and only a limited number of studies focus on the design evaluation from a user's perspective. A systematic literature review is therefore conducted in this study, which focuses on end-user participation. The purpose of this is to explore the extent to which VR is used and to find potential research directions for further studies. The results indicate that VR is a useful aid in a pre-occupancy evaluation which is acceptable and reliable for users.

Keywords: Pre-occupancy evaluation · User experience · Virtual reality

1 Introduction

In an architectural domain, there are various types of design process. Most of these generally start at the briefing stage and end with design drawings [1, 2]. The pre-occupancy evaluation in this process is understood as an environmental evaluation from the user's perspective, prior to the occupation of a building [3]. It plays a crucial role in the design process, aiming to evaluate construction safety [4], customer satisfaction [5], cost effectiveness [4, 6], time and effort prior to the construction phase [7]. In particular, the safety evaluation of the construction site is an important part of planning projects [4]. To be more specific, it supports the reduction of physical risks [5] throughout the communication between designer and client. Client-designer communication is an important part of all these phases of design and is the principal concern of architecture [8].

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Virtual reality (VR) is explored here in terms of its potential to support the building evaluation. Patel et al. [9] concluded that VR technology has the potential to improve the client design review process within the construction industry. It enhances the communication within the visual presentation of architecture between designers and clients. The related studies suggest that the use of VR tools during the early construction stages is the key theme within 3D visualisation [10, 11].

Some earlier studies have concentrated on methods of researching and applying VR technology. For example, Paes and Irizarry [12] explored the most relevant human factors and cognitive aspects associated with the use of three-dimensional virtual reality models. Lertlakkhanakul et al. [13] applied VR as a platform to simulate a smart home service configuration. In addition, VR has also been applied to evaluate the integrity of occupancy information to close the building energy performance gap [14, 15]. Kuliga et al. [16] demonstrated that in addition to user cognition and behavior, the user experience is analogous to the real and virtual environments. Woksepp and Olofsson [17] explored the credibility and applicability of virtual reality models, which were experienced and assessed within a workforce. Norouzi et al. [7] presented an overview of a design approach focusing on the designer-client relationship. Westerdahl et al. [18] compared the user experiences of employees in a virtual building and the completed building. Another piece of research with a new approach [19] considered a method of virtual pre-occupancy evaluation (VOE) using VR to assess human performance for people with disabilities. Shen et al. [1] enhanced the limited experience of clients by developing a user pre-occupancy evaluation (UASEM) which adopted VR in a case study (a university campus project) including four steps: preparation of the building information model, specification of user activities, simulation of user activities and a pre-occupancy evaluation. A methodology known as VIC-MET [20] has been suggested to include the user in a creative innovation process. VIC-MET has four design spaces that support different functions in the design process: contextual enquiry, a conceptual modeling space, a functional consolidation space and a solution space. The virtual environments are CAVE (Fig. 1) [21], Panorama (Fig. 2) [22], a game console-based solution and a virtual world in second life (Fig. 3) [23].

Fig. 1. CAVE virtual environment

Fig. 2. Panorama

Fig. 3. A scenario in second life

Another methodology has been developed [24, 25] to ensure the usability of virtual environments through user-centered design and evaluation, and has been shown to have a cost-effective strategy which assesses and iteratively improves user interactions in built virtual environments. Santos [26] insisted on user satisfaction in the use of the VR system, and HMD interaction performs better than the desktop setup. Essentially, the architectural design process shows high rates of iteration by design teams [6]; however, the role of the user in this process is also significant. Therefore, an understanding of the user experience with VR tools might to some extent support architectural designers and researchers in being more effective. Nevertheless, the number of studies investigating VR in pre-occupancy evaluations from the user's perspective seems to be low.

This study therefore aims to explore the effectiveness of user participation in the design process using VR and to find potential research directions for further studies of VR.

2 Methodology

2.1 Data Sources and Search Strategy

This study aims to use a meta-analysis method to retrieve articles related to the potential application of VR within a user pre-occupancy evaluation. A search strategy is formulated with filtering rules which focus on exploring related studies that include virtual reality in a user pre-occupancy evaluation, with data drawn from ScienceDirect, Scopus, Web of Science (WOS) and Google Scholar. In addition, the literature review was conducted without a time limit on publications, in order to explore the trends in related studies. There is a great deal of research exploring VR in the engineering field of ScienceDirect, and following the Web of Science and Scopus. The current study also collected related studies published between 2006 and 2016, as more recent changes in commercialized products allow a broader application of VR in engineering and construction [5]. Six main keywords including virtual reality, user experience, pre-occupancy evaluation, designer-client communication, user participation and architectural design were selected for a search strategy related to the application of VR in a user pre-occupancy evaluation.

2.2 Retrieval Methods and Screening Criteria

Retrieval was conducted using ScienceDirect, Scopus and WOS by searching abstracts, titles and keywords to retrieve virtual reality and engineering keywords in all years. The six keywords were used to reduce the insignificantly related results, checking in couples and triples of keywords. Using a publication time limit of between 2006 and 2016 reduces the results of this study. Simultaneously, repeated papers and less relevant papers checked through the abstract were excluded.

The filtering rules were articles that included (1) main keywords and synonyms with a high database reliability; (2) information related to the use of VR in exploring user experience via studies or tests with user participation and methodology in improving client-designer communication; (3) identification of the effects of VR or its contributions in architectural design; and (4) present work clearly related to this study in the abstract. According to these four rules, a total of 17 articles comply with Rules 1 to 3 and finally, a total of eight articles complied with Rules 1 to 4.

3 Results

In order to reduce the numerous results in ScienceDirect when searching all fields to retrieve virtual reality and engineering keywords in all years, we conducted a subsequent search which included the abstract, title and keywords. The following main keywords are the focus of this research: (1) virtual reality (2) user experience (3) pre-occupancy evaluation (4) designer-client-communication (5) user participation and (6) architectural design were combined. However, the search strings in ScienceDirect did not match more than two keywords. A total of 236 articles were eliminated from the three pairs of keywords (1) and (2), (1) and (3), (1) and (5), while 1197 results from the pair (1) and (4) were excluded due to the high quantity of results. Similarly, a search of the article title, abstract and keywords was conducted to retrieve virtual reality and engineering keywords in the Scopus database, reducing the number of articles from 10748 to 444 results. A further 42 were eliminated to reduce the number from 563 to 521 when searching for a topic to retrieve the same keywords in WOS. In particular, Scopus and WOS allow the matching of more than two keywords. Google Scholar launch was also used as an additional search, using the same method of checking the main keywords and excluding the repeated results to retrieve three more related articles.

Following this, the collected articles for each set of keywords were checked to exclude similar and less related papers through the abstract; a total of 17 articles complied with Rules 1 to 3. Finally, a total of 8 articles complying with Rules 1 to 4 were chosen for discussion. Figure 4 illustrates the selection process.

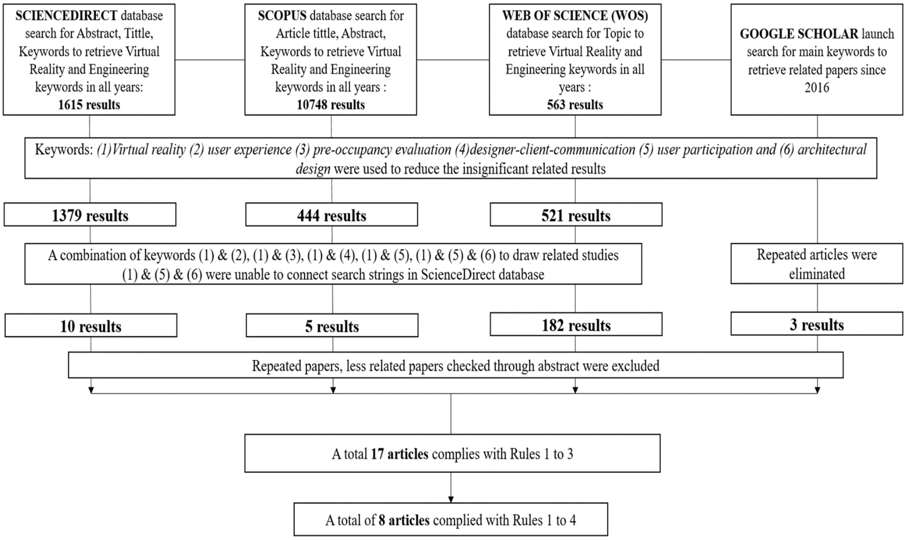

Fig. 4. The selection process

4 Discussion

The related studies discuss a number of useful applications applying VR to meet the demands of clients in the design process. As a result, VR opens up a vast number of opportunities in the innovation of architectural design, with valuable findings. User experience is vital in studies of human–environment interaction, and should be taken into account when examining ‘naturalistic’ human behaviour in real and virtual environments or the usability of buildings. There is almost no difference between the virtual environment (VE) and the real environment, although there are still some limitations, such as the level of spatial legibility and factors related to atmospherics. VR, for this reason, has the potential to be used as an empirical research tool for architectural researchers and designers. Moreover, the present procedure which distributes information using 2D CAD drawings is assessed as having low effectiveness. Virtual reality itself needs to have a high level of realism in order to obtain a high level of immersion and similarity compared with a real scenario, however. For a better presentation, Spatial Legibility of users, as well as the quality of virtual presentation, should be considered.

A positive result from the user's perspective was that virtual models were useful and well accepted by participants. For instance, by giving a fairly accurate presentation of the real building, VR is a useful aid in the decision-making process concerning the future workplace of employees.

However, virtual simulations are mostly used in the evaluation of environmental performance in relation to people who do not have particular needs. Sometimes, there was a difference in user experience that was believed to be due to a difference in computer experience and the age of the employees. This means that the virtual experience is not similar between users; it varies individually depending on personal characteristics.

Table 1. VR Devices on the Market

Name	Photo
Oculus CV1's Touch [27]	
HTC Vive [28]	
Samsung Gear VR [29]	

Therefore, a focus on specific users would be exhaustively able to resolve certain concerns in post-occupancy evaluation such as the level of safety.

The methods of evaluation of user participation also contribute to an improvement in users' understanding of the design process, users' confidence in expressing comments and an increase in their willingness to work with designers. In this case, VR plays a role as a requirement management technique. Nevertheless, the information of the building simulation model is limited to only basic architectural information. Some users would like to obtain more information, such as the decoration, lighting and details of materials. Furthermore, it seems that the method of presentation and cooperation with the designer is somewhat complicated. For instance, there are limited possibilities for transferring building models from the construction industry's traditional design tools to a 3D representation of Second Life virtual world. This is a significant barrier to an efficient use of the VR tool.

In terms of the virtual devices on the market, several products may be considered. Oculus CV1's Touch and HTC Vive support controllers to users for interaction. These VR devices are more beneficial and easy to use for general users. This would probably be a more simple way, especially for a more popular use. This issue is solved in research which focuses on the evaluation of construction site safety using head-mounted displays (HMDs). With a VR headset and a phone, the designer will be able to present their work to clients easily. Table 1 shows three popular VR devices on the market.

Generally, VR is a useful aid which is acceptable and reliable to customers. It is an empirical research tool, a requirement management technique and a presentation tool providing users with cognition impacts such as spatial perception or orientation, presence or immersion, spatial behaviour, spatial dimension, contextual information and sense of realism. VR also allows for the interaction between users and specific objects

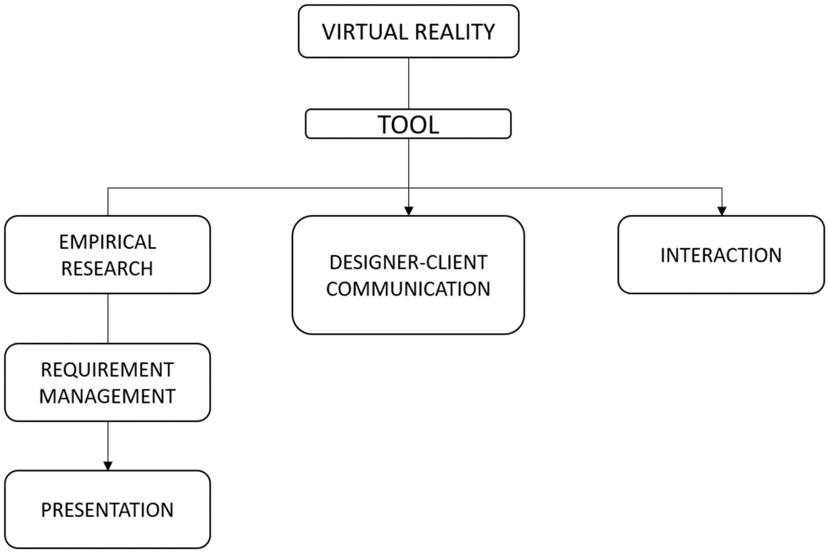

Fig. 5. VR architectural design

in a virtual environment. In pre-occupancy evaluation methods, VR is employed to support end-users in communication with designers regarding their vision of their future work and the building's appearance (Fig. 5).

However, there are several issues related to the quality of representation to users as well as a suitable method applying VR to users in a pre-occupancy evaluation. An investigation of different users with distinguishing characteristics in terms of VR experience, age, physical and psychological concerns is essential for further research.

5 Conclusion

This study conducted a comprehensive literature review to discover the potential applications of VR on a pre-occupancy evaluation. The results indicate that VR is a useful aid in pre-occupancy evaluation, which is both acceptable and reliable for users. In addition, VR brings several benefits not only to designers but also to users. Future studies should focus on investigating users with different physical and psychological characteristics. Research into the VR experiences of these users in terms of the level of realism, human performance and appropriate VR systems and methods for various cases is recommended.

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References

1. Shen, W., et al.: The user pre-occupancy evaluation method in designer–client communication in early design stage: a case study. Autom. Constr. **32**, 112–124 (2013)
2. Archer, B.L., The structure of design processes. Royal College of Art (1968)
3. Guski, R., Schuemer, R.: Umweltevaluation. Lantermann & V. Linneweber (Hrsg.), Umweltpsychologie **1,** pp. 785–810 (2008)
4. Hilfert, T., Teizer, J., König, M.: First person virtual reality for evaluation and learning of construction site safety. In: Proceedings of the International Symposium on Automation and Robotics in Construction ISARC 2016. Vilnius Gediminas Technical University, Department of Construction Economics & Property (2016)
5. Yang, J.-B., Peng, S.-C.: Development of a customer satisfaction evaluation model for construction project management. Build. Environ. **43**(4), 458–468 (2008)
6. Serginson, M., et al.: Assessing the effectiveness of architectural design communication through public participation methods. Des. Manag. Prof. Pract. **6**(1), 61–84 (2013)
7. Norouzi, N., et al.: A new insight into design approach with focus to architect-client relationship. Asian Soc. Sci. **11**(5), 108 (2015)
8. Kalay, Y.E.: Architecture's New Media: Principles, Theories, and Methods of Computer-aided Design. MIT Press, London (2004)

9. Patel, N.K., Campion, S.P., Fernando, T.: Evaluating the use of virtual reality as a tool for briefing clients in architecture. In: Proceedings of the Sixth International Conference on Information Visualisation. IEEE (2002)
10. Bucolo, S., Impey, P., Hayes, J.: Client expectations of virtual environments for urban design development. In: Proceedings of the Fifth International Conference on Information Visualisation. IEEE (2001)
11. Frost, P., Warren, P.: Virtual reality used in a collaborative architectural design process. In: Proceedings of the IEEE International Conference on Information Visualization. IEEE (2000)
12. Paes, D., Irizarry, J.: Virtual reality technology applied in the building design process: considerations on human factors and cognitive processes. In: Rebelo, F., Soares, M. (eds.) Advances in Ergonomics in Design. Advances in Intelligent Systems and Computing, vol. 485, pp. 3–15. Springer, Cham (2016). doi:10.1007/978-3-319-41983-1_1
13. Lertlakkhanakul, J., Choi, J.W., Kim, M.Y.: Building data model and simulation platform for spatial interaction management in smart home. Autom. Constr. **17**(8), 948–957 (2008)
14. Ryu, J., et al.: Application of human-scale immersive VR system for environmental design assessment-a proposal for an architectural design evaluation tool. J. Asian Architect. Build. Eng. **6**(1), 57–64 (2007)
15. Niu, S., Pan, W., Zhao, Y.: A virtual reality integrated design approach to improving occupancy information integrity for closing the building energy performance gap. Sustain. Cities Soc. **27**, 275–286 (2016)
16. Kuliga, S.F., et al.: Virtual reality as an empirical research tool—exploring user experience in a real building and a corresponding virtual model. Comput. Environ. Urban Syst. **54**, 363–375 (2015)
17. Woksepp, S., Olofsson, T.: Credibility and applicability of virtual reality models in design and construction. Adv. Eng. Inf. **22**(4), 520–528 (2008)
18. Westerdahl, B., et al.: Users' evaluation of a virtual reality architectural model compared with the experience of the completed building. Autom. Constr. **15**(2), 150–165 (2006)
19. Palmon, O., et al.: Virtual environments for the evaluation of human performance: towards virtual occupancy evaluation in designed environments (VOE) (2006)
20. Christiansson, P., et al.: User participation in the building process. J. Inf. Technol. Constr. **16**, 309–334 (2011)
21. Wikipedia: Cave automatic virtual environment (2017). https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment
22. Wikipedia: Panorama, 09 March 2017. https://en.wikipedia.org/wiki/Panorama
23. Moi, C.: Chez Moi Furnitures (2017). http://secondlife.com/destination/chez-moi-furnitures
24. Drettakis, G., et al.: Design and evaluation of a real-world virtual environment for architecture and urban planning. Presence Teleoperators Virtual Environ. **16**(3), 318–332 (2007)
25. Gabbard, J.L., Hix, D., Swan, J.E.: User-centered design and evaluation of virtual environments. IEEE Comput. Graph. Appl. **19**(6), 51–59 (1999)
26. Santos, B.S., et al.: Head-mounted display versus desktop for 3D navigation in virtual reality: a user study. Multimedia Tools Appl. **41**(1), 161–181 (2009)
27. Corp, O.: Oculus Rifts (2017). https://www.oculus.com/rift/
28. Corp, H.: HTC Vive (2017). http://store.steampowered.com/app/358040/
29. Corp, S.: SAMSUNG Gear VR (2017). http://www.samsung.com/global/galaxy/gear-vr/