Augmented Reality (AR) and Virtual Reality (VR) in construction industry:
An experiential development workflow

Dr. Poorang Piroozfar

School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, A.E.Piroozfar@brighton.ac.uk

Mr. Amer Essa

School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, ameressa@outlook.com

Mr. Simon Boseley

School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, sboseley@outlook.com

Dr. Eric R. P. Farr

NONAMES Design Research Foundation, 1249 F Street, San Diego, CA 92101, USA Eric.R.P.Farr@gmail.com

Dr. Ruoyu Jin

School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, R.Jin@brighton.ac.uk

Abstract

Augmented Reality (AR) and Virtual Reality (VR) in the Architecture, Engineering and Construction (AEC) industry have a sustained track record of research and development proving both technologies to be beneficial to various stakeholders throughout the lifecycle of buildings. Previous research in different areas of AR/VR in the AEC industry is not rare but rather scattered and some areas have benefitted more than others. One of the less researched areas in this field is the workflow development of the instrument in experiential research in AR/VR. With an empirical research paradigm at its core, this paper seeks to provide evidence to bridge this gap using two generic case studies, one for AR and the other for VR. A systemic procedural process is used to explain the workflow development of both experiments aiming at establishing a method which can be adopted, adapted, or customized to best suit the specifics of any similar research project in this field.

Keywords

Augmented Reality, Construction Industry, Handheld Devices, Head-Mounted Devices, ICT Application, Virtual Reality

1. Introduction

A limited number of studies carried out on AR and VR (under 15%) have used handheld and mobile devices such as smartphones as their 'Computing Units' or 'Enabling Technologies'. This, at least to some extents, is due to specificity and costs associated with specialized Head-Mounted Displays (HMDs) and their exclusive firmware and/or software applications. Consequently this also makes it too difficult to generalize the knowledge claims of such studies as they remain very much context-specific with limited scope for triangulation of findings. However, with the development of smartphones, and affordable yet generic VR headsets, the emphasis needs to be shifted on how generic experiments can be developed using a systemic approach so that they can be used by a broader range of handheld devices and smartphones – either on their own or in combination with affordable VR headsets which can use smartphones as their core VR processing unit. The need for research instruments to facilitate, enable or support applied research, puts the systematic design of user-centered experiments at the core of empirical research in AR and VR in the AEC industry. Initially developed for different studies, two experiments have been utilized in this paper to further elaborate on their workflow and expand on two creative, systematic and customizable solutions for similar research in the field. Research is not abundant in the specific field of this study but is deemed to be of paramount importance because it can help remove the research deadlock in this area. A broad literature review on AR and VR and the use of handheld and mobile devices will be provided first. The paper then carries on with the AR experiment, for which we had no option but to use a specialized device obtained from a leading technology provider for a research project. This however, does not disqualify the AR experiment developed here to be used with less sophisticated and more affordable devices such as handheld devices and tablets. In such cases, depending on the application(s) used, minor adjustment to the model might be inevitable. The paper then moves onto the development process of the VR experiment which is intended to be used as a 3D stereoscopic experiment by research participants or project stakeholders. Given the fact that workflow development research in AR/VR is very limited in scope and number, this research is a unique attempt and probably one of the first ones in this area.

2. Literature Review

The construction industry is dependent on visual imaging solutions to accurately communicate form, functions-related and performance-related information. In this context, virtual solutions can prove far more practical than using physical prototyping due to time and cost constraints, convenience, health and safety issues and logistics (Brandon et al. 2005). Although the conceptual principles, the technology both in terms of software and hardware and the scopes, applications, purposes and applicability of AR and VR are different, their definitions, what they entail or are understood to be, and how and where they can be most beneficial, are not mutually exclusive and are still determined by subjective readings. Raajana et al. (2012) believe that confusion between AR and VR is an enduring problem. However, there is almost an incessant continuum between actual and virtual reality and several terms have been coined to denote one or the other or a mix of both. Those include amplified reality, augmented reality, augmented virtuality, blended reality, diminished reality, mediated reality, mixed reality, virtualized reality, just to name a few (see e.g. Schnabel 2009). Milgram and Colquhoun Jr. (1999), who have been referenced by many other researchers (e.g. Azuma et al. 2001, Dunston and Wang 2005, Yuen et al. 2011, Raajana et al. 2012, Meža et al. 2014), assert that there are two distinct definitions for AR in the literature. The more common one, which is built around the technology, includes hardware (a display system i.e. Head-Mounted Display (HMD) or Heads-Up Display (HUD)). The second definition, which is

rather theoretical, does not necessarily involve an instrument (i.e. a display system) but represents a concept. However, what differentiates VR from AR is that it removes the real elements – regardless of the type of display device – and instead immerses the user in a totally virtual environment where virtual objects are used to represent actual reality. In either case, the virtual elements can be based on 2D or 3D objects or information, or even sound, light or scent. Efforts to establish VR outweigh those for AR and started earlier, especially in education and entertainment industries. However, over the past two decades, the applications of both AR and VR have grown rapidly due to development of mobile and wearable devices (Piroozfar et al. 2017). Bae et al. (2012) and Bae et al. (2013) developed Hybrid 4-Dimensional Augmented Reality (HD^{4}AR) which uses site photography to identify location and orientation of field personnel to allow them to query and access semantically rich 3D cyber-information and see it precisely overlaid on real-world imagery. Irizarry et al. (2013) use KHARMA (Hill et al. 2010) to develop an Information Surveyed Point for Observation and Tracking (InfoPOST), as a mobile AR tool for facilities managers for accessing information about the facilities they maintain. Handheld and mobile devices such as smartphones and tablets are feasible options for AR/VR systems, each of which have their own advantages and limitations for AR and/or VR applications. New advancements in software, firmware and hardware technologies have portrayed handheld devices as viable solutions for AEC applications. Research into the use of such applications is still few and far between. Wang et al. (2013) suggest that out of 38 journal papers and 82 conference papers published on AR in the AEC industry between 2005 and 2011, there were only 14.8% (N=9) where a hand-held device had been used. Combined with basic HMD units smartphones are gaining popularity and momentum as they offer a compact, affordable and agile yet multi-purpose device which combines advanced and customizable processing power with an infinite and customizable source of software technology (i.e. mobile device applications).

3. Research Design and Methodology

This paper presents the workflow of two experiments which have been developed for two research projects, one on AR and the other on VR in the AEC industry. After the research question, aim and objectives, and the theoretical framework of each research were formulated and critical review of literature corresponding to each were carried out, a task list for each project was articulated and the experiment was designed to fulfill those requirements and provide answers to the research questions. The aim of this paper is to expand on the development process of the two experiments in comparison with each other to provide an insight into the similarities and differences, possibilities and difficulties associated with each experiment. The paper sets out to establish a generic but systemic pathway for the design of such experiments. The experiential nature of both research enquiries required that experiments be designed with a very specific account of the research participants in mind:

> In the new paradigm [of experiential research], this separation of roles [of the researcher's and the subject's] is dissolved. Those involved in the research are co-researchers and co-subjects. They devise, manage and draw conclusions from the research; and they also undergo the experiences and perform the actions that are being researched (Heron 1982).

Ease of use (of both software and hardware), practicality, interactivity, active engagement were the most important criteria among more common ones such as replicability, validity, reliability,

reproducibility of the instrument and the process of data enquiry and analysis in the research design. More specifically, in the process of development of both experiments, special attention has been paid to:

Value of human experience; focusing on the wholeness of experience; searching for meanings and essences of experience; obtaining descriptions of experience through first-person account; regarding the experiential data as imperative; formulating questions and problems that reflect the interest, involvement, and personal commitment of the researcher; and last but not least, viewing experience and behavior as integrated and inseparable discourses.

The development process of an experiment for AR from a 3D model using an industry standard BIM application (Autodesk Revit 2016) will be explained next.

4. Development of AR Experiment

The University of Brighton's (UoB) new Advanced Engineering Building (AEB) was selected for this experiment and the development of the AR Experiment was carried out through the following steps:

4.1 Part 1: Preparing the 3D Scene

The 3D BIM model of the building was acquired from the architectural practice who were in charge of the design for this new facility, pre-tender stages (Figure 1). The aim of this exercise was to use the existing construction drawing documents and models for developing this AR experiment to avoid rework and also to test interoperability between different software applications. For the model to be viewed on a pair of M100 Smart Glasses™ utilizing AR, the first step involved ensuring all required components of the model are present, before being exported. As this experiment was designed to view the building mostly from the exterior, most of the interior of the AEB were not relevant to the experiment, hence the majority of the interior details were removed to keep the file size to a minimum, with an aim to reduce the processing time.


Fi_____**omponent**_____**t)**
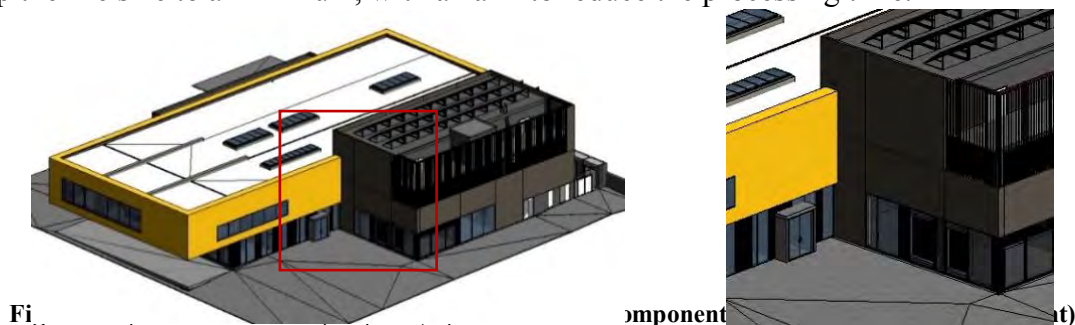
Interoperability between the AR hardware/software and 3D model is key to ensuring the model can be viewed with the Smart Glasses. The Smart Glasses utilize an exclusive operating system which is not directly operable with the BIM application file format. Therefore, the 3D model must be prepared in an application to generate a file format which is readable by the AR application installed on the Smart Glasses. Due to its wide usage, high flexibility and powerful image analysis/processing and rendering capabilities Autodesk 3DS Max was the software of choice to bridge the gap between the 3D model and the AR Smart Glasses. Moreover, 3DS Max is owned by the same software application vendor as Revit (Autodesk) which meant problems with

interoperability should not occur at least at one end. The model must be exported to a file format native to the AR hardware. For this purpose .fbx format was selected, which is a proprietary file format used to provide interoperability between digital content creation applications.

4.2 Part 2: Importing the Scene into AR Environment

After the model was imported into 3DS Max (Figure 2a), the process of generating the AR scene could begin. This includes the generation of a 'marker' to assist the Smart Glasses with when and where to display the model. Upon inspection after the first run-through, it was found that the materials on the AEB building had seemingly been lost, meaning the building was displayed as a series of grey-colored plastic components, as shown in Figure 2b.
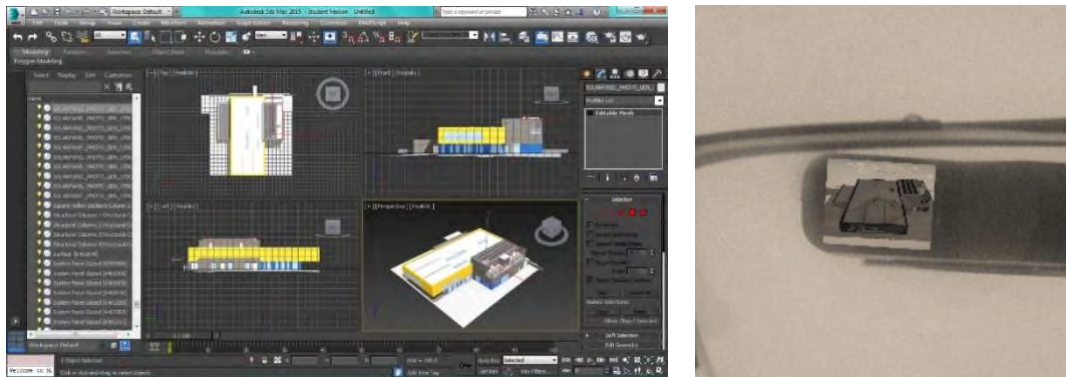
Figure 2: a) The model imported into 3DS Max using .fbx file format, and b) greyed-out AEB building through AR Smart Glasses

Ultimately, this is due to the materials being native to Revit, but not to 3DS Max. Even though the materials appear to have been imported into 3DS Max with the model (as shown in Figure 2a), the augmentation showed this not to be the case. Therefore, the materials must be manually applied to each component using the Materials Editor tool in 3DS Max. Once the materials native to 3DS Max had been generated and applied to all components (Figure 3a), the generation of the scene could then progress. This involved the use of 'AR Media', an AR plugin compatible with the Smart Glasses software, to export the scene (Figure 3a) and to create the marker (Figure 3b).
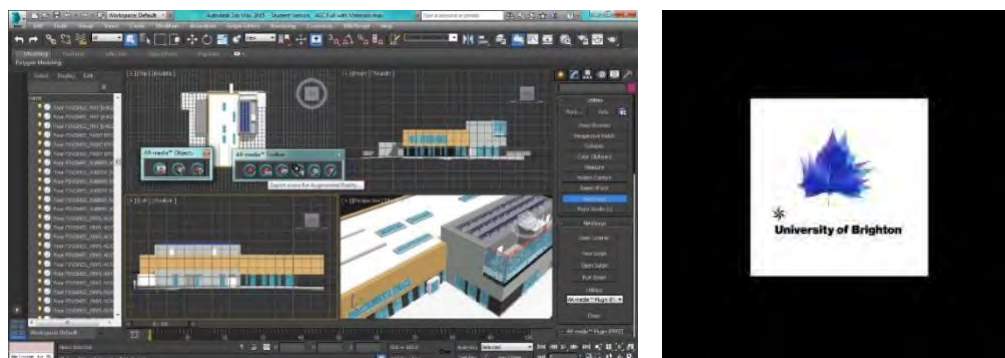
Figure 3: a) The model being exported using AR Media after materials being applied in 3DS Max, and b) The marker being created using AR Media

Once the AR model was exported from 3DS Max, it needed to be downloaded onto the Smart Glasses via the AR Media application using a Wi-Fi connection. Smart Glasses will then display the 3D Revit model if the customized marker is sighted. The projected visual data (in perspective) before and after the marker is sighted are illustrated in Figure 4. It should be noted that the size of the augmented model relates to the size of the marker when printed, and increase in marker size results in a larger augmented model.
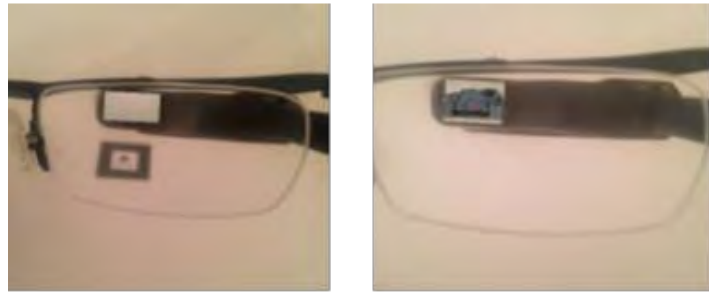

Figure 4: Smart Glasses view a) before, and b) after sighting the marker

5. Development of VR Experiment

The same building (UoB's AEB) was used for this experiment and the development of the VR experiment included the following steps:

5.1 Part 1: Preparing the 3D Scene

A 3D model and a 3D scene are required for this exercise. This can be created using a 3D modelling software or by importing an existing 3D BIM model from supported software applications. In this experiment, the model was developed from scratch in SketchUp™ (Figure 5a).
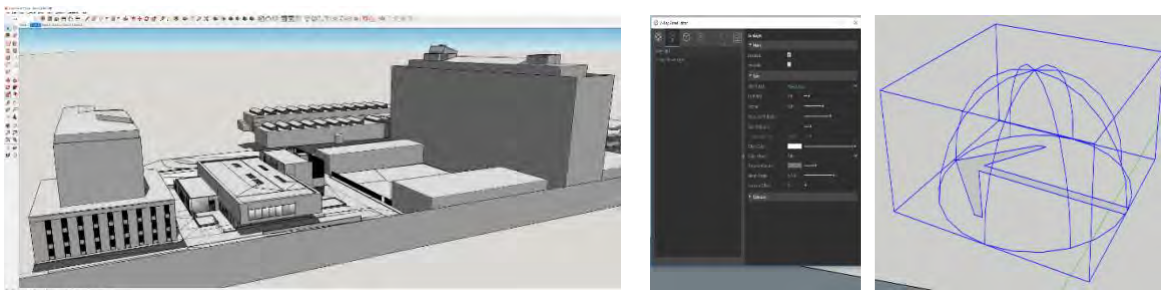

Figure 5: a) SketchUp model of the building, b) Lighting options and, c) Light dome in model space

Had BIM model (e.g. in Autodesk Revit) been used, it could have been setup in 3DS Max, exported as a compatible file into SketchUp to start the project, which may have added some additional steps required to address compatibility and rework. The alternative route in this experiment has been taken intentionally to avoid such complications and to provide a proof of concept as to how alternative routes, compared to the one taken for the previous experiment, can be used. This workflow, however, is not obligatory and is dependent on user preference, knowledge, and ability, the project timeline and budget constraints, and access to various software packages which may also entail potential problems with interoperability and cross-compatibility. At the next step, materials and textures are set up and assigned to the 3D model and the lighting parameters are configured to suit, using V-Ray™ (Figure 5b and 5c). For this purpose, V-Ray 'plug-in' can be

utilized to render and export relevant images. It supports different digital content creation applications such as SketchUp (as shown here), 3DS Max, Revit and Maya.

5.2 Part 2: Generating a Cubemap

Once the scene was completed with finalized geometry, materials and lighting setup, a Cubemap – a series of six images assembled together to create a full 360˚ view – would have been ready to be rendered in V-Ray. In the case of stereoscopic views, as in this experiment, two cubes are used requiring twelve images. This can easily be set up in V-Ray. Then the Cubemap dimensions should be set up as per the mobile device's display resolution. After setting up the resolution, the scene
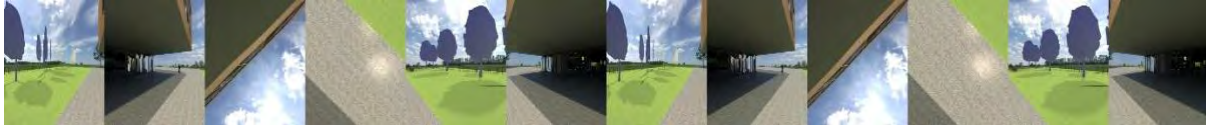
will then be rendered (Figure 6).

Figure 6: Rendered stereoscopic Cubemap (12-sides, 6 per eye)

## 5.3 Part 3: Utilizing Cubemaps

Cubemaps (using image file formats such as JPEG, PNG etc.) need to be uploaded to an application which supports mobile VR using Cubemaps. In this case, an online open source application has been used which also supports standard 360˚ (non-Cubemap) panoramas. As walkthrough function was intended for this experiment, the application should also support this function. The walkthrough option was selected and set up which requires uploading more than 1 Cubemap. Subsequently each Cubemap, should be edited and assigned a starting

Figure 7: Utilizing Cubemaps and setting up hotspots

view as desired (Figure 7). 'Hotspots' – visual markers that direct the user to alternate Cubemaps – were set up with a chosen graphic overlay – in this case arrows – and placed at a suitable point within the viewer's perspective indicating the suggested location the hotspot will deliver the user to (Figure 7). A link to the VR project was created and shared via the Projects Overview page, enabling access without the need for account registration or login.
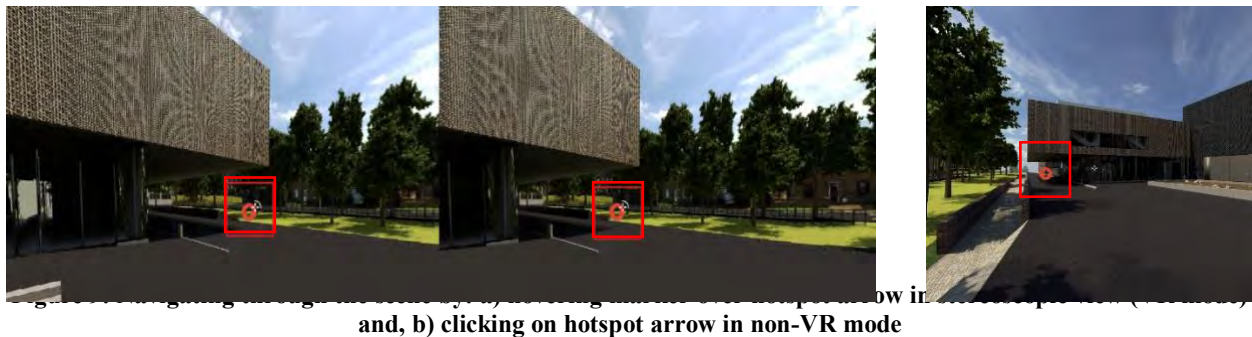
5.4 Part 4: Viewing the Project

Once the project was loaded via the web address or directly within the projects page, the VR icon can be selected to enable Stereoscopic view (Figure 8a). A HMD VR viewing hardware for mobile devices is required for this function. The user viewing preference and the mobile device may also need to be calibrated for VR using the VR Setup function (Figure 8b). This may vary depending on the mobile device and application(s) used.
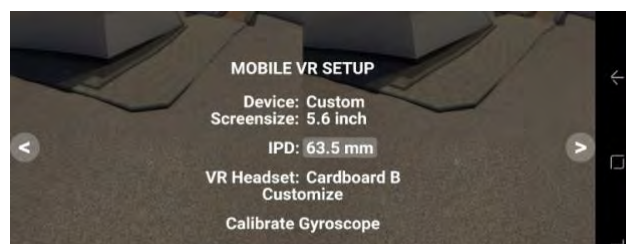
Figure 8: a) Enabling the stereoscopic view and, b) calibrating the mobile device and user viewing preferences for VR

Finally images can be navigated through by hovering the marker over hotspot icons or arrows if in VR mode (Figure 9a) or by clicking on hotspot icons or arrows when not in VR mode (Figure 9b).

Figure 9: navigating through the scene by a) hovering marker over hotspot arrow in stereoscope view (VR mode) and, b) clicking on hotspot arrow in non-VR mode

6. Concluding Comments and Future Research

Previous research in AR/VR in the AEC industry indicates a gap in how the experiments can be developed and used as data collection/analysis instruments for user-centered research. Particular attention should be paid to the participants in experiential research as no longer does the traditional division between the researcher and the subject exist and the participants will have a new role of co-subjects/co-researchers. Two experiments were developed to ensure the ease of use, applicability and fitness to serve the purpose of the studies for which they were designed. For the specific purpose of this paper, the experiments were then revisited and redesigned to ensure that they stay generic and present a customizable workflow which can be adopted and adapted to the specifics of similar research in the field. Despite the expectations, the software applications – even those provided by the same vendors – remain, to some degree, incompatible, and their interoperability is still an outstanding issue. However, there is a common logic behind how such experiments can and should be developed and this paper tried to shed some light on such logic by presenting a systematic workflow for an AR and a VR experiment. Interface tracking, visual clarity, intuitiveness, cost effectiveness, swift customizability, control over unlimited design variations and visualization parameters are just to name a few advantages which can be realized through an effective workflow design for an AR/VR experiment. Although the AR experiment seemed to be more straightforward, the issues regarding interoperability and file transfer and extra preparation work was heavier than what appeared to be in the development of the VR experiment. Besides, the local and global registration of the virtual entity still remains a major hurdle on development of an effective AR solution. The bridges between actual and virtual realities are still inept and real-time registration is far from reach, chiefly due to shortage and inefficiencies in hardware, software, processing speeds and web technologies. This paper helped improve our

current understanding of logic, procedure and process of how different technologies can work together and/or be deployed to enable AR/VR as a research instrument for experiential research in this area. The user experiment is key in such research and was accounted for during the first stage of development. This paper also revealed that further work in this area is still very much needed. Future research in this area can benefit from closing the circle through a feedback loop from the participants, not only about the main research question but also about how they found the experiment itself. Further areas which can benefit from the two procedural experiments explained in this paper are yet to be explored in more detail. Although coding might not be a favorable area, there are still opportunities in this area to be explored more and with Visual Programing Languages (VPLs) becoming popular, opportunities are arising to offer more adjustable/ customizable options for the design and during the application of such experiments.

7. References

Azuma, R., Y. Baillot, R. Behringer, S. Feiner, S. Julier and B. MacIntyre (2001). "Recent advances in augmented reality." IEEE Computer Graphics and Applications 21(6): 34-47.

Bae, H., M. Golparvar-Fard and J. White (2012). Enhanced HD4AR (Hybrid 4-Dimensional Augmented Reality) for Ubiquitous Context-aware AEC/FM Applications. 12th international conference on construction applications of virtual reality (CONVR 2012), National Taiwan University, Taipei, Taiwan.

Bae, H., M. Golparvar-Fard and J. White (2013). "High-precision vision-based mobile augmented reality system for context-aware architectural, engineering, construction and facility management (AEC/FM) applications." Visualization in Engineering 1(1): 3.

Brandon, P., H. Li and Q. Shen (2005). "Construction IT and the 'tipping point'." Automation in Construction 14(3): 281-286.

Dunston, P. S. and X. Wang (2005). "Mixed Reality-Based Visualization Interfaces for Architecture, Engineering, and Construction Industry." Journal of Construction Engineering and Management 131(12): 1301-1309.

Heron, J. (1982). Empirical validity in experiential research. Guildford, University of Surrey.

Hill, A., B. MacIntyre, M. Gandy, B. Davidson and H. Rouzati (2010). KHARMA: An open KML/HTML architecture for mobile augmented reality applications. 2010 IEEE International Symposium on Mixed and Augmented Reality.

Irizarry, J., M. Gheisari, G. Williams and B. N. Walker (2013). "InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach." Automation in Construction 33(Supplement C): 11-23.

Meža, S., Ž. Turk and M. Dolenc (2014). "Component based engineering of a mobile BIM-based augmented reality system." Automation in Construction 42(Supplement C): 1-12.

Milgram, P. and H. Colquhoun Jr. (1999) "A Taxonomy of Real and Virtual World Display Integration."

Piroozfar, P., A. Essa and E. R. P. Farr (2017). The application of Augmented Reality and Virtual Reality in the construction industry using wearable devices. The Ninth International Conference on Construction in the 21st Century (CITC-9): "Revolutionizing the Architecture, Engineering and Construction Industry through Leadership, Collaboration and Technology" Dubai, United Arab Emirates.

Raajana, N. R., S. Suganya, R. Hemanand, S. Janani, S. N. N.S and S. V. Ramanan (2012). "Augmented Reality for 3D Construction." Procedia Engineering 38(Supplement C): 66-72.

Schnabel, M. A. (2009). Framing mixed realities. Mixed reality in architecture design and construction. X. Wang and M. A. Schnabel. London, Springer.

Wang, X., M. J. Kim, P. E. D. Love and S.-C. Kang (2013). "Augmented Reality in built environment: Classification and implications for future research." Automation in Construction 32(Supplement C): 1-13.

Yuen, S., G. Yaoyuneyong and E. Johnson (2011). "Augmented Reality: An Overview and Five Directions for AR in Education." Journal of Educational Technology Development and Exchange 4(1): 119-140.