The application of Augmented Reality (AR) in the Architecture Engineering and Construction (AEC) industry

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

Mr. Amer Essa
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, ameressa@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) as a concept has been in use for many years and prevalence of new mobile technologies, such as smartphones and handheld devices, have facilitated the concept of AR becoming fully realized. Various fields are exploiting the increasing feasibilities the concept of AR can offer; one of these being the Architecture, Engineering and Construction (AEC) industry. This paper introduces a research project that investigates benefits and limitations of AR for use in AEC industry. It starts with a brief background to the research before presenting a critical literature review, which forms the basis for the development and design of an AR experiment and a questionnaire for participants in the study. Results are provided with an in-depth discussion on their possible significance, before a conclusion is presented. The results suggest that although the participants believed that AR can offer a wide range of benefits to different tasks and at different stages of a project, it seems more beneficial to some specific tasks or at some specific stages than the others. Using the specific findings of this study future research in this field is proposed in different areas.

Keywords

Augmented Reality, Construction Industry, Handheld Devices, ICT Application, Virtual Reality

8. Introduction

Augmented reality (AR) and Virtual Reality (VR) have found momentum in the Architecture, Engineering and

Construction (AEC) industry. As AR has become an increasingly feasible concept, opportunities for its use are expanding and leading to innovation in various fields. The fields which augmented reality can be applied to, as discussed by Azuma (1997), are diverse. One such field that shows potential for adopting AR is the 'prevalently visual' AEC industry. Due to the nature and context-specifics of the AEC industry however, in-depth and specialized research in this area seems to be few and far between. This study aims to explore the possible uses of AR in the construction industry as well as the potential solutions it could provide as a tool in various construction related tasks, gauging the benefits and limitations associated with the concept. In order to realize this aim, a practical experiment has been developed as an instrument to conduct a problem-solving approach to the study. A questionnaire has been designed and used to gather quantitative and qualitative data in order to analyze the feasibility of using such methods in the construction industry. The results suggest that although the participants believed that AR can offer a wide range of benefits to different tasks and at different stages of a project, it is deemed more beneficial to some specific tasks or at some specific stages than the others.

9. Literature Review

Augmenter Reality (AR) is essentially a form of Mixed Reality (MR) and can be defined as the concept of integrating virtual elements (generally, computer generated) onto the user's real world environment (Azuma 1997). Several terms have been used to define the spectrum between actual and virtual reality: amplified reality, augmented reality, augmented virtuality, blended reality, diminished reality, mediated reality, mixed reality, virtualized reality, etc. (e.g. Schnabel 2009 among others). Widely referenced by many researchers (e.g. Dunston and Wang 2005; Azuma *et al.* 2001; Yuen, Yaoyuneyong, and Johnson 2011; Raajana *et al.* 2012; Meža, Turk, and Dolenc 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 a Head-Mounted Display (HMD) or Heads-Up Display (HUD) whereas the second definition is more general without a reference to a display system. These virtual elements can be 2D or 3D objects, or even sound, light or scent. The features of AR permit the user to follow their viewpoint by means of a tracking system, superimpose virtual objects onto the user's view of a real-world scene, render the combined image of virtual objects and a real-world scene in real time and locate virtual objects in a real world scene to the correct scale, location and orientation (Shin and Dunston 2008).

Key benefits of using AR applications were found to improve communication between all parties involved, increasing project understanding and accelerated decision making, better scheduling and budget-management, real time visualization, enhanced collaboration, increased safety and greater implementation of BIM (Jones 2014). The literature also highlights differences between the countries (Greenwood *et al.* 2008) in terms of the perception and the uptake of such technologies which would suggest that VR/AR applications could be used more frequently if attitudes and popularity of these technologies change. It is suggested that the construction industry is heavily dependent on visual imaging solutions to accurately convey form and performance information, where virtual solutions such as AR can prove far more practical than using physical prototypes due to cost, potential risks and logistics (Brandon, Li, and Shen 2005). A study (Shin and Dunston 2008) highlights eight areas which they consider suitable for AR applications, including: site layout, excavation, positioning, inspection, coordination, supervision, commenting, and strategizing. Conversely, it was also concluded that there may be certain tasks that would derive little to no benefit from utilizing AR solutions. However, what seems to have gone unnoticed not only in this study, but much more widely, is design, ranging from architectural design to detail development and from structural design to building services. Moreover, activities more specific to refurbishment, restoration and remedial work on, and maintenance of, existing buildings, where AR can play a major role to cut the cost and time, and improve on quality, as well as health and safety pertaining to such activities are not included.

It was found that except for a couple of specialized suppliers, offering specifically developed hardware gears at rather expensive prices, currently there are not many affordable solutions employed on a large scale to provide a benchmark for quality application of AR in AEC industry. The literature does however, illustrate a general modus operandi among developers for the assembly of AR systems. Other researchers have discussed the use of animation in construction through the 'traditional' configuration, including the use of a new customized software framework developed specifically for animation purposes (Behzadan and Kamat 2009), but problems were found in display of animation in combination with GPS. Follow-up work suggests that virtual elements should be displayed as independent entities, so that each object's respective position, orientation and size can be changed independently (Behzadan and Kamat 2011). Another study (Malkawi and Srinivasan 2005) presents an AR framework which allows interaction and visualization of buildings and their thermal environment. Named Human-Building Interaction (HBI) Model, the proposed AR system, consists of four components, where It was shown that the system works well in permitting the user to see the thermal environment of a building and that the HCI component improved use of this system significantly. Other research (Fuge *et al.* 2012) gives account of developments on the use of gesture recognition AR where the results indicate that it can be integrated successfully into systems, improving ergonomics of AR applications. One of the most significant barriers to successful operation in the last two studies remains to be the issues with registration (Azuma 1997) which occurs when the positioning of the virtual objects fails to display at the correct location in the real world. To address this problem AR systems may employ 'markers', a visual cue, placed on site to improve software/hardware recognition and these work as location targets to define where the virtual objects should be displayed. The use of markers can increase robustness and reduce computational requirements (Park and Park 2010). The disadvantage of marker-based systems is that they are often visually intrusive or unappealing. A hybrid alternative to ordinary marker systems is proposed to overcome this issue (Park and Park 2010). The solution was to use invisible markers by application of UV ink.

AR systems can also use smartphones, tablets or handheld devices as an alternative option. Modern day advances in handheld devices allow certain AR solutions to become viable for AEC applications. Research into their use for this application remains limited at this stage. A review of mainstream studies (Wang *et al.* 2013) suggests that there have been 38 journal papers and another 82 conference papers filtered out of initially 154 identified papers published on AR in the AEC industry between 2005 and 2011, where only 14.8% (N=9) were carried out using hand-held devices as their ‘Computing Units’ under the ‘Categories of Implementation’ or ‘Enabling Technologies’ as suggested in this paper. Construction Opportunities for Mobile Information Technology (COMIT) does provide some precedent in this case. One of COMIT's recent projects carries out research into the use of augmented reality in construction, where HoloLens have been used to implement Augmented Reality to visualize 3D/4D in site and in 1:1 scale in a Balfour Beatty project.

10. Research Design and Methodology

The aim of this research is to determine the suitability of AR for the construction industry and associated tasks, gauged through the perceived benefits and limitations of the concept and technology through use of mobile and handheld devices. Secondary research was carried out by means of a literature review to build an extensive knowledgebase and understanding for AR to then be used in the design of the research instrument for this study. Primary research was undertaken utilizing a mixed-methodology approach to overcome limitations which may be imposed by a single method approach. This would be achieved through quantitative and qualitative means, by way of a questionnaire after the participants took part in an experiment developed for this study. Particular care was taken to adapt primary research methods in the most appropriate manner in order to mitigate the fact that AR can be seen as a complex and/or confusing topic to those who may have limited exposure to the concept in its intended context of application; a less considerate approach could have resulted in misrepresentation of, or at best case scenario an unintended bias in, findings. Pivotal to the data collection instrument of this study was the experiment design which was developed following the break-down of the tasks and intentions required to be fulfilled for the specific purpose of this study.

10.1 Development of Experiment

The search for a platform in which to create a suitable AR application was carried out extensively over a significant period of time. Many Smartphone- and Tablet-based solutions, applications and methods were trialed to gauge how effective they could be for providing a workable design visualization solution. A suitable application called ‘LayAR’ was eventually found that would fulfil most of the requirements set out in this research. LayAR is not essentially designed for use in the AEC industry but rather as an AR browser. LayAR is easier to use and setup compared to some other applications designed with the same purpose. It supports 2D images, 3D models, sounds and video as AR information which are given a location-specific address. Initial experimentation found that the process of creating and implementing customized AR content remained a relatively complex task, but was still significantly easier than some other applications tested.

At this point, a web-based solution called 'Hoppala Augmentation' was found to aid automation of the process of integrating AR content (images, 3D models etc.) without the need for computer coding which makes the system more intuitive. The process works by 'uploading' an image or 3D model file to the Hoppala online database, the user then enters location data for the AR content by providing latitude and longitude, altitude and scale information. Hoppala then generates a code which is sent to LayAR to publish the content.

The first successful trial of this method used a 2D image file of a skyscraper building design created by the researchers. The general feeling was that the concept did work but there were issues with performance; the GPS continually refreshing itself making the image appear to 'skip around' the user display, where the location of the object changed with renewed GPS data. This was resolved by fixing (setting) the location of the device at a certain latitude/longitude. This solved the issue, but meant that grid coordinates are required and that the GPS component could not be used. This is perhaps the ideal solution until advancements are made with internet, hardware or software to allow increased performance or else an interface would be required to link to an external GPS tracker to an IPS (Indoor Positioning System) receiver to assist the app to locate the model on the site context in real-time. It was decided that improvements should be made to increase clarity of information shown. This would be achieved by using 3D models rather than 2D images, as shown in Figure 1a. Using 3D models allow the user to, in a sense, walk around and inside the building/or structure (3D object), as shown in Figure 1b.

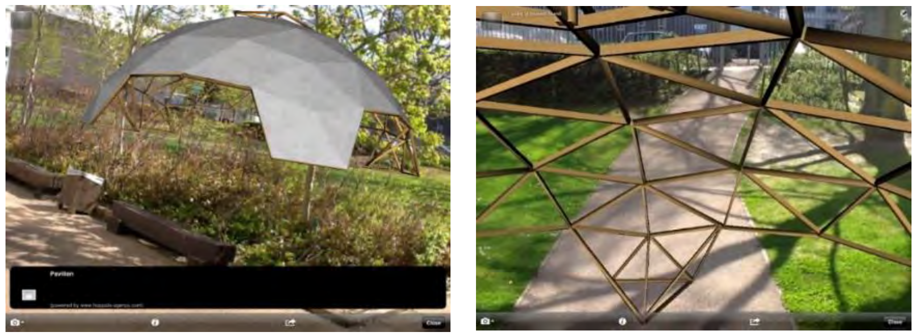


Figure 1: AR experiment developed using fixed location: a) pavilion structure in the context (left); b) pavilion structure's internal perspectives (right)

In comparison to earlier methods tested, the selected solution is more effective at presenting information as well as being more interactive and as such, is more likely to involve users through design stages.

10.2 Questionnaire

Informed by the findings of critical review of literature, the questionnaire was designed and split into four sections as follows: General Information: to identify respondent backgrounds; Knowledge of AR/VR: to assess respondent understanding of AR; AR in the construction industry: to measure participant's view on suitability of AR to construction tasks; and Study Focus: to gauge feasibilities of adopting AR solutions in construction industry. Most questions were multiple choice or Likert scale 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 and also to ensure that any possible bias – positive or negative – is strictly avoided.

10.3 Data Collection

Respondents were selected using Purposive Sampling techniques on a university campus where the only requisite was having an academic background (being a student or a member of staff), to ensure a common degree of understanding and knowledge of the field of application exists between the survey participants with no need to have prior experience of AR in the AEC industry or otherwise. The sampling was intentionally aimed at audience at a university setting as most participants were expected to be young future professionals as rather tech-savvy and more likely potential users of modern technologies in their professional career. The questionnaire analyzed participants' opinions on how intuitive the application was and the perceived level of values it could offer to factors such as productivity. Before the questionnaire was presented to respondents for data collection, a pilot study was conducted to prevent possible issues/errors occurring.

11. Results and Discussion

Part 1 - General Information: The respondents were asked about their career or field of study. This information was required to gauge the level of knowledge regarding the study topic in particular and the construction industry in general. Most of the participants (76%) had a background in construction. The experimental AR system was developed for architectural design tasks, so with most participants being students in relevant disciplines, the demography is apt to the investigation.

Part 2 - Knowledge of VR/AR: When asked if they had heard of VR/AR and if yes in what capacity, 70% of participants stated that they had heard of VR with only 62% for AR. For those that replied 'Yes', the most popular application of VR was for use in games and films. When asked 'If applied, in which area do you think VR or AR would be most useful?', the outcome showed the applicability of these concepts not only to construction as highest (N=21) but also into other industries with Entertainment N=17, followed by Military and High Risk Training, N=11 and 10 respectively, with

Manufacturing, Education and Social Networking with N=5,4,3 at the bottom of the table. This demonstrates that perceptions toward the applicability of AR for construction are generally positive. The unexpected anomalies here seem to be Education and Social Networking where only 4 and 3 people believed that VR and AR would be most usable.

Part 3 - Use of AR in the Construction Industry: The experimental AR system was introduced to participants to gauge their opinion on use of such a system in the construction industry and analysis of the system itself. Part 3 is designed, considering the RIBA plan of work, to justify the use of AR through pre-construction, construction and post-construction phases. It focuses on various tasks under these phases to judge overall applicability. The participants were asked in which areas they think AR is most applicable, if used in the construction industry. This question draws upon the users' experience of the presented AR experiment to gauge participants' opinion on applicability pertaining to the listed tasks. Likert scales were utilized to classify a level of applicability. Users were asked to give their verdict on the perceived benefit of the AR system to pre-construction phase of works such as design, project management and site management. The results showed a mixed outcome in respect to pre-construction tasks, with the general viewpoint being that the concept lends well to design tasks better than others (Figure 2). To summarize, AR seems to be applicable to the various phases of works set out under the RIBA plan of works, according to the views of the questionnaire respondents. This supports the view that AR would be useful for construction tasks but would have needed more work in some certain areas (such as project/site management as well as inspection and maintenance) than the others, should its wider and deeper application in the AEC industry be intended.

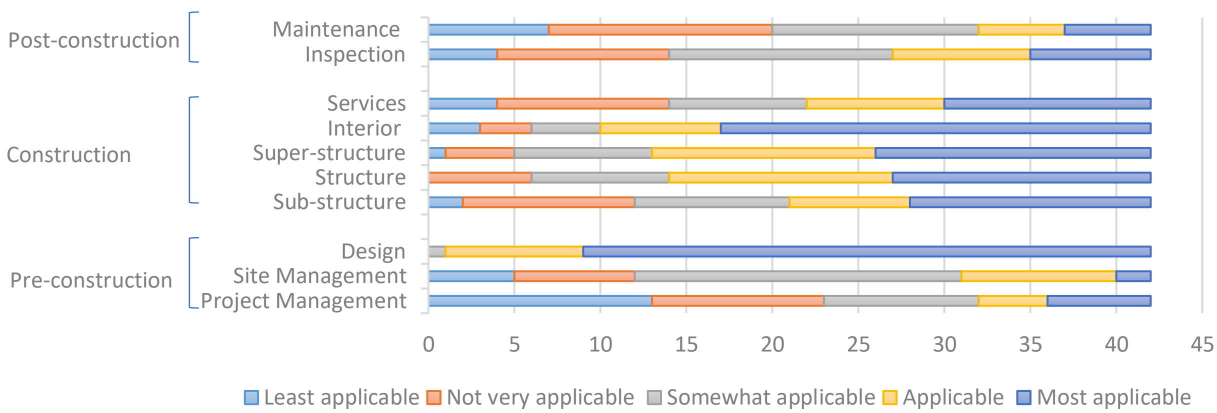
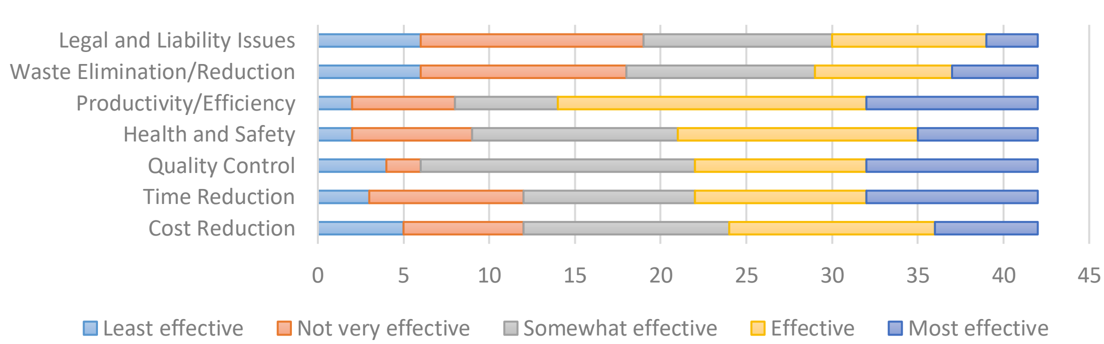


Figure 2: AR Applicability to different stages at pre-, in- and post-construction phases

Part 4 - Study Focus: Part 4 aims to measure the potential benefits AR could bring to the construction industry and the overall feasibility of its introduction. Questions cover factors such as cost, time and obstacles associated with integrating AR in construction. The participants were asked how effective they think the application of AR could be in construction tasks/goals regarding a series of issues as listed in the question. Here, participants' experience of the experimental AR application was used to gauge their opinion of the efficacy of applied AR systems. Overall, the findings showed that respondents believed AR can provide benefit to construction tasks (Figure 3).

Figure 3: The effectiveness of AR for different tasks/goals pertaining to a construction project



The answers to the question: In your opinion, how effective a tool is this in encouraging the client's participation in the design and construction process?' showed that the majority of respondents (90.5%, N=38) agrees that the application would be an effective or a very effective tool for encouraging user's and client's participation in construction tasks. This indicates the potential for such technology to change the way in which issues between construction professionals and clients are negotiated and resolved, with assistance of improved visual communication. To gauge the feasibility of introducing such an application into construction projects, the participants were then asked if they employ such solutions if they were in charge of a project. 74% (N=31) stated that they would do where 19% (N=8) were undecided and only 7% (N=3) said they would not employ such technologies if they were in charge, mostly due to time and costs involved.

Another question was asked to find out with all realistic potentials and hindrances on the way of employing such technologies, if the participants think this is a way forward in the construction industry. Results showed that 93% (N=39) of the participants believed, despite potential issues and constraints, that the integration of AR solutions would be the way forward for the construction industry. This result demonstrates little doubt that AR has potential for use in construction tasks. The participants were then asked if they thought this was the way forward, how long they envisaged it would take for the construction industry to pick up those technologies. 45% (N=19) believed that it would take around 5-10 years for the UK construction industry to pick up such technology, while the same number thought it would take up to 5 years. Only one respondent (2%) believed it would take more than 10 years to implement those technologies and 7% (N=3) did not answer the question.

To further investigate what might be perceived as a hindrance, the participants were asked what, in their opinion, might be the most significant barrier to wider implementation of such technologies.
This question assesses which of the key factors listed, was felt to be the most significant barrier preventing AR solutions from being implemented in the construction industry. Respondents were also given the opportunity to specify other reasons. Respondents identified cost as the leading factor (25%, N=11). Other top factors selected were the need for change (18%, N=8), time (15%, N=6) and attitudes (15%, N=6). Issues regarding attitudes toward the technology could be the most difficult to resolve; as where the industry may uphold traditional values, it may be difficult to persuade staunch perspectives otherwise. However, most factors represented are interrelated and where one factor can be mitigated, others can be too respectively.

12. Concluding Comments and Future Research

The findings of this investigation suggest that AR solutions can provide a functional use to the various facets of the construction industry. Although diverse in possible applications to construction related tasks, AR and its perceived benefits may be more suited to certain tasks than the others. Design and inspection related tasks were concluded to be more befitting in its use. Among potential uses for the technology, one such interest is the opportunity to aid communication, information exchange and involvement with/of clients during the design phase. Subsequently, issues caused by lack of clarity and understanding could be addressed.

The research highlighted that many models exist, be it software or hardware systems, which can be used to implement AR solutions. Furthermore, new and modern mobile devices such as smartphones, tablets and handheld devices are replacing conventional methods which were relying on preliminary hardware such as HMDs and laptops backed up by external GPS receiver or GPS total stations. Developments in hardware are improving user-friendliness, producing refined ergonomics, increasing computing power and accommodating integrated software, components and tools e.g. built-in cameras, compasses, GPS, etc. These improvements are yielding increasingly viable options for AR solutions and methods of their implementation, thereby improving the efficacy of AR to be used as a tool in the construction process and demonstrating the need for a review of up-to-date methods.

The consensus towards AR shows that the technology can be a way forward for the construction industry, with the general stance on its use being largely positive. Despite such perceptions of AR, the investigation shows there is a common sense of obscurity about AR; many are unfamiliar with what AR is and particularly, how it differs from VR. This indicates that such technology and its application need to be introduced better and promoted more profoundly, probably much earlier on and as a part of formal curriculum in higher and further education.

The biggest factors affecting implementation of AR solutions in the construction industry are perceived to be: i) Time needed to implement the technology/technologies; ii) The financial cost to adopt the related hardware and software systems; and, iii) The discerned need for change and attitudes toward the technology.

The finding of this research may be used to help inform the future of research and practice of AR (and to some extents

VR) in the AEC industry. More resources can be redirected into areas which were picked up in this research as areas where such applications are considered to be under-utilized or less likely to be used.

13. 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: 34-47.

Azuma, Ronald T. 1997. 'A Survey of Augmented Reality', *Presence: Teleoperators and Virtual Environments*, 6: 355-85.

Behzadan, A.H. , and V.R. Kamat. 2011. 'Integrated Information Modeling and Visual Simulation of Engineering Operations Using Dynamic Augmented Reality Scene Graphs', *Journal of Information Technology in Construction*, 16: 259-78.

Behzadan, Amir H., and Vineet R. Kamat. 2009. 'Automated Generation of Operations Level Construction Animations in Outdoor Augmented Reality', *Journal of Computing in Civil Engineering*, 23: 405-17.

Brandon, Peter, Heng Li, and Qiping Shen. 2005. 'Construction IT and the 'tipping point'', *Automation in Construction*, 14: 281-86.

Dunston, Phillip S., and Xiangyu Wang. 2005. 'Mixed Reality-Based Visualization Interfaces for Architecture, Engineering, and Construction Industry', *Journal of Construction Engineering and Management*, 131: 1301-09.

Fuge, Mark, Mehmet Ersin Yumer, Gunay Orbay, and Levent Burak Kara. 2012. 'Conceptual design and modification of freeform surfaces using dual shape representations in augmented reality environments', *Computer Aided Design*, 44: 1020-32.

Greenwood, David, Margaret Horne, Emine Mine Thompson, Carl Martin Allwood, Claes Wernemyr, and Börje Westerdahl. 2008. 'Strategic Perspectives on the Use of Virtual Reality within the Building Industries of Four Countries', *Architectural Engineering and Design Management*, 4: 85-98.

Jones, K. 2014. "Five Ways the Construction Industry will Benefit from Augmented Reality." In.: Construction Data Company.

Malkawi, Ali M., and Ravi S. Srinivasan. 2005. 'A new paradigm for Human-Building Interaction: the use of CFD and Augmented Reality', *Automation in Construction*, 14: 71-84.

Meža, Sebastjan, Žiga Turk, and Matevž Dolenc. 2014. 'Component based engineering of a mobile BIM-based augmented reality system', *Automation in Construction*, 42: 1-12.

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

Park, Hanhoon, and Jong-Il Park. 2010. 'Invisible Marker–Based Augmented Reality', *International Journal of Human-Computer Interaction*, 26: 829-48.

Raajana, N. R., S. Suganya, R. Hemanand, S. Janani, Sarada Nandini N.S, and Sruthi V. Ramanan. 2012. 'Augmented Reality for 3D Construction', *Procedia Engineering*, 38: 66-72.

Schnabel, Marc Aurel. 2009. 'Framing mixed realities.' in Xiangyu Wang and Marc Aurel Schnabel (eds.), *Mixed reality in architecture design and construction* (Springer: London).

Shin, Do Hyoung, and Phillip S. Dunston. 2008. 'Identification of application areas for Augmented Reality in industrial construction based on technology suitability', *Automation in Construction*, 17: 882-94.

Wang, Xiangyu, Mi Jeong Kim, Peter E. D. Love, and Shih-Chung Kang. 2013. 'Augmented Reality in built environment: Classification and implications for future research', *Automation in Construction*, 32: 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: 119-40.