The application of Augmented Reality and Virtual Reality in the construction industry using wearable devices

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Abstract

Augmented Reality (AR) and Virtual Reality (VR) have been implemented in many industries including the Architecture, Engineering and Construction (AEC) industry. Confusion between AR and VR exists, despite several researchers seeking to clarify the differences. As context-specifics have significant influence on the AEC industry, testing AR/VR applications is not as streamlined as in some other industries. This paper introduces a research project carried out on application of AR/VR in the construction industry whilst attempting to clarify the differences between the two. It starts with an introduction and the justification before a critical literature review sets the scene for discussion of methodology, details of the experiment designed using advanced AR and VR technologies, which forms the basis of a questionnaire. Results are provided with an in-depth analysis before a discussion which leads to conclusion. The authors suggest future research takes one of three possible routes; i) to develop an AR or VR system with more specific applications based on the findings of this research; ii) to develop this research to test the hypothesis that AR and VR technologies are optimal when used combined on a project or iii) to progress this research building upon more recent advances in AR technologies.

Keywords

Augmented reality, Construction industry, Head-mounted device, Virtual reality, Wearable devices.

1. Introduction

Many new and advanced technologies have been established in the AEC industry including: Building Information Modelling (BIM), 3D printers, Drones/Unmanned Aerial Vehicles (UAV), 'Cloud' platforms, Augmented Reality (AR) and Virtual Reality (VR). Not only do AR/VR have the potential to change the way stakeholders view specific tasks but, more importantly, they also affect the way professionals carry out tasks, possibly saving much wasted time, energy and costs. AR is sometimes confused with VR so it is crucial that the distinction between the two types is clarified at the beginning. If

a system comprises of a real-world scene superimposed by virtual elements, this constitutes an AR environment (Meža *et al.*, 2014). However, if the real-world scene is replaced with a virtual scene, this produces a VR environment (Azuma *et al.*, 2001).

AR has a history of more than 50 years dating back to works of Morton Heilig in 1960 (Head-mounted TV display) and Ivan Sutherland in 1996 (Head-mounted Display; HMD), but more specifically that of Tom Caudell's for Boeing who was the first to coin the term (Virtual Reality, 2015). Morton Heilig also contributed to the development of VR earlier on (Sensorama in 1956) before the technology advanced considerably in 1980. In the early 1980's Jaron Lanier was first to offer a commercial VR system (Reality Built for Two) prior to the term eventually being coined by Jaron in 1987 (Axworthy, 2016). AR and VR have been developed/researched in many industries and they found their ways into the AEC industry more recently. However, due to the nature and context-specifics of the AEC industry, the research in this area has been faced with more obstacles than in many other industries.

The potential for AR/VR in the AEC industry holds new and exciting prospects. This is due to the advantages which AR/VR can offer if used correctly. Compared to the advanced technologies mentioned previously, AR is more sustainable, less intrusive and more adaptable to the ever-growing, dynamic, fast changing and challenging industry. Furthermore, integrating AR systems throughout the lifecycle of a project may improve health & safety of work environments, reduce cost incurred due to insufficient time management, performing iterative processes whilst providing stakeholders and professionals alike with a system that is easy, cost effective and safe to use. In doing so, this research aims to establish the applicability of AR/VR within the construction industry with a particular emphasis on wearable devices, namely HMDs, for both. To achieve this aim, first of all a critical review of the state-of-the-art in AR/VR application in the AEC industry will be carried out which will help identify the areas of specific application of AR/VR to be developed and used for this study. These will then be used to design an experiment to first increase the awareness of the participants in this study but also, more importantly, to gauge and analyse their opinions as future generation of professionals in the AEC industry. To ensure that the research question is to be answered in the most proportionate way, a mixed methodology approach to this project has been taken. Further details will be provided subsequently in the next sections of this paper.

2. Literature Review

Wearable devices are used for both AR and VR applications. Given the extensive literature on AR/VR, this review focuses on key areas associated with the application of wearable devices for AR/VR in the AEC industry, namely the status quo, recent advancements, application areas, problems associated with implementation and, advantages and disadvantages, before providing a conclusion to the review which would help identify the gap in the knowledge and help the design of this research.

Widely referenced by many researchers (such as Azuma *et al.*, 2001; Dunston and Wang, 2005; Yuen *et al.*, 2011; Raajana *et al.*, 2012; Meža *et al.*, 2014), Milgram and Colquhoun Jr. (1999) assert that two definitions for AR exist in the literature. The first and most common definition includes a display system such as an HMD or Heads-Up Display (HUD) whereas the second definition is more general without reference to a display system.

Raajana *et al*. (2012) state that confusion between AR and VR is a long-running issue. This confusion is due to the two technologies having a similar approach, however the differences can be easily understood. AR is an interface that overlays digital information onto the user's view, with the digital objects spatially aligned to the physical environment (Zollmann *et al.*, 2014). AR is developing into the most encouraging method to support 3D tasks (Baratoff *et al.*, 2002). However, VR differs from AR in that it removes the real elements and instead immerses the user in a totally virtual environment with virtual objects. Figure 1

shows an example of the difference between AR and Virtual Reality (VR), as produced by Behzadan and Kamat in 2005:

Figure 1: Difference between AR (left) and VR (right) for a construction project (Behzadan and Kamat, 2005)

Efforts to establish VR outweigh those for AR and started earlier; especially with regards to the education and entertainment industries. For example, the first experiment where VR was used as a learning tool occurred in the early 1990's and there are instances where the term 'virtual reality' became attached to games after the term had become popularized (Schroeder, 1993). Appreciating that AR is traditionally behind VR, in 2001, Azuma *et al.* rightly point out that the state-of-the-art in AR was comparable to the early stages of VR. However, over the past two decades, the application of AR and VR has grown rapidly due to development of mobile and wearable devices. Because such devices have "an array of sophisticated sensors, powerful processing and storage capabilities, and persistent network connections that make them ideal platforms for building AR applications" (White *et al.*, 2014, p.121), "they are becoming smaller, more powerful, and less expensive" (Chi *et al.*, 2013, p.116) and they are "powerful mobile AR platforms enabling the embodied interaction throughout the physical and virtual environments" (Kim, 2013, p.80).

The need and potential around integrating mobile and wearable devices with BIM may facilitate the uptake of AR/VR systems. Given that BIM is initially associated with and nurtured by VR, Wang *et al.* (2014) investigation of implementation of AR with BIM which developed four 'AR+BIM' prototypes, with each prototype having a specific application, i.e. walk-through, context-aware mobile system, on-site assembly and way-finding, may be taken as an attempt to strike a balance between the interoperability between both AR and VR with BIM. Rapid expansion of AR applications available for the mass consumer/prosumer markets is another more recent development which has applications in but is not only limited to the AEC industry. However, both types of devices also have their limitations. For instance, they are not always able to process the quantity of information contained in building information models (Meža *et al.*, 2014).

As mentioned earlier AR is by nature behind VR in its development and uptake. Problems associated with hindering the wider use of AR can be categorized into three areas: technological limitations, user interface limitations and social acceptance issues (Azuma *et al.*, 2001). Privacy concerns are given as one of the social acceptance issues preventing wider use of AR. The 'Google Glass' project is one example of how evident privacy concerns are where sales were ceased due to the privacy concerns of consumers. Another obstacle on the way of higher uptake of both technologies which is often perceived as unnecessary and avoidable, is the complication of 3D modelling (Wang *et al.*, 2014). This is because it is normally difficult to manipulate a 3D model using traditional devices (Billinghurst *et al.*, 2003) whether it is for AR or VR application. This means that for an increased uptake of 3D modelling, a device should permit the user to manipulate a 3D model easily and efficiently. In line with Azuma *et al.* (2001) the problem of technology implementation with regards to HMDs can be classified as "…difficulty in calibrating the correct correlation between real and virtual positions, a confusing sense of depth and, occlusion of the real scene" (Shin and Dunston, 2010, p.171). Drascic (1996, cited in Azuma *et al.* 2001), also suggest that

implementation errors, technological problems as well as limitations of current HMDs all hinder AR display and hence AR adoption. However, Shen *et al.* (2001, cited in Dunston and Wang 2005) showcase the development of a video-based, calibration-free AR approach (in urban planning). Another area which may be deemed to hinder more widespread use of AR to catch up with VR systems in construction is the need for calibration of AR systems; what evidently is not the case with VR. With some degrees of success, Fuhrmann *et al.* (1999) seem to have solved this issue by proposing a scheme which allows for fast calibration of a HMD without the need for additional equipment or complex procedures.

3. Research Methodology and Design

This project utilizes a mixed methodology, aiming to "understand, explain, explore, discover and clarify situations, feelings, perceptions, attitudes, values, beliefs and experiences of a group of people" (Kumar, 2010, p.103) with regards to AR and VR. The quantitative aspect comes from the determination of the strength of people's beliefs and opinions and the subsequent conversion of these characteristics into inferential statistical analysis. Secondary research, in the form of a literature review, was carried out then followed by the development of an experiment and the design of a questionnaire which forms core of the primary research. The experiment was split into two sections to avoid the risk of confusion between AR and VR amongst participants, as was found to be the case in research from the literature.

3.1 Description of Experiment

Different software applications and hardware equipment available on the market were investigated to be utilized for the project. The experiment and questionnaire were both directly dependent on whether and to which AR/VR HMD devices access could be secured. This section will briefly discuss what was involved in this process before providing an outline design of the experiment.

3.1.1 Choice of Wearable HMD

Four companies were identified as leading companies in AR market with possibility of employing their products for AEC applications. Two parallel methods were utilized to contact the companies: a written correspondence which was sent in post and a direct email to work email addresses or in-mail messaging services on professional network i.e. Linked In. Further investigation of the product, their capabilities and limitations as well as the professional judgment made based on correspondences exchanged one of the leading market providers of AR solutions was chosen for this study. The VR application chosen to be used for this study was Oculus Rift, due to its widespread use, high flexibility, advanced features and in-house availability.

3.1.2 Development of Experiment

The Advanced Engineering Center, a new building facility on University of Brighton's (UoB) Moulsecoomb campus was selected as a case study for this research. At the time of carrying out this research, the building was at its final design and initial tendering stages. Planning applications on the local council website database were utilized and with support of the UoB's Facilities Management Department, HASSELL, the architects in charge of the design were contacted to obtain the BIM models for the project, who then provided all the documents as requested.

The AR Experiment: The Revit files were then needed to be exported in a FBX file format which was compatible with the HMD software application. For the AR device to be able to view the 3D Revit model, a marker and a scene needed to be prepared. 3DS Max was used to generate the scene and to include the materials for the AR application whereas Maya was used to generate and link up the customized marker. Once that was done, the scene was ready to be downloaded on to the AR software application to be viewed by the see-through AR device (Figure 2).

The VR Experiment: The software specifics of the chosen VR headset (Oculus Rift SK2) determined that the most appropriate link software to add materials to the import file from Revit for generating an as close a model to reality as possible to be used in VR section would require the use of a 'game engine'. Two leading open source game engines namely 'Unity' and 'Unreal' were explored. After the first run of the tests, Unity showed to be most suitable (Figure 2). Although Unreal seems to have a more advanced user interface, the functions were more difficult to work with, specifically the addition of materials and the generation of collision objects. It is worth noting that incompatibility of the native materials in Revit with Unity, led to extra effort to sort this problem. This could have been sorted out using an additional plug-in for Unity but would have come at some additional costs.
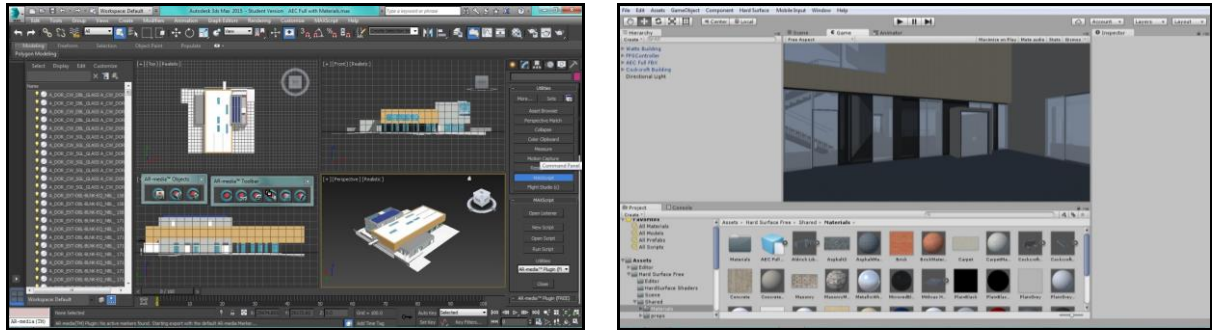
Figure 2: 3DS Max for AR section (left) Unity for VR section (right)

3.2 Questionnaire

Triangulated with the results of the critical literature review and informed by the limitations and opportunities of the developed experiments as well as the deployed hardware and software, a questionnaire was utilized to gauge the opinions of participants on the applicability of AR/VR in the construction industry. It comprised a total of 16 questions split in 2 parts. Part one was used to establish the background of the participants' and their level of understanding of AR/VR prior to the experiment, whereas part two sought to gauge their opinions on the applicability of AR/VR at, but not limited to, different stages of a project after having experienced the wearable HMD for both technologies. Most questions were multiple choice in nature. However, the participants were provided the opportunity to expand on their responses wherever deemed necessary. Prior to the questionnaire being finalized, a pilot was undertaken to ensure clarity, integrity and the flow of the questions.

3.3 Data Collection

Both random sampling and cluster sampling techniques were adopted for the experiment, ensuring a reliable selection of participants from the intended target audience who are the future professionals in the built environment and civil engineering subject areas. In total, 35 participants took part in the experiment and filled in the questionnaire. Each participant was informed about the process prior to taking part. They were then asked to fill the first part of the questionnaire prior to the experiments. On completion of the two sections of the experiment (AR/VR), the users were then asked to complete the remainder of the questionnaire.

4. Results and Discussion

Although some findings seem to confirm what previous research has found, some were significantly different showing that there might be a change in attitude towards the advanced technologies, raised level of awareness and change in expectation or skills, at least between the younger generations of professionals within the UK construction industry context. For instance, contrary to Wang *et al.'s* (2014)

suggestions, an overwhelming majority (80%) of participants strongly disagreed that 3D modelling is an unnecessary complication. The majority of participants also disagreed that AR gives a confusing sense of depth. Perhaps even more promising is the fact that the vast majority of respondents feel that AR/VR are the inevitable future of the construction industry; with only 6% disagreeing with this. The summary of results is presented in Figure 3:
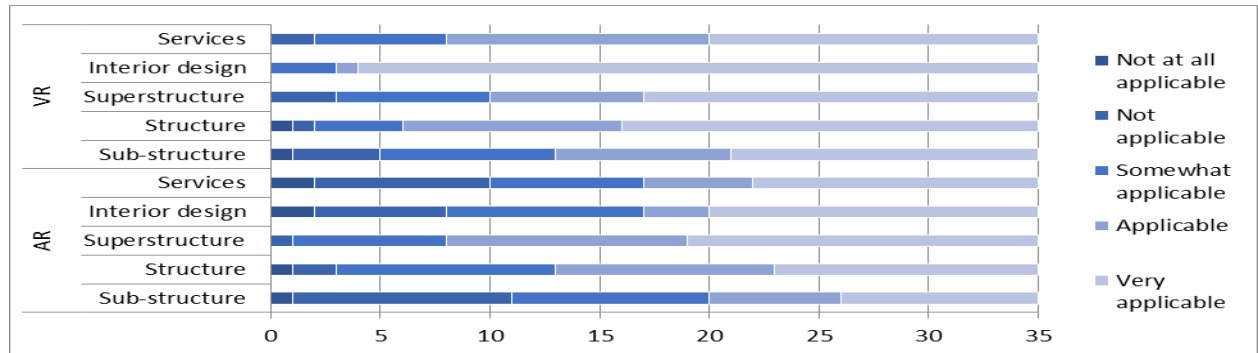
Figure 3: Summary of results

Given the health and safety implications of all construction projects and their importance in determining the success of a project, it is reassuring to learn that a significant portion of participants either agreed or strongly agreed that AR/VR technologies reduce the risks and improve health and safety. However, there were some participants (6%) who strongly disagreed specifically with regards to VR technology. The reason for was reported by users as health issues, most likely sense of nausea, motion sickness or probably claustrophobia which might have been triggered by the use of HMD for VR. Rather surprisingly, although this seems to be a prominent issue, the authors have not come across this being widely referred to in the literature.

63% of participants believe that AR can facilitate an earlier detection of problems at the design stage. An even larger proportion of participants believed this is the case for VR (88%). This can serve as a strong driver for the implementation of these technologies into the design phase of a project.

Confirming findings from previous research, 66% and 80% of respondents viewed AR and VR as being capable of reducing the reliance on cognitive functions for tasks. when asked to provide rationale, the majority of participants referred to the technology as allowing users to view 3D visualizations of the design and being able to have a 'walk-through' in the building. However, those who disagreed more often than not stated that the representations were not clear enough either because of the size of the illustration or problems with the technology itself such as the lag involved or the viewpoint of the AR equipment used, meaning the reliance on thought process actually increased for some of the participants.

From the literature, the authors identified several factors that were given as being issues that prevented the wider usage of AR in the construction industry (smaller devices, more powerful devices, cheaper devices, more widespread/cheaper training). When asked to specify any other factors the participants feel is a contributor in this regard, more powerful devices and more widespread/cheaper training reached an equal of 27% responses. This implies that if the usage of AR is to become more widespread, the devices currently available may not be fully developed to ensure a smooth transition into the industry and that if more powerful devices were to be implemented, then a robust and cheap method of training users in this technology will be required. Other factors that participants specified included the use of more advertisement and more possibilities in the built environment, the use of an easily portable device and the health and safety implications for using AR technology on site.

Research carried out by Shin and Dunston (2010) found their prototype, the ARCam, to be most suitable to small-sized projects. However, results from this experiment do not confirm this. Respondents viewed

AR technology as being most suitable to medium-sized projects. The reason for this could be that AR systems have probably become more powerful, smaller, more reliable and more portable since 2010. However, as discussed earlier, the current opinions indicate that systems are still not powerful enough to be utilized in the industry as easily as they could possibly be.

Interestingly, more participants strongly believed VR could be used for real-time workforce training, while most participants remained neutral with regards to AR. This is surprising given the fully immersive nature of VR. This was also true for participants' attitude towards the use of AR/VR in reducing the dependency on user manuals for construction-related tasks. 54% of respondents do not feel that AR can achieve this, with only 54% believe that VR can offer such opportunity.

When asked to identify the significant factors that would prevent the implementation of AR for a construction project, users equally weighted three factors each at 20% as: reliability, proper calibration and use of sensitive data. The issue surrounding the use of sensitive data is in line with findings from the literature with business implications for, for instance, the Google Glass. Perhaps most surprisingly, cost is weighted as least effective for implementation of AR; a factor which usually plays a critical role in determining whether or not technology is implemented.

The final question provided users with an opportunity to express their opinions or to add further comments about the technology. A large number of participants reported that they felt dizzy or motion-sick after using the VR technology. Some went as far to say they could use it for no longer than 5 to 10 minutes. Some participants viewed AR as being less fit-for-purpose than VR in its current state, for the construction industry. This highlights the need for more research in order to propose a more thorough system that can be implemented into the construction industry.

5. Concluding Comments and Further Research

The outcomes of this investigation imply that HMD AR/VR systems can be applied to construction projects at different phases, although the applications of VR are more evident than AR, this may be due to users being more familiar with VR compared to AR. The findings from this research have challenged some previous findings with regards to AR/VR and in fact, from time to time even contradicted what was found previously, most notably suggestions that 3D modelling is an unnecessary complication.

Upon concluding this research, the authors see it fit that future research takes one of three possible routes. The first option is to develop either AR or VR technologies separately, with more specific applications based on the findings of this research. Another option would be to develop this research to test the hypothesis that AR and VR technologies are optimal when used on a project in conjunction with one another; interoperability could be the underlying principle in this case. The third option is to progress this research by building upon more recent advancements in AR/VR technologies such as the use of the next generation of smart glasses provided by leading technology providers on the market, both the one that kindly supported this study and the others. Either of these three options should seek to address the very valid concerns pointed out by participants in the questionnaire, especially the health and safety implications for the use of such technologies on site.

6. Acknowledgements

7. References

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