

I Spy with my Little Eye: Improving User Involvement in Elderly Care Facility Design through Virtual Reality

Abdul-Majeed Mahamadu, Udonna Okeke, Abhinesh Prabhakaran, Colin A. Booth and Paul Olomolaiye

Faculty of Environment and Technology, University of the West of England (UWE), Coldharbour Lane, Bristol BS16 1QY, UK

Abstract

Recent studies have established that an ageing population is currently the most prevalent problem in healthcare provision as a result of an increasing number of people living with age-related chronic conditions such as dementia and stroke. More recently, this has been exacerbated by the outbreak of the COVID-19 pandemic which has exposed elderly people to more risks. One of the ways of improving the quality of life of aged patients is to design care facilities that meet their care and personal user needs. One area of innovation is participatory design where stakeholder views are sought in the design process in order to enhance the patient experience when the facilities are built. However, the current approaches to participatory design are challenging because of reliance on single interface methods based on 2D and 3D visualization and communication of design information. This study aimed to enhance elderly user participation in healthcare facility design through interactive Virtual Reality (VR). A novel methodology for incorporating fully-immersive and interactive VR into the workflow of care facility design is proposed highlighting potential challenges and safety considerations. A prototype VR application was developed and used in an experiment involving care experts and designers ($n=7$) to ascertain the usefulness of the methodology for capturing user requirements during building design specifically for elderly care scenarios. Findings indicate that VR improves design communications and user engagement in the process, however, there remain safety issues that hamper the full deployment of a fully-immersive VR application for elderly participants. This includes loneliness in virtual space, potential dizziness when navigating as well as usability challenges associated with disability and loss of dexterity which is often more prevalent among the elderly. Features such as teleportation while stationary were found as very useful in offering a safer approach to navigation in VR for elderly users. Also, for future developments, it is proposed that semi-immersive and augmented reality approaches are tested in order to ascertain their relative advantage when compared to fully immersive solutions.

Keywords: Health Ageing, Virtual Reality, Building Design, Users

Introduction

The healthcare industry according to Lim et al., (2000) has been ascribed as one of the fastest-growing industries in the service sector. Deloitte (2019) report on global healthcare outlook ties the healthcare industry's teeming growth to the world's ageing and growing population, greater prevalence of chronic diseases and exponential advancement in innovative digital technologies.

The provision of healthcare facilities to meet global standards and evolving demands has been met with increased complexities and rigorous challenges at every stage of procuring the design, construction, operation and maintenance of these facilities. Contributing factors to the multifaceted concern range from stakeholder (physician, nurse practitioners, physicians' assistants, specialists, etc.) participation and satisfaction, energy consumption, fit for purpose versus ideal for use arguments and the effect of facility design on patient's status of physical and psychological recovery.

Ulrich (2000, 2001) emphasises the impact of environmental design in improving medical outcome, propagating the theory of supportive design, with growing research supporting this concept (Laursen et al., 2014; Dalke et al., 2006). According to Leung et al. (2019), interior building design features and layout have a significant impact on elderly patients' physical health, psychological wellbeing, social relationships and cognitive functioning. As a result of this, it is recommended that there is more user involvement in the design process to ascertain user's preferences as well as acceptance of design at an early stage.

User Engagement in Health Care Facility Design

Sharma et al. (2017) define patient or user engagement in healthcare as the active partnership between patients, families, caregivers and other stakeholders, working together to inform quality improvement initiatives in healthcare delivery (Khodyakov et al., 2017). Stakeholder or user engagement is considered a critical criterion in the design of any facility, more so a healthcare facility, and while researchers deliver compelling ethical rationale that supports patient engagement, there also seems to be a common consensus on the limitations of how best to go about user engagement. Khodyakov et al. (2017) further note that a gap often exists between the intentions to involve stakeholders and the actual engagement of stakeholders.

Approaches such as community-based participatory research (CBPR) and evidence-based research (EBR) pulls at improving patient outcomes by the active involvement of community members, organisational representatives and researchers in all aspects of the research process (Israel et al., 1998). Kim et al. (2018) cite initiatives in the United States, The Precision Medicine Initiatives which seeks comprehensive user engagement through the life cycle of health research.

Traditional methods of engagement involve focus groups, in-depth interviews, surveys, email communication, conference calls, patient home visits, patient advisory boards, deliberative sessions, and consensus-building techniques, relying primarily on in-person or small-group interaction (Deverka et al., 2012; Domecq et al., 2014; Kim et al., 2018). For Carman et al. (2016), this mode of engagement is plagued by logistical barriers, huge expenses, potential selection biases, ethical concerns and legal impediments. Lavalley et al. (2014) in proffering a solution to above challenges highlights the impact of communication technologies (online surveys, email communication, conference calls or webinars) in facilitating more heterogeneous user engagement and participation, though this may be perceived as impersonal and shallow in the depth of engagement (Kim et al., 2018).

Thus, in order to facilitate more meaningful user engagement, there is the need to engage technologies and strategies that are far-reaching and still able to attain meaningful user participation. This is even more important in the building design scenario given the need for communicating technical details in the most user-friendly manner.

Virtual Reality and User Involvement in Health Care Facility Design

Although there is user involvement in some cases, traditional approaches to user engagement often rely on 2D drawings and documentation including architectural renderings of viewpoints and paper models (Lin et al, 2018). However, this process is characterised by misunderstandings and information gaps and has often proven futile as end-users fail to fully understand the concept and content of these drawings. Primarily this is because they lack engineering knowledge and experience to interpret these highly technical pieces of 2D data (Lin, et al, 2018). Recently, the concept of Building Information Modelling (BIM) is viewed as a key enabler of collaborative communication as well as design visualisation. In healthcare facility design, BIM-enabled technologies rely on object-oriented modelling thus can allow end-users to visualise spaces and provide effective feedback that can help designers better understand and interpret user requirements (Okada et al., 2017). This process involves 3D visualisation, but on 2D interfaces, hence the need for technologies that provide near-real life or immersive capabilities (Kang et al., 2014).

Evidence from many researchers echo two common deficiencies in practices associated with healthcare facility design, including the difficulty experienced by medical practitioners and stakeholders in understanding and interpreting design concepts (communication), and the discrepancy between the rendered design images and the finished construction product (simulation) (Huang et al., 2017; Lin et al., 2018). Researchers have therefore developed other innovative processes to combat some of these deficiencies.

For example, Huang et al. (2017) presented BIM Visualisation and Interactive System (BIM-VIS), a real-time rendering system that integrates BIM with a game engine and VR technologies to achieve more realistic scenes in the design of healthcare facilities, with the option of a wireless gamepad for navigation. This tool is however semi-immersive VR and relies on several projection screens to display BIM model views. This system thus relies on several pieces of hardware and significantly difficult to set up.

Lin et al. (2018) presented a Database Supported VR/BIM-based Communication and Simulation (DVBCS) similar to the BIM-VIS concept. This system integrates BIM with a game engine and VR technologies in a semi-immersed VR environment, with the option of a gamepad for navigation. The core distinction with this approach is the dismantling of the file-based BIM model into BIM elements, which are saved as database BIM elements of the BIM model, usable for advanced simulations and communication.

Kang et al. (2014) presented a BIM Computer Aided Virtual Environment (BIM CAVE) system based on Autodesk Navisworks to display the BIM 4D construction sequence. The system initially included 3 screen walls and 3 computers to project the rendered images in real-time. This was later modified to include 9 screen walls to enhance virtual reality and user experience. Hilfert and Koning (2016) have suggested the need for more cost-effective approaches that require less hardware.

The above developments have significantly improved concerns of communication and simulation plaguing health care facility design (Lin et al., 2018; Hilfert and Koning, 2016) and while the issue around hardware cost may cause hesitation among stakeholders, the new generation of VR tools offer a more cost-effective solution. There is a need for tailored VR solutions. Furthermore, the above developments have focussed on hospital design rather

than care facilities. It is worth noting that care facilities are used by mostly elderly users and thus there is a need for exploring the most suitable VR systems in this scenario as well as identify design requirements. In order to address this, the current study explores safe and fully immersive Virtual Reality (VR) communication systems for capturing user requirements and preferences during health care facility design. The feasibility of using this to engage elderly care facility users is explored. Furthermore, the functionality that can allow for more effective use of VR tools on the care facility user scenario is explored.

Proposed Approach

A two-stage approach was followed. The first was the development of the prototype VR system using a direct prototyping methodology. This is presented in Figure 1 below. This was subsequently tested through demonstration and interviewees with healthcare and design practitioners.

In the first phase, Building Information Modelling (BIM) software (Autodesk, 2019) was utilised as the primary modelling tool to develop libraries of elderly care design objects. A fully functional parametric model was developed using Autodesk Revit with a focus on interior design elements as well as furniture, fixtures and finishing. Filmbox (.fbx) file formatting was used to improve model fidelity and visuals (Simmons 2014). The interactivity was achieved through a game engine, Unity3D (Unity3D, 2019), in conjunction with FBX library purposely used to ensure faster file exchange in the workflow. FBX format allowed lightweight parametric model where only relevant metadata for the proposed tool was extracted. Unity3D further supported virtual visualization and interactivity through its intuitive tools and objected-oriented programming (OOP). The interactivity built into the model related mainly to interior design manipulation for visualising different options of interior décor including furniture, building fixtures, finishes, positioning of objects. C-Sharp (C#), an objected oriented programming (OOP) language was used for the development of the custom tools and user interface for enabling human-computer interaction (HCI). The VR system developed also allowed users to outline preferences through an interactive form. The system was developed as a fully-immersive VR simulation and was trialled on two headsets, Oculus Go and HTC vive. Furthermore, third party texture enhancement applications were used in conjunction with the gaming engine (i.e. unity3D). The outputs from the visualization are presented in Figure 2. The user interfaces included in virtual tablet (Figure 3) used for object manipulation through hand gestures which are read by motion sensors connected to the VR headset.

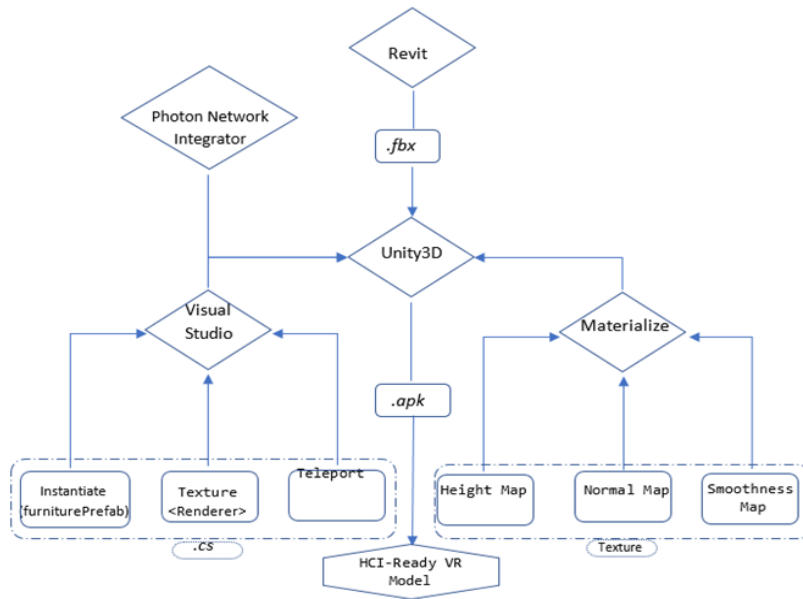


Fig. 1: Details the interactive VR development workflow.



Fig. 2: Screenshots of Scenes in the Interactive Care Facility Design User Engagement VR System



Fig. 3: Screenshots of virtual-tablet user-interface for object manipulation and interaction in the VR System

Testing of Proposed System

The study relied on a quasi-experiment and qualitative interviews approach to test the application's usefulness, practicability and potential risks (Prabhakaranh et al., 2018). The participants were engaged in a direct-prototyping format where their feedback was used in improving the system as the research went along (Eid, 2015). Each participant had the opportunity to test applications in a fully-immersive and interactive VR environment using two different headsets. This was followed by interviews and transcription of interview responses. A sample of seven (n=7) experts with experience in healthcare, healthcare building design and VR development were thus interviewed. These professionals were chosen because of their understanding of user requirements in the research domain. This was to allow for their input for improving the system before a more tailored and safe approach can be designed for elderly users themselves. The profile of the interviewees is presented in Table 1. A thematic analysis of the interview responses was performed in order to systematically document participant's views in relation to the potential usefulness, safety considerations and elderly-specific user requirements. This aided the proposition of future considerations for research in this area.

Table 1: Profile of Participants

Interviewee	Experience in Health Care	Participant Reference
Research Fellow - Elderly Care	4	A
Health Care Practitioner - Nurse	3	B
Health Care Practitioner - Nurse	3	C
Health Care Practitioner - Carer	10	D
Architect	10	E
Health Care Building Design Expert	20	F
Health Care Project Manager	6	G

Findings and Discussion

Based on the thematic analysis it was concluded that the proposed system was very effective in communicating design intent as well as the elicitation of user requirements. The key findings are discussed in the themes below.

Elderly Friendly Functionality

The key themes identified were: Aesthetics; Isolation and Multiplayer Functionality; Navigation Ease; and Multisensory Experience. The following were identified as the most critical user engagements functions which can enhance the experience of elderly users: variations in a colour contrasting, wall surface and finishing fidelity, lighting, furniture selection and layout, scenery and location of windows, ability to test the nostalgic value of design features [Interviewee A, B, C, D, E, F, G]. This concurs with previous studies that have highlighted the importance of fidelity and visuals in VR immersion (Johnny et al, 2014; Lin et al., 2018; Hilfert and Koning, 2016; Leung et al., 2019). In addition to aesthetics, the VR experience was identified to be isolating for elderly [Interviewee A] (Hodge *et al*, 2018). This

could be improved by multi-player VR-gaming functionality that allows several people to experience the same scene at the same time. The multi-player approach to exploring designs is less isolating especially if other participants can be viewed as an avatar. Furthermore, this multi-player functionality could allow participation of more able-bodied persons or carers who can take control of navigation rather than elderly users who may have disabilities or dexterity issues. The significance of multi-player functionality cannot be overemphasised at a time where social distancing is critical due to the impact caused by the COVID-19 pandemic. Teleportation functions were viewed as more appropriate than walking navigation. Teleportation was also viewed as a safer option for the elderly who could sit on a chair and be stationary while navigating to different scenes in the virtual environment [Interviewee A, B, C, D, E, F, G]. Furthermore, this approach is regarded as safer with walking navigation viewed to have more propensity of causing dizziness [Interviewee A, B, C, D, E, F, G]. In the opinion of participants, incorporation of multisensory experiences would improve the usefulness of VR in the elderly user scenario [Interviewee A, D, E, F, G]. The use of sound instructions was highlighted as advantageous. Intuitive functions and voice command was identified more suitable for elderly users thus reducing the need for user orientation. Gesture recognition for interactivity was viewed as a limitation in the elderly care scenario. The outlined safety concerns are not unusual given the delicate nature of elderly care and requirements for the design of their living spaces (Nichols and Patel, 2002; Hodge *et al*, 2018).

Non-immersive technologies also appear more suitable in elderly care scenarios from the experiments in this study [Interviewee A, F]. Some of the main concerns for elderly users was mobility, tripping, likelihood of falls and potential dizziness when fully immersive VR is used. These have also been reported as VR risks in other application scenarios (Nichols and Patel, 2002). However, it was also established that in order to provide the right level of rendering the system will require higher specification hardware to set-up. High fidelity mixed reality (MR) system thus seems to be the best alternative although related technologies are not as advanced yet (Prabhakaran *et al.*, 2018). Interviewees also wanted an approach that allows saving of user preferences such that different choices and configurations of design can be compared whilst the tool is being used [Interviewee A, B, C, D, E, F, G].

Desirable Features of the Virtual Building Design

The key themes identified were: Improving design options and Incorporating standards. Interviewees thought that design rules regarding safety and other health-building standards should be incorporated in the system as additional information to guide choices [Interviewee A, F, G]. Such a system should be built into the interactivity to help users to dynamically view the impact of their choices and implications on meeting building, and design regulations as well as standards (Lin *et al.*, 2018). This includes incorporating functionality for assessing navigation, social distancing features, infection and cross-contamination risks associated with alternative designs and fixtures. This cannot be overemphasised in view of the need to follow new standards and approaches in healthcare facility design in response to COVID-19 pandemic (Waite and Pitcher, 2020). Participants also suggested the incorporation of a larger object library consisting of home adaptation equipment with 'non-clinical looking' design options. The digital objects libraries relied on the VR simulation should be connected to a live

database of available design components to improve a variety of choices in real-time. Similar limitations have been highlighted in previous experiments and development of VR for participatory design (Lin et al., 2018; Hilfert and Koning, 2016).

Conclusion

This research explored how to enhance healthcare stakeholder's involvement in the design of healthcare facilities. A novel interactive Virtual Reality (VR) communication systems for capturing user requirements and preferences during health care facility design was developed and tested. Based on pilot tests, it has been established that interactive immersive technology (VR) can be used to engage users in care facility design. The current generation of fully-immersive VR tools, however, support care professionals more than the elderly end-users or patients themselves. The research found that safety issues hamper the deployment of fully-immersive VR for the elderly users who may have navigation challenges as well as hindered spatial awareness which could lead to trips and falls. Teleportation functions built into the application were found to be very useful. From the findings of this study, it is therefore suggested that fully immersive experiences are supported by multi-player (multi-user) functionality as well as teleportation functions for user navigation. Multi-player functionality could address potential issues of loneliness in the virtual world as well as allow more physically-abled participants to coordinate controls while an elderly person is immersed in the same experience. Furthermore, use of such functionality will also help in the maintenance of social distancing while enabling elderly user participation in healthcare facility design without exposing them to the risk of infection given their vulnerability. It was also suggested that semi-immersive methods are tested to ascertain their relative advantage over fully-immersive solutions in the context of safety for elderly users. Although semi-immersive solutions like augmented and mixed reality could potentially be safer in terms of visibility of surroundings, they often provide less visual quality when compared to fully-immersive VR. Future work will aim at developing a high fidelity mixed-reality version of the tool and also incorporate conversational interaction including voice command systems to achieve more intuitive interactivity.

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