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# Extended Reality Approach for Construction Quality Control

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## Abstract

Inspection is one of the most important factors in quality management. Neglecting inspection process may cause construction errors, quality degradation, and unnecessary expenses. Quality management is performed by the site manager to ensure construction work specifications are implemented according to the design. The conventional method of construction site inspection required site manager to record information about the defect in documents manually (e.g., checklist, drawings) and then re-entered this information into the company server. Furthermore, this process depends mainly on the inspector's skill which may be inefficient and time-consuming. This study aims to leverage the quality control and site inspection process with the overall objective of reducing major error and extra costs using BIM-based extended reality.

The recent advancement of extended reality technology has shown the potential of being the future visualization tool of the AEC/FM industry. The visualization capability of this technology to retrieve virtual models and other related built environment data in a real-world environment and overlaid the existing building structure can enhance the quality of inspection. However, there are many challenges associated with the implementing of extended reality technology and its efficiency in a real workplace. In this paper, the implementation and the feasibility of BIM-based XR technology for quality control inspection have been investigated and discussed based on an experiment on a real construction site.

**Keywords:** Augmented reality, BIM, Quality control, Inspection, Built environment

# 1. Introduction

In the construction field, quality control (QC) inspection is taking place after specific work packages are completed to ensure the construction work is following design specifications. In most cases, the site manager is responsible for audit and record information about the defect in construction manually based on a checklist and drawings and then generate a reported with all issues that need to be discussed among project stockholders. This process depends on the inspector's skill of extracting the necessary information from design and compare it with the as-built which might be inefficient and time-consuming. Recently there are many efforts in the BE to improve this process especially with the latest advancement in digitalization.

In the last decade, the built environment (BE) witnessed a significant improvement in digitalization, converting building information into a digital format (Chu et al., 2018), building information modeling (BIM) has started to become the official form of the BE. The use of BIM has allowed project parties to obtain project information and relevant data all integrated into three-dimensional (3D) digital form. The benefits brought by BIM have been reported in several areas and different stages of a project life cycle (Zhao, 2017). However, the execution of BIM to support construction site activities is associated with many difficulties such as how to bring BIM outside the office environment.

Obviously, BIM is not just a 3D model technology, but it is also advanced project documentation, it includes information like geo-location, spatial data, and construction schedule, yet, the implementation of BIM for on-site operation still depends on printed drawings or portable devices with BIM viewer. This approach has several limitations, 1) The user of BIM viewer needs to do manual operations to reach the required information, such as navigation, cross-section, hiding components; 2) difficulty to show the model based on user location on-site; 3) Moreover, the construction crew still prefers the conventional method, 2D projection drawings, to extract design situation and draw them directly on the workspace. Thus, any misinterpretation to the design information might lead to construction error which is costly in time and resources. Accordingly, the level of interaction between BIM and construction environment is extremely week, which might hinder the grasp of project information and limits the integration of BIM for on-site job task (Wang et al., 2014).

The recent advancement of extended reality (XR) technologies has been explored by many applications in the BE, such as virtual reality (VR) for design review (Maftei and Harty, 2015), training (Bosché et al., 2016), augmented reality for construction assembly (Wang et al., 2014), and so on. Augmented reality (AR) is an enhanced version of reality where the user is able to visualize and interact with virtual contents in the real environment (Wang et al., 2016). Although AR technology appears to be a promising medium to improve communication and integration of construction crew with BIM, the usability and effectiveness of this technology have not been proved (Wang et al., 2013). Additionally, the number of studies investigate proof of the benefits of AR to enhance construction tasks are limited (Meža et al., 2014). Since BIM and AR are complementary technologies (Wang et al., 2013), the available research in the BE domain demonstrates numerous frameworks of integration using many technologies in hardware and software, most of them examined BIM-AR integration from a technical perspective only. Hence, there is a need for sufficient insight into how that might work on a real job site.

AR studies in construction domain focused on the system development process rather than validate the application approach on the hand of end users (Wang et al., 2013). Nowadays, many AR systems are available, AR headset like a Magic leap, Hololens and Meta 2, BIM AR plugins like Trimble Connect and VisualLive. The application development is different for each device, but the concept is still the same. Therefore, this study decided to investigate the feasibility and practicality of AR technology as a concept for QC inspection. It has to mention this study is aware of the level of maturity of the current AR devices and the developing tool as this can affect the overall AR experience and lead to false validation results.

To this end, the current study has utilized the conventional role of AR technologies to visualize design data that feed into the AR headset and give the inspector easy access to specific type of information that can enhance his or her reality to do the required task. BIM has been used as a primary source of delivering the necessary information for the inspector, such as geometries, dimensions, and component properties. There are several technical challenges associated with the integration of BIM and AR technology have investigated like the complexity of the model, data format, the processing capability of AR devices. Nevertheless, this study aims to demonstrate on a job-site a smooth and sufficient AR experience that can enable the site manager to retrieve design information on the construction environment.

# 2. XR Applications in Construction

Extended reality is a term used to describe the whole spectrum of simulated reality technologies, starting from the real environment to completely virtual see *Figure 26*. XR applications first introduced to the public in the 90s, however, it wasn't mature enough for adoption (Steinicke, 2016). In recent years, XR technologies have started to span many fields such as education (Freina and Ott, 2015), healthcare (Huang et al., 2018, Kim et al., 2017b), cultural heritage (Bekele et al., 2018), military (Page, 2000, Delaney, 2014), in fact, any domain relies on digital graphics can benefits from the visualization capability of this technology (Linowes, 2015). Today, the BE has a significant improvement in the digitalization, the benefits of BIM become clearer (Drettakis et al., 2007). Cloud computing capabilities have leveraged communication and information exchange among stakeholders. Portable smart technologies provide easy access to up-to-date building information (e.g., plans, schedules, budgets) anytime anywhere. Although there are many positive aspects of digitalization, a huge concern raised about its impact on workers productivity (Agarwala, 2014), as they might be exposed to a significant amount of data that required more time to manipulate or managing the data. Consequently, they will confront the complexity of the system, rather than gain its potential benefits (Aral et al., 2012, Chu et al., 2018).

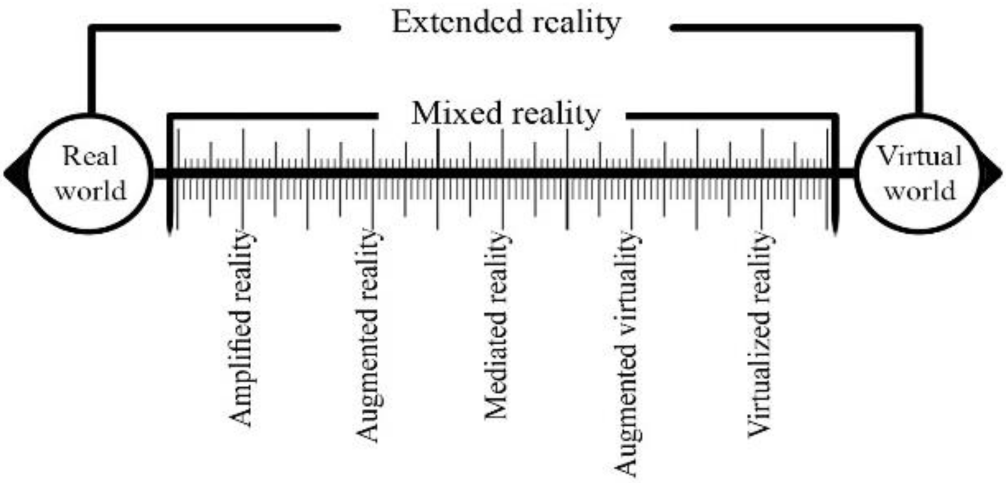


*Figure 26: extended reality (XR) spectrum*

A growing number of studies has started exploring the visualization capability of AR technology, as it has appeared to be a promising medium to improve several activities in the construction domain (Li et al., 2018, Jennifer Whyte, 2018). In the last five years, the research community in the construction domain has presented several studies exploring AR applications to support fieldwork, handheld devices (i.e., smartphones, tablets) has been used widely in their studies. For the purpose of construction monitoring, the integration of BIM and AR has been investigated by (Meža et al., 2014) to enable the project manager to follow up with the planned schedules, while (Zaher et al., 2018) integrate 5D BIM and AR to update cost information. Some researcher developed a solution to retrieve data from BIM to reduce the cognitive load of workers (Wang et al., 2014, Chu et al., 2018), they find out that AR can lower workers misinterpretation of drawings and improve their productivity. AR has also been used as a hazard avoidance system to promote health and safety on construction site (Kim et al., 2017a).

Although these studies urge the benefit of BIM and AR, workers still tend to use 2D drawings and checklist to do a job-task. AR applicability and usability in the construction domain is limited due to the functionality of the available tools and its capabilities to transfer information to workers on their exclusive platforms (Wang et al., 2016, Wang et al., 2013, Chu et al., 2018).

## 2.1 Augmented reality for inspection

Researchers in the BE have shown the potential benefits of AR technology. Inspection is one of the areas that has received attention in recent years. The traditional method of site inspection is a manual based process (e.g., checklist, drawings) where the site manager is in charge of record any deviation between as-built and as designed information. The information needs to be stored in the project database for further action. This process is inefficient, time-consuming and depends on inspector skills and experience to identify the defects (Hernández et al., 2018, Kwon et al., 2014).

A previous study on reinforcing concrete was aimed to improve the manual-based defect system by integrating mobile AR technology, BIM, and image-matching. They proposed a process comprises of two defect system. First, an image-matching system to enable off-site quality inspection. Second, a mobile AR application to give worker or site manager to detect dimension errors and omissions on the job site automatically. An experiment to evaluate the proposed system has proved the effectiveness of the system and can be extended to other applications (Kwon et al., 2014). In tunneling construction (Zhou et al., 2017) investigate the usability of AR technology to detect segment displacement through augmenting quality inspector ability to retrieve QC digital model into the workspace. The main challenge was the accuracy of the tracking approach. The registration of three coordinates, the coordination of inspector AR camera, virtual model coordination and global coordination. A marker-based method has been used in this implementation to overlay the QC digital mode onto the physical environment using mobile AR wearable device. The evaluation experiment has compared the conventional measurement method with the proposed system, which has shown a significant improvement in time over the conventional inspection practice.

Daniel Atherinis et al. (Atherinis et al., 2018) present a system with the purpose of automating falsework inspection. This system utilized radio frequency identification (RFID) and a digital model over a web viewer using mobile devices. The study has concentrated mostly on the efficiency of the RFID component for member identification. The digital model was expected to enable more accurate positional identification of members within the entire falsework configuration. In the laboratory test of RFID technology was faster than the current inspection method, however, for the component positioning test, using the viewer to assess the structure was found to be a more tedious process than checking physical drawings. It was less efficient than the currently practiced method.

Many researchers have found that one of the key challenges of developing an inspection application is the implementation of the appropriate interoperability standards for data exchange in which multiple formats combined in a common standard. The current tools and equipment deployed on-site do not speak the same language (Hernández et al., 2018). Therefore, the intuitive of self-inspection techniques using AR for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components (INSITER)(2018) proposed a framework for self-instruction and self-inspection by utilise industry foundation classes (IFC) as a common standard to integrate several technologies such as BIM model viewer, QR reader and generator, dashboard for monitoring and VR/AR features. Under this approach, different data and information can be merged (Hernández et al., 2018). The main goal of INSITER project was to minimize the energy-performance gap between as-designed and as-built.

# 3. Research Approach

This study is based on an on-site experiment to develop an understanding of the usability of AR technology for QC on the construction site and its potential impact on user performance. Participants in this study are a diverse group of construction professional from a company based in West Yorkshire, United Kingdom. The experiment was conducted on a construction site of five-storey, 7,500 square meter university building in Huddersfield. This project is BIM-based where all design packages are combined, architecture, structure, and MEP to check for clashes and issues that could affect the construction programme and costs. Participants in this study selected based on their availability in the allocated day. In addition to studying the feasibility of AR application through observing participants' behavior, participants were asked to provide feedback on their overall experience. The following section discusses in detail each step of the research approach.

## 3.1 Selection of case study

The objective of this study is to improve QC inspection on construction site. The case study was selected based on the current stage of construction progress during the time of the experiment. Thus, the decision was made to check the as-built MEP work and compare it with the as-designed. Since the building is under construction, the chosen spaces for the experiment were restrained to accessibility and health and safety issue. The experiment was carried out in two spaces. The first space is the High Voltage (HV) switch Room 37 $m^2$, the room was empty, all surfaces are in finish levels such as wall and ceiling, and switchgear was not installed yet see Figure 27. The second space is 261 $m^2$ open studio, the HVAC system was already installed, finishing work such as drywall and flooring was on progress see *Figure 28.*

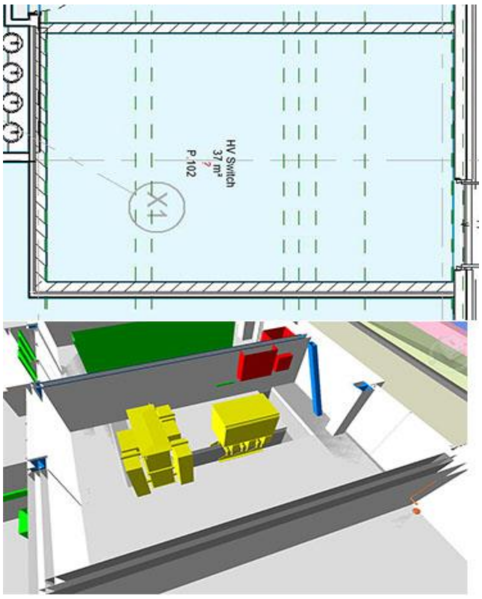


*Figure 27: The HV switch Room*

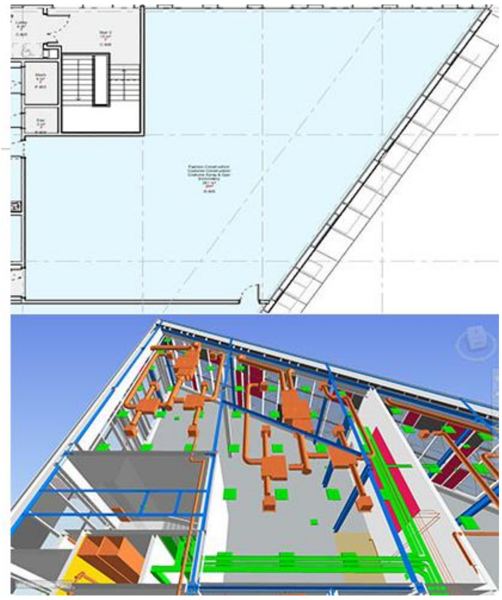

*Figure 28: The open studio*

## 3.2 Development of BIM AR application

In order to study the impact of AR in the QC inspection process, the development of BIM and AR system is established. A number of different AR devices could have been used theoretically in this experiment such as Daqri and Meta 2. However, the researchers selected Microsoft HoloLens. The HoloLens is a standalone head-mounted display (HMD) with a capability of presenting digital contents over a see-through screen into a physical environment. This headset provides a hands-free operation without the need of physical connection to a computer, which is extremely important to the nature of construction site and the experiment, as it gives the participant a freely move in the space.

To develop BIM and AR solution to examine the MEP system on construction site, all related work packages (e.g., architectural, mechanical, electrical) need to be integrated into one unified BIM platform like Autodesk Navisworks before being exported to Unity game engine. Despite the variety of methods presented in the previous study (Al-Adhami et al., 2018), forge toolkit has been used in the development of this application. This approach can eliminate the complexity of previous interoperability issues. None of the BIM contents was changed during this process, see *Figure 29* workflow of the development.

Once the BIM model imported to unity, build settings were set to be applicable with HoloLens. Then the scale of the model was verified in the lab to make sure it works at 1:1 scale. The tracing approach of AR application is one of the key challenges. Previous studies claimed that a market-based approach could provide high quality and accurate tracking (Wang et al., 2013, Wang et al., 2014, Zhou et al., 2017). Accordingly, this approach has been adopted after it has proved its effectiveness in the early testing of the application. One of the characteristic features of most AR devices is interacting using a hand gesture, this approach of human-machine interaction (HMI) requires from users to familiarize themselves with the system. Thus, voice commands were included in the application to streamline control of BIM packages for non-expert users.

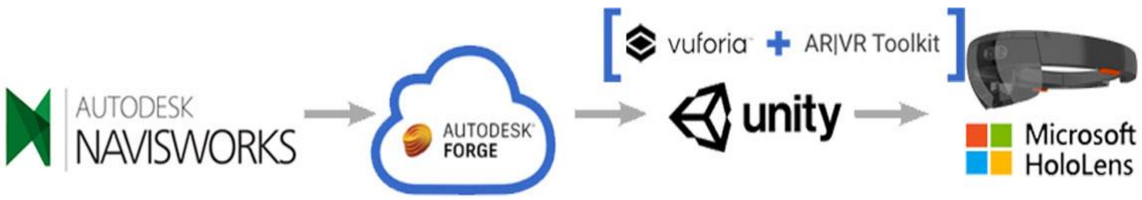


*Figure 29: BIM AR Application workflow*

## 3.3 On-site Implementation

The implementation of the system on site comprises three steps. 1) The tracking system of the developed AR application is marker-based, so it requires to set a physical marker on job site to match exactly the one in the digital version; 2) run the application and read the marker using the camera on the HMD (Hololens), this step can determine the coordination of the user in the virtual environment. Therefore, it is essential to set the marker in the first step correctly; 3) once the Hololens recognize the marker, the application began to retrieve BIM data on the job site at 1:1 scale and overlaying the existing structure. Starting from here, the QC inspector can audit the construction work and compare it with the designed model without the need for switching from a physical environment to drawings and vice versa. BIM components and its properties are already stored in the system, the user can pick any component available in the displayed scene using gaze and tap with finger down to retrieve the component properties see *Figure 30*. It is worth to mention that due to construction health and safety (H&S) regulations a Hololens hard hat was used. Although the Hololens hard hat is part of Personal Protective Equipment (PPE), it also distributes the weight of the device and provides a comfortable experience.

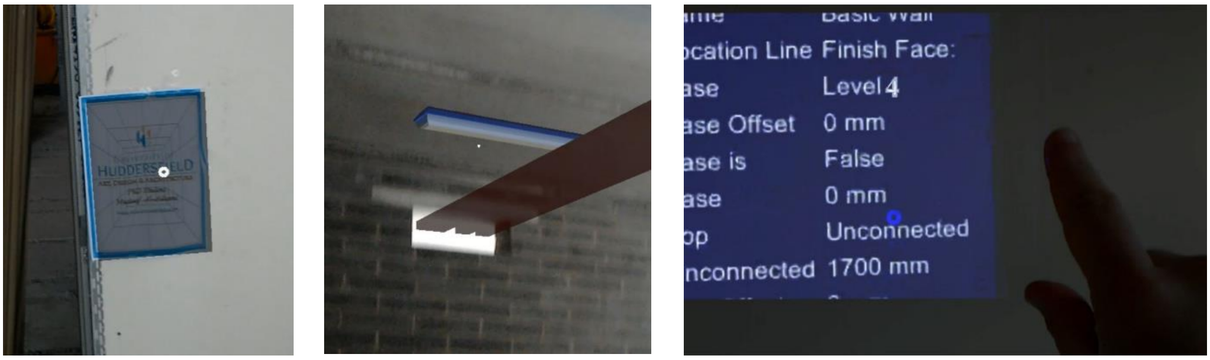


*Figure 30: AR implementation*

The aim of this study to validate the feasibility of the proposed AR application on the hand of construction professionals. This is to ensure whether the visualization capability of the current AR devices are mature and can be considered in today's construction framework.

# 4. Results and discussion

This work demonstrate the utilization of AR application on a job site as part of QC inspection. The results from onsite experiment evaluated based on participants satisfaction, job environment and practicality issues. In this study nine construction professionals participated including BIM manager, design manager, architects, and MEP technicians. In general, they had little or no experience with the AR applications or AR headset. Participants were asked to use the Hololens and run the BIM AR application in the selected spaces, HV switch Room and open studio, to retrieve the MEP model on-site. All participants were able to achieve the task, the AR experience was straightforward and the alignment of the virtual model in the physical space was accurate. However, conducting this experiment on a construction site faced several challenges.

The virtual overlapping on-site is an essential factor of this type of AR applications, it requires to bring BIM geometrical data in real-world scale and fit precisely over the existing structure. This experiment used image-marker technique to achieve this virtual overlapping. The marker needs to be placed in a suitable location in both real and virtual environment that shared the same coordinate. In the HV switch room, the physical image-marker was placed on a finish surface level; this has delivered a precise alignment of holographic data on the job site. While in the second space "open studio," it was hard to find a base point to incorporate both environments "virtual and physical" on the existing structure, as all surfaces were not on finish level and the installed partitions were not reliable. Some participants faced difficulty reading the physical marker, especially in HV switch room as the lighting condition was poor during the time of the experiment and that affected the ability of the hololens to recognize the image-marker. Moreover, the nature of the construction site requires different personnel and activities to interfere which might damage the marker or need to be relocated and that can add more time to the inspection process. Consequently, the marker-based tracking approach is not a practical solution for this type of application.

The narrow field of view (FOV) of the AR headset was one of the main challenges that had an impact on participants' satisfaction. This issue has been recorded during the experiment as participants felt uncomfortable visualizing the model in the HV switch room as they needed to move around to get a clear view. Whereas, in the open studio, participants did not complain of this issue as the task was visualizing the HVAC system in the ceiling which is around 4 meters in height. The HMI using hand gesture was frustrating at the beginning of the experiment as the participants were not familiar with this type of interaction. It has been noticed some of the participants started to switch hands after spending a few minutes of gazing and taping. The added voice command function was useful as it gave easy access to design information, hide/show building elements or retrieve specific data, yet, in high noise spaces, the response was significantly weak.

## 4.1 Limitations

The experiment has several limitations that can be described as follows: First, none of the participants was from the QC team, and they have no experience in the QC process. As a result, the evaluation can be considered as on hand user experience. Second, despite the experiment took place on a job site, the work environment had been set, cleaned and prepared by the construction company before the experiment started for H&S concerned. Theoretically, the impact would be different as more laborers will be on-site. Furthermore, augmented virtual objects might disconnect the user from reality which can cause H&S issue. Third, the currently available AR devices are suffering from many technical limitations that affect the overall AR experience such as HMI, FOV, HMD weight, and battery life. Moreover, its processing capacity is not adequate to handle heavy geometrical data, this adds more effort and time to the application development process to deliver an acceptable BIM-based AR experience. Thus, it's not practical for everyday on-site activity.

# 5. Conclusion

Using a checklist and drawings in the inspection process requires switchover between physical and mental process. Hence, the inspector might make some mistakes or omit some content.(Zaeh and Wiesbeck, 2008, Zaeh et al., 2009, Towne, 1985). In this study, an AR system was developed to provide QC inspector an easy access to as-design information, geometrical and textual, on construction site. The developed system used to audit and check the installed MEP works on-site and compare it with the design specification. The application has worked as on-site physical-virtual clash detection based on human observation as this is not an automated process. The developed system has the following features, 1) user can interact with BIM in immersive interactive virtual environment on construction site, 2) virtual overplaying 1:1 scale using image-marker technique, 3) HMI using hand gesture and voice command.

Several limitations and barriers have been explained in accordance with the available AR technology, construction environment, and user perception. The validation method of this study was based on an on-site experiment where construction professionals take part. The developed AR system was used to visualize the HVAC system and switchgear of five-story under construction building. During the analysis on the construction site, the potential benefit of AR has proven, the feedback from the participants have also supported this argument. However, industry professionals have proposed to use it in the office environment for design review or public engagement. Finally, they concluded that the technology not mature, it has several technical limitations and very expensive for daily use on the construction site but they recommended keeping an eye on it latest development as it can bring a great benefit to the construction industry. Although the challenges of the development of the system were not the main concern of this study, future work would be directed toward facing those challenges and quantify the evaluation method.

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