

2017/18 Mini-Project Designing safe complex environments

Final Report

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Abstract

The built environment can be sparse in what it affords people with functional limitations, it can disable them through design.

Ensuring buildings and social spaces are designed to enable people is complex, often with conflicting requirements. People with balance impairments are not well represented in the literature of building design. Virtual reality (VR) may be important in evaluating designs digitally and optimising them before committing to expensive prototypes.

This project investigated the principles of universal design applied to the built environment and specifically with reference to people with impairment. The validity of using VR as a test method was assessed by reviewing the neuroscientific justification and the new field of neuroarchitecture. Finally, examples of how VR is applied to the treatment and understanding of balance disorders were reviewed.

Principles of universal design are important to delivering built environments that meet the changing need in society, VR has a neuroscientific basis, from which it's reasonable to determine people's response to a built environment. VR has a basis in the treatment, and therefore affects a change in, the way people with balance problems interact with virtual spaces. VR is considered to be a powerful tool in designing the built environment as an enabling space.

Research Question

Is it possible to use virtual reality to support the design of safer built environments for people with complex sensory impairments?

Designing environments to meet diverse need is complex and often results in conflicting requirements. Given the well published models on the way in which the environment mediates the transition from health conditions to disability there is very little research on the application of inclusive design principles in architecture. Most notably, given the relatively recent development of the field of Neuroarchitecture, there has been very little work to determine the value of digital techniques to help design building in the presence of neurological impairment.

Methodology

A literature review was conducted in the three areas on interest. Specifically:

- Principles of universal design for those with complex sensory impairments,
- The application of Virtual Reality to the design of Built Environments,
- The application of Virtual Reality with people with complex sensory impairments.

A keyword search was used within pubmed, google scholar, and web of science. Keywords were developed by reviewing mesh terms and published keywords within primary articles.

To review literature related to the principles of universal design the following keywords were used:

- ("Universal design") AND (("built environment") OR Architecture) AND (Health)
- (Architectural Accessibility) AND (Environment Design)

70 articles met these search criteria. To review the application of virtual reality to built environments the following keywords were used:

• ((neuro architecture) OR neuroarchitecture) AND (virtual reality)

14 articles met these criteria. To review the application of virtual reality to vestibular impairments the following key words were used.

(vestibular*) AND (rehabilitation) AND (virtual reality)

20 articles met these criteria, all results were limited to articles related to human subjects.

In addition to the review of literature, hardware and software tools were developed to evaluate the feasibility of implementing VR devices for the assessment of architectural spaces.

A framework of 3D environments was developed within the Unity3D games engine. The environments were geographically accurate representations of city streets and buildings. These environments enabled the user to walk in a variety of different scenarios; dense city spaces, sparse rural spaces and open cityscapes. In addition, certain characteristics of the environment could be adapted such as the floor pattern. Participants walked at a self-selected speed on a treadmill. A Kinect 2 was used to allow the participant to move within the environment, arm gestures enabled turning left and right.

Kinematics of walking were measured both by the Kinect camera and a 10 camera Vicon motion capture system. The Kinect was able to simultaneously measure basic temporal spatial parameters of walking, including swing stance ratios and left right symmetry. The VICON motion capture system was used simultaneously to the Kinect to capture full lower limb kinematics. The Vicon plug in gait marker set was used to model the lower limb. Sixteen passive retroreflective markers were placed on the Pelvis (left and right anterior superior iliac spine, posterior iliac spine) thigh, knee, shank, ankle, heel and toe.

To assess the feasibility of taking measurements as participants walked within the virtual environment 5 subjects walked in three different scenarios 1) a dense urban environment with a high spatial frequency 2) a sparse rural environment 3) a lower spatial frequency urban environment 4) an environment without an avatar being present. The order of the walking tests was randomised. Walking times were consistent between subjects.

Discussion

Literature

The core output of the Digitally built Britain project is the development of Building Information Modelling techniques that enable us to digitise the life cycle of built assets. To "produce more efficient methods of designing, creating and maintaining building assets". The building information model will deliver a "digital representation of the physical and functional characteristics of the asset". Leatherbarrow in Architecture Oriented Otherwise [1] describes how the cultural role of architecture is minimised when "it is reduced to either an aesthetic object or functional solution, or some compromise between the two". Leatherbarrow clearly challenges architecture to meet these needs equally and without compromise, however, the functional challenge, in particular, resonates profoundly within the healthcare field.

Our aim of the literature review was to draw together the evidence that would inform and enable practical tools for design of the built environment which can support the enablement of those with

vestibular and balance problems. The starting point was to re-establish that the built environment is a mediator for disability, Verbrugge states that Disability is not a personal characteristic, but is instead a gap between personal capability and environmental demand [2]. The impact of the built environment of stroke survivors and disablement has been studied, revealing barriers to social participation [3][4][5]. More recently the built environment has been shown to directly impact on physiology and unhealthy behaviours [6] and cue reactivity for addiction [7]. Decision making i.e. good decisions about health, can be influenced by the design of the space for example the use of stairs [8], people's desire to walk in an environment [9], everyday social participation in those with disabilities [10], activity and food choice [11]

Universal design is a concept articulated by Ronald Mace, though not without its controversies; the persistence of ableism for example [12] or the problem of reducing diversity to the "universal" [13], the principle of designing for all has an appeal of common sense. Though recent reflections on this paradigm suggests that designing for accessibility as distinct from purely universality is an important consideration [14]. These design principles have been applied when looking at the built environment and mobility. Walking in older age [15], [16], use of wheelchairs [17]and [18]. There are fewer examples that relate directly to architecture and the processes of applying a universal design culture. In the case study by Gossett [19] an argument is put forward about the integration of design frameworks; universal design, accessibility and sustainability. In the centre of these exists the ideal design solution. Furthermore, Gossett describes the, sometimes conflicting, design requirements of disabled groups. Dalton [20] aligns building design with the concept of interaction design, paralleling the terms used when designing services such as web applications, to our interactions with the built environment. Dalton in reviewing this field references the work of Neutra [21] who speaks of our response to design, "what design can actually do" in terms of sensory input. Usefulness as defined by utility and usability can be achieved through optimising learnability', 'efficiency' 'memorability' 'errors' and 'satisfaction, these concepts can be transferred from user experience design into architectural design. O shea's [22] review of the universal design framework and methods advises having separate methodologies contextualising universal design and allowing for the creation of an evaluation tool more practical in use. Balancing universal design and specific design drivers Imrie [23] suggests opportunities for enabling this within interactive and responsive environments, but that we need mechanisms to evaluate those responses this at scale. Returning to Ronald Mace we may conclude universal design principles need good prototypes.

We can accept therefore that there is the opportunity to design in and design out disability from built environments. In the culture of design, the ability to test assumptions and verify designs before committing to manufacture is well embedded. However, is it possible to test the assumptions and strategies within architectural design which are intended to act as enablers for those with impairment? More widely, the need to quantify the human impact of architecture led Neutra to reflect in 1954 in his book Survival Through Design [21] that there "existed generally valid scales and gauges for judging design" and argued that these must be used. Eberhard, an early proponent of the neuroarchitecture movement spoke of the gap between the paradigms of neuroscience and architecture [24]. The recent increase in publications on the subject would suggest that these barriers are falling.

Traditionally, the effect architecture has on us was investigated through philosophical analysis or psychology principles. In recent years the neurosciences have established a more mechanistic view of the effect of architecture. The neurosciences, in association with underlying philosophical and psychological understanding of architecture, have created the foundations of a more holistic and systematic scientific framework to test its impact. The neurosciences can help explore the underlying mechanisms that reflect our experiences of architecture. For example the neurosciences have advanced our understanding and ability to investigate traditionally philosophical topics such as

aesthetics [25]. Or to investigate physiological responses such as to the human response to light in a built environment [26] or to natural versus urban images (Heerwagen and Orians 1990) (Ulrich et al. 1991). Functional MRI has been used to measure brain activation areas and could be linked to emotional responses fear, arousal, novelty and spatial frequency [27]. Even though there is a growing body of work presenting a measured perception of different environments; in a recent review, Banaei [28] reinforces that nearly all preceding work utilised two dimensional images but that we perceive our world in three dimensions. As described by Jelic [29], In reality humans experience architecture not as disembodied entities but through a continuous interaction of brain and body with the world; a coupled relationship between organism and environment. Concepts extending from the seminal work of Varela the embodied mind [30].

To be able to investigate how humans respond to built environments, it is clear that subjects need to be immersed in their environments. Importantly it has been established that virtual spaces can produce expected neurophysiological responses supporting the view that it may be possible to generalise the results of tests in the virtual space to the real world [29], [31].

We have established that the design of our built environment impacts on us emotionally and physiologically and that impact can directly relate to health and disablement. We have also established that using methods in neuroscience, these effects are measurable. Furthermore, there is an ecological validity in evaluating these responses within a virtual environment. However, we have not associated the use of virtual reality within the population of patients with vestibular function problems and how we might apply the principles we have covered practically to this population. Virtual reality has been applied to the treatment of several balance conditions. Pavlou [32], used virtual reality as an adjunct to vestibular rehabilitation to treat visual vertigo in patients with unilateral peripheral vestibular disorder. Garcia [33] used VR stimuli to treat patients with Ménière's disease. Gutiérrez [34] similarly used VR to treat balance conditions in people with multiple sclerosis. Lloréns [35] successfully used VR to treat people with brain injury, Sessoms [36] used a CAREN system to provide rehabilitative program to subjects with vestibular problems following TBI. This study showed an increase in gait speed and improvement in scores related to stability; close to those scores seen in health participants and greater than those undertaking traditional therapy. These data suggest the affect that a virtual environment can have on the motor response of an individual with vestibular and sensory impairments.

Hardware and software development

The project was able to establish a working low-cost virtual reality system (figure 1). Unfortunately, given the short time frame to develop hardware and software tools we were unable to meet the health regulatory requirements to evaluate patients with the virtual reality system. However, the project has developed the protocols and documentation necessary to trial the virtual world with patients in the future. Over the next six months the project team will submit for HRA approval and to trial the system with patients. The system was trialled with five subjects without pathology to test collection protocols, ensure system operation and to define normative patterns of response to the virtual world. The system functioned effectively enabling synchronised data collection from both low cost and high-fidelity motion capture systems. Initial analysis suggests that there is good agreement between system with respect to temporal spatial parameters, however, greater work is required to establish the kinematic accuracy of the Kinect system.

Safe Complex Environments



Figure 1 Virtual World A) Global View of the city B) Selection of area to walk C) User view of environment with avatar

There were no clear differences between the patterns of walking between the different walking environments. There was an expectation that high density, high visual frequency environments may have had some impact on walking patterns as the proximity of walls within a virtual environment has been seen to change the sensory perception of proximity [28]. It is not clear as yet if the level of embodiment achieved with the system is sufficient and this may be associated with the use of an avatar or the nature of the virtual display. Further research is required to determine if this system performs better with a heads-up-display system. Data collected without the avatar has yet to be analysed and could provide insight into this influence. Evidence would suggest that it is possible to achieve sufficient level of embodiment to affect a change in a subjects behaviour [29].

Reviewing the results of this project against our initial aims we have established through a review of literature the state-of-the-art in immersive environments used with those with difficulty processing complex environments. The project has produced a virtual environment, prototyping a complex space. This has also implement tools to produce an immersive experience for a user. The project has in a small number of people validated motion capture tools to measure a user's kinematic response to moving through the environment and in parallel validate low-cost alternatives to measuring a user's response. However, we continue to put in place the regulatory requirements to test this with patients and this work will continue over the coming months.

Conclusion

Literature supports the concept that we need to design building for accessibility and to meet the needs of those with complex sensory conditions to ensure these built environments do not act as disablers. However, the techniques to design inclusively / specifically are lacking for architectural design, in particular the ability to prototype environments for different users and test concepts. Modern neuro-architectural approaches give an insight into the use of virtual reality to support the design of new buildings; that responses from the virtual experience may generalise to the real world. Evidence from literature also reflects that Virtual reality is able to affect a change in the motor response in those with complex sensory problems and that therefore virtual reality can be argued as a useful tool to evaluate different built environments in this population.

This project has also shown the practicality of using low cost virtual reality equipment and motion capture facilities to act as a prototyping framework.

Acknowledgements

This project was supported by a mini-projects award from the Centre for Digital Built Britain, under InnovateUK grant number 90066

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