APPLICATION AREAS OF AUGMENTED REALITY AND VIRTUAL REALITY IN CONSTRUCTION PROJECT MANAGEMENT: A SCOPING REVIEW

Mahmoud Mohammed ALBAHBAH

Master's Thesis

Department of CIVIL ENGINEERING

Programme in CONSTRUCTION MANAGEMENT

Supervisor: Assoc. Prof. Dr. Serkan KIVRAK

Eskişehir

Anadolu University

Institute of Graduate Programs

August 2021

ABSTRACT

APPLICATION AREAS OF AUGMENTED REALITY AND VIRTUAL REALITY IN CONSTRUCTION PROJECT MANAGEMENT: A SCOPING REVIEW

Mahmoud Mohammed ALBAHBAH

Department of CIVIL ENGINEERING
Program in CONSTRUCTION MANAGEMENT
Anadolu University, Institute of Graduate Programs, August 2021

Supervisor: Assoc. Prof. Dr. Serkan KIVRAK

The construction industry is increasingly moving towards embracing more and more computer-based technologies to provide better performance in various construction projects, and visualization is one of the main application areas. Augmented reality (AR) and Virtual reality (VR) technologies are some of the advanced computer technologies that can provide significant advantages through visualization to the construction industry. In recent years, many researchers have focused on implementing AR and VR technologies in the Construction Project Management (CPM) domain, where these technologies have shown promising futures to advance the CPM domain and have shown a significant contribution to the advancement of the CPM aspects in many areas. Therefore, a structured review on AR and VR applications in the CPM domain is needed to invert the present status of these technologies implementation in the CPM domain.

This study tried to fill this gap by conducting a comprehensive scoping review on the application areas of AR and VR technologies in the CPM domain. Ninety-four studies retrieved from peer-review journals and conference proceedings were included, reviewed, and analyzed. The studies were classified according to publication date, publication venue, study design, and geographical location. Three main components of AR, including the display method, interaction device, and spatial registration method, were identified and discussed. Three main components of VR, including display method, interaction device, and level of immersion, were identified and discussed. The application areas of each technology were thematically analyzed and classified under main topics.

Keywords: Augmented reality, Virtual reality, Construction project management, Construction management, Construction industry, Scoping review.

ÖZET

İNŞAAT PROJE YÖNETİMİNDE ARTIRILMIŞ GERÇEKLİK VE SANAL GERÇEKLİK UYGULAMA ALANLARI: KAPSAM İNCELEMESİ

Mahmoud Mohammed ALBAHBAH

İnşaat Mühendisliği Anabilim Dalı

Yapı Yönetimi Bilim Dalı
Anadolu Üniversitesi, Lisansüstü Eğitim Enstitüsü, Ağustos 2021

Danışman: Doç. Dr. Serkan KIVRAK

İnşaat endüstrisi, çeşitli inşaat projelerinde daha iyi performans sağlamak için giderek daha fazla bilgisayar tabanlı teknolojiyi benimsemeye doğru ilerlemektedir, ve görselleştirme ana uygulama alanlarından birisidir. Artırılmış Gerçeklik (AG) ve Sanal Gerçeklik (SG) teknolojileri, inşaat endüstrisinde görselleştirme yoluyla önemli avantajlar sağlayan gelişmiş bilgisayar teknolojilerinden bazılarıdır. Son yıllarda birçok araştırmacı, İnşaat Proje Yönetimi (IPY) alanında AG ve SG teknolojilerini uygulamaya odaklanmıştır. Bu teknolojilerin IPY alanının gelişimine umut vadettiği ve IPY alanının gelişiminin birçok alanda ilerlemesine önemli katkılar sağladığı görülmektedir. Bu nedenle, IPY alanında bu teknolojilerin uygulanmasının mevcut durumunu irdelemek amacıyla IPY alanındaki SG ve AG uygulamalarında yapılandırılmış bir incelemeye ihtiyaç duyulmaktadır.

Bu çalışma, AG ve SG teknolojilerinin IPY alanındaki uygulama alanlarıyla ilgili kapsamlı bir kapsam incelemesi yaparak literatürdeki boşluğu doldurmaya çalışmıştır. Bu çalışmada hakemli dergilerden ve konferans bildirilerinden alınan doksan dört çalışma analiz edilmiştir. Bu çalışmalar; yayın tarihi, yayın yeri, çalışma tasarımı ve coğrafi konumlarına göre sınıflandırılmıştır. AG'nin görüntüleme yöntemi, etkileşim cihazı ve mekansal kayıt yöntemi dahil olmak üzere üç ana bileşeni tanımlanmış ve analiz edilmiştir. Ayrıca, görüntüleme yöntemi, etkileşim cihazı ve daldırma seviyesi dahil olmak üzere SG'nin üç ana bileşeni tanımlanmış ve analiz edilmiştir. Bununla birlikte her bir teknolojinin uygulama alanları tematik olarak analiz edilmiş ve ana başlıklar altında sınıflandırılmıştır.

Anahtar Kelimeler: Artırılmış gerçeklik, Sanal gerçeklik, İnşaat proje yönetimi, İnşaat yönetimi, Yapı sektörü, Kapsam incelemesi.

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my supervisor, Assoc. Prof. Dr. Serkan KIVRAK, for his guidance and advice that carried me through research duration. I would also like to thank the committee members for letting my defence be an enjoyable moment and for your brilliant comments and suggestions.

Finally, I would like to extend my sincere thanks to my parents and my friends. Without your continued support and encouragement, this achievement would not have been possible. Thank you.

Mahmoud Mohammed ALBAHBAH

26/08/2021

STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES AND RULES

I hereby truthfully declare that this thesis is an original work prepared by me; that I have behaved in accordance with the scientific, ethical principles and rules throughout the stage of preparation, data collection, analysis, and presentation of my work; that I have cited the sources of all the data and information that could be obtained within the scope of this study, and included these sources in the references section; and that this study has been scanned for plagiarism with "scientific plagiarism detection program" used by Anadolu University, and that "it does not have any plagiarism" whatsoever. I also declare that if a case contrary to my declaration is detected in my work at any time, I hereby express my consent to all the ethical and legal consequences that are involved.

Mahmoud Mohammed ALBAHBAH

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AR	: Augmented Reality
VR	: Virtual Reality
HMD	: Head-mounted Display
AEC	: Architecture, Engineering, and Construction
AEC/FM	: Architecture, Engineering, Construction, and Facility Management
MR	: Mixed Reality
CEET	: Construction Engineering Education and Training
CPM	: Construction Project Management
AV	: Augmented Virtuality
KARMA	: Knowledge-based Augmented Reality for Maintenance
MARS	: Mobile Augmented Reality System
SPA	: Spatial Augmented Reality
IWAR	: International Workshop on Augmented Reality
ISMAR	: International Symposium on Mixed Reality
ISMAR	: International Symposium on Mixed Reality and Augmented Reality
MARTA	: Mobile Augmented Reality Assistance
BIM	: Building Information Modelling
OST	: Optical See-Through
VST	: Video See-Through
FOV	: Field of View
HUD	: Head-up Displays

D4AR	: 4-Dimensional Augmented Reality
RB-2	: Reality Built for 2
CAVE	: Cave Automatic Virtual Environment
IVR	: Immersive Virtual Reality
Non-IVR	: Non-Immersive Virtual Reality
WoW	: Window on World
BOOM	: Binocular Omni-Orientation Monitor
MVSTS	: Multiuser Virtual Safety Training System
JBI	: Joanna Briggs Institute
CIB W78	: International Council for Research and Innovation in Building and Construction
SMVS	: Safety Management and Visualization System
VSAS	: Virtual Safety Assessment System
VIFITS	: Virtual Field Trip System
CoVR	: Collaborative Virtual Reality

1 INTRODUCTION

1.1 Background

The history of Augmented reality (AR) and Virtual reality (VR) technologies development can be traced back to the 1960s, where the first 3D optical see-through Head-mounted Display (HMD) was presented by Ivan Sutherland (Cheng, Chen, & Chen, 2020a). Confusion exists between VR and AR, which is a long-running issue (Piroozfar, Essa, & Farr, 2017b). Both technologies have a similar approach and shares some underlying technologies, yet they display distinctly diverse experiences (Peddie, 2017). VR differs from AR in a way that in VR, the real elements are removed, and the user is immersed in a virtual environment with virtual objects (Piroozfar et al., 2017b), while AR provides the user additional visual information overlaid on the real world (Peddie, 2017). Furht (2011) defined AR as a real-time view of a real-world environment that has been augmented by adding virtual digital information to it. Virtual reality refers to a computer simulation that generates a view that appears to the user's senses in much the same way that perceives the real world (Craig, Sherman, & Will, 2009).

AR and VR technologies are becoming more variable and implemented in many industries and practical programs such as education, design, manufacturing, entertainment, and healthcare. The construction industry is considered as one of the least digitized industries around, but it is increasingly moving towards embracing more and more computer-based technologies to provide better performance in various stages of construction projects, and visualization is one of the main application areas (Shin & Dunston, 2008). AR and VR technologies are advanced computer-based technologies that can provide significant advantages through visualization to the construction industry. The increased need of the construction industry for visualization technologies such as AR and VR arises from the complex nature of the industry and its high demand for information access for assessment, communication and collaboration (Rankohi & Waugh, 2013).

1.2 Problem Statement

Many researchers have drawn attention to the benefits and implementations of AR and VR technologies in the Architecture, Engineering, and Construction (AEC) industry in recent decades. Although the effective use of AR and VR in the construction industry is not easy, various areas in the construction sector have shown a successful implementation of these technologies as desired (Ahmed, 2018). Delgado, Oyedele, Beach, and Demian (2020) conducted a detailed analysis of the factors driving and constraining the adoption of AR and VR in the construction industry. In addition, (Noghabaei, Heydarian, Balali, & Han, 2020) investigated the adoption trends of AR and VR technologies in the AEC industry. Cheng et al. (2020a) conducted a state-of-the-Art review on Mixed reality (MR) applications in the AEC industry; they identified the application areas and classified them into four main categories. In terms of construction safety (Li, Yi, Chi, Wang, & Chan, 2018) conducted a critical review on the applications of AR and VR in construction safety from various aspects, including technology characteristics, application domains, safety enhancement mechanisms, and safety assessment and evaluation. Wang, Kim, Love, and Kang (2013b) demonstrated a literature framework classification for the AR research in the built environment. Wang, Wu, Wang, Chi, and Wang (2018) conducted a critical review of VR implementations in Construction Engineering Education and Training (CEET) and identified the technologies, applications and future research directions. Rankohi and Waugh (2013) illustrated a statistical review of the AR in the construction industry with a time frame of fourteen years (1999-2012). Regarding the Construction Project Management (CPM) domain, (Ahmed, 2018) conducted a study on the potential opportunities of utilizing AR and VR in CPM.

In recent years, many researchers have focused on the implementation of AR and VR technologies in CPM where these technologies have shown a great contribution to the advancement of this sector in many areas such as cost and time management, defect management, safety management, education and training, progress monitoring and tracking, and information collection. Therefore, a comprehensive review of AR and VR applications in the CPM domain is needed to invert the present status of these technologies implementation in the CPM domain.

1.3 Research Aim

This study aims to provide a comprehensive, structured review on the application areas of AR and VR in the field of CPM, which would provide a solid platform for the researchers and construction practitioners to explore the potential application areas, understand the effective use of these technologies, and explore new use cases.

1.4 Research Objectives

The principal objective of this study is to systematically map the development and trends of AR and VR in the CPM sector through exploring the size, range, and nature of the existing literature about the AR and VR applications in the CPM and identifying the critical application areas of these technologies in the CPM domain.

1.5 Thesis Structure

The thesis is structured into seven chapters: Chapter 1 presents a background, problem statement, and study's aim and adjectives. Chapter 2 presents definitions, a brief history, and general information about AR systems; furthermore, a review of literature about AR in the construction industry. Chapter 3 presents definitions, a brief history, and general information about VR systems; furthermore, it presents a review of literature about VR in the construction industry. Chapter 4 presents a narrative summary of the most known knowledge synthesis methods. Chapter 5 illustrates the methodical approach for conducting this scoping review. Chapter 6 illustrates and discusses the obtained results. Finally, Chapter 7 introduce the conclusion and recommendations.

2 AUGMENTED REALITY

AR impacts the mobile computing industry by radically shifting the interaction between humans and computers (Wang, Kim, Love, & Kang, 2013a). AR creates direct, automatic, and practicable connections between the physical world and digital information by providing a simple and immediate user interface to a digitaly enhanced physical world (Schmalstieg & Hollerer, 2016). AR provides an environment where computer-generated information such as graphics, sounds, videos, or digital information is superimposed in a real world view -in real-time and in the correct spatial position (Davila Delgado, Oyedele, Beach, & Demian, 2020; Rankohi & Waugh, 2013; Wang et al., 2013a). Van Krevelen and Poelman (2010) described AR as the technology that enables users to perceive virtual and real objects as coexisting in the same space. Furht (2011) defined AR as a real-time view of a real-world environment that has been augmented by adding virtual digital information to it. In 1994, the concept of Reality–Virtuality continuum (Figure 2.1) was defined by Paul Milgram and Fumio Kishino. Two major subsets lie within the MR range of the Reality-Virtuality continuum: AR and Augmented Virtuality (AV). MR was defined as the full range of combinations of AR and AV, AV was defined as augmenting the virtual environment with objects from the real environment, and AR referred to augmenting the real environment with virtual objects (Cheng, Chen, & Chen, 2020b; Davila Delgado et al., 2020; Dunston, 2008; Milgram & Kishino, 1994). Azuma suggested the most vastly accepted definition of AR in 1997 (Schmalstieg & Hollerer, 2016). According to Azuma (1997), AR technology can be defined as a system that has the following three characteristics:

- integrates real and virtual in the real world
- run interactively in real-time
- registered in 3D

At the outset, researchers defined AR in terms that limit the concept to certain display technologies, such as HMDs, or to the sense of sight (Bademosi & Issa, 2018). Although Azuma definition does not require a specific output device, nor does it limit AR to visual media, the definition requires real-time control and spatial registration, which means rigorous real-time alignment of corresponding virtual and real information (Schmalstieg & Hollerer, 2016).

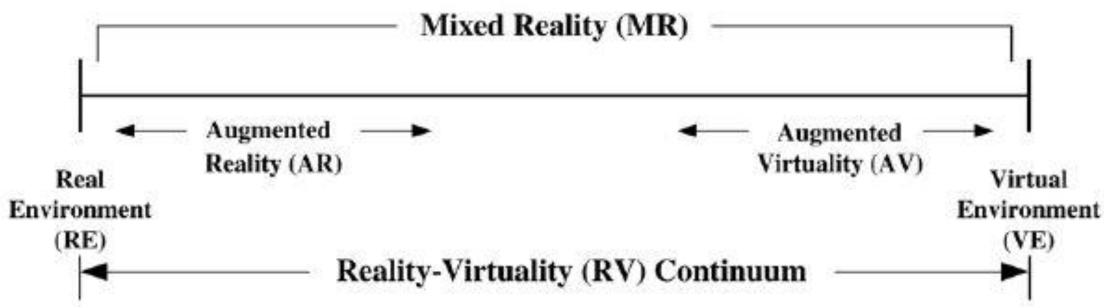

Figure 2.1. *Reality–Virtuality continuum (Milgram & Kishino, 1994)*

2.1 A Brief History and Recent Developments

Over the past four decades, research and development in the field of AR have continued (Bademosi & Issa, 2018). The outset of AR dates back to the appearance of Sutherland's work in the 1960s (Azuma et al., 2001; Bademosi & Issa, 2018; Cheng et al., 2020b; Schmalstieg & Hollerer, 2016). The beginning of the field that would eventually turn into both VR and AR can be credited to Ivan Sutherland (Schmalstieg & Hollerer, 2016). In 1968, Ivan Sutherland and his students from Harvard University and University of Utah used the first optical see-through HMD to present 3D graphics (Figure 2.2) (Azuma et al., 2001; Bademosi & Issa, 2018; Furht, 2011; Peddie, 2017; Schmalstieg & Hollerer, 2016). The used display included head tracking and used see-through optics, and due to its weight, it had to be pended from the roof (Schmalstieg & Hollerer, 2016).

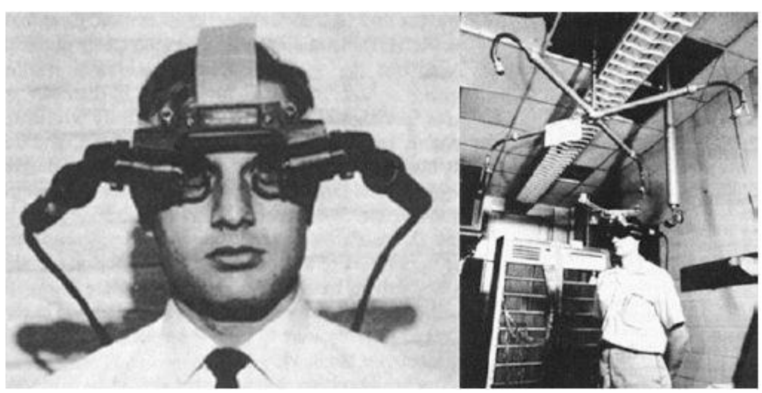

Figure 2.2. *The world's first head-mounted display (Schmalstieg & Hollerer, 2016)*

Throughout the 1970s and 1980s, AR was a research topic at some research centres and institutions (Bademosi & Issa, 2018; Peddie, 2017). In 1992 the term "Augmented

Reality" was coined, where the birth of this term is attributed to Thomas P. Caudell, and David Mizell, former scientists at Boeing Corporation (Bademosi & Issa, 2018; Peddie, 2017; Schmalstieg & Hollerer, 2016; Thomas & David, 1992). Thomas and David (1992) sought to develop an experimental AR system aimed to assist workers in an aeroplane factory by displaying wire bundle assembly schematics in a see-through HMD (Figure 2.3) (Bademosi & Issa, 2018; Peddie, 2017; Schmalstieg & Hollerer, 2016).

Figure 2.3. *A see-through HMD to guide the assembly of wire bundles for aircraft (Schmalstieg & Hollerer, 2016)*

Knowledge-based Augmented Reality for Maintenance Assistance (KARMA) presents the first major scientific paper on an AR system prototype that was published in 1993 (Bademosi & Issa, 2018; Cheng et al., 2020b; Furht, 2011; Peddie, 2017; Schmalstieg & Hollerer, 2016). The KARMA system automatically indicates suitable instruction sequences for repair and maintenance procedures (Figure 2.4) (Schmalstieg & Hollerer, 2016). In the same year, the first operational AR system called Virtual Fixtures was developed (Bademosi & Issa, 2018; Furht, 2011).

(a) (b)

Figure 2.4. *(a) KARMA was the first knowledge-driven AR application. (b) user with an HMD could see instructions on printer maintenance (Schmalstieg & Hollerer, 2016)*

The Touring Machine was the first Mobile AR System (MARS) developed in 1997 at Columbia University (Figure 2.5) (Bademosi & Issa, 2018; Peddie, 2017; Schmalstieg & Hollerer, 2016). The Touring Machine was rendered as a 3D visual tour guide and provided information about buildings already seen by the visitor (Bademosi & Issa, 2018). it uses a see-through HMD with GPS, a handheld tablet display, and a backpack with a computer (Peddie, 2017; Schmalstieg & Hollerer, 2016).

Figure 2.5. *The Touring Machine was the first outdoor AR system (Schmalstieg & Hollerer, 2016)*

Azuma (1997) published the first survey in AR (Azuma et al., 2001; Bademosi & Issa, 2018). The survey offers a widely accepted definition of AR, as mentioned previously (Furht, 2011). In 1998, at the University of North Carolina, the concept of Spatial Augmented Reality (SAR) was introduced, where virtual objects are rendered directly on the user's physical space in the real world (Bademosi & Issa, 2018; Peddie, 2017). In the late 1990s, with the initiates of several conferences on AR, AR became an unmistakable area of exploration. In October 1998, the First International Workshop on Augmented Reality (IWAR) was held in San Francisco, and in March 1999, The First International Symposium on Mixed Reality (ISMR) was held in Yokohama, Japan. These two conferences were merged into one conference, called the International Symposium on Mixed and Augmented Reality (ISMAR); the first edition of this conference was held at Darmstadt, Oct. 2002 (Chi, Kang, & Wang, 2013a; Yu, Jin, Luo, Lai, & Huang, 2009). No AR software was available outside expert research laboratories until 1999. Mark Billinghurst and Hirokazu Kato developed the first open-source software platform for AR called AR Tool Kit in 1999 at the University of Washington (Schmalstieg & Hollerer, 2016). The AR Toolkit has been adopted as a platform of most noted AR applications for architecture and design since its implementation is simple (Wang, 2009). Cellular phones and mobile computing started rapidly evolving after 2000 (Bademosi & Issa, 2018). The First AR system on a consumer mobile phone for tracking 3D markers was achieved in 2004 (Peddie, 2017). In recent years, developers have paid more attention to AR, and many AR systems and applications have been targeted at consumers audiences (Bademosi & Issa, 2018). Car manufacturers started using AR to substitute vehicle service manuals. In 2013, Volkswagen developed the MARTA application (Mobile Augmented Reality Assistance) that provided virtual maintenance support in stages, for example, includes detailed information that helps service technicians (Bademosi & Issa, 2018; Peddie, 2017). In 2013, wearable augmented reality started to emerge (Peddie, 2017), Google Glass with AR functions has been produced by Google. Google Glass can be linked to a user's cell phone or via Bluetooth to access the Internet. It can monitor the user's movements and react when they speak (Cheng et al., 2020b). In 2016, investment in AR firms and startups mounted to $1.5 billion (Peddie, 2017). In the same year, Microsoft entered the market and released one of the latest advancements in AR called HoloLens (Cheng et al., 2020b; Peddie, 2017). HoloLens is an AR See-through display that use computer-generated projections to overlay

Building Information Modeling (BIM) model elements over the real environment (Figure 2.6). The device enables users to interact with 3D shows projected in the real location (Hamzeh, Abou-Ibrahim, Daou, Faloughi, & Kawwa, 2019).

Figure 2.6. *Microsoft HoloLens (Hamzeh et al., 2019)*

2.2 AR Display

One of the most significant aspects of AR is the user's ability to see his or her surroundings (Peddie, 2017). The need to merge the real and virtual environments is one apparent demand that distinguishes AR displays from conventional computer-generated displays (Schmalstieg & Hollerer, 2016). There are three ways to visually present AR: (1) Video see-through, (2) Optical see-through, (3) Projective or (spatial AR) (Peddie, 2017; Schmalstieg & Hollerer, 2016; Van Krevelen & Poelman, 2010).

Optical see-through (OST) display is the fundamental way to create an AR view (Peddie, 2017) that includes the approach developed by Sutherland in the 1960s, as mentioned previously (Peddie, 2017; Schmalstieg & Hollerer, 2016). OST displays generally depend on an optical component that is partially transmissive and partially reflexive to achieve the merge of real and virtual (Figure 2.7) (Schmalstieg & Hollerer, 2016; Silva, Oliveira, & Giraldi, 2003), and leave the user's perception of the real-world unmodified (or restricted) (Peddie, 2017). Achieving the merge of the real and virtual through an optical component such as transparent mirrors and lenses make a disadvantage for the OST display technique, as it reduces brightness and contrast of both the virtual objects and the real environment, making this technique less suitable for outdoor use (Van Krevelen & Poelman, 2010).

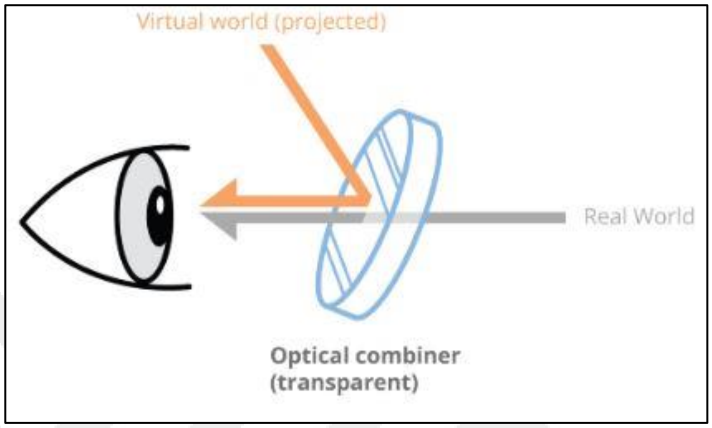

Figure 2.7. *Optical See-Through Scheme (Yadav, 2018)*

Video see-through (VST) display is more complicated than OST AR (Silva et al., 2003). VST displays achieve the merge of real and virtual electronically (Schmalstieg & Hollerer, 2016). VST display method presents the following advantages: being the cheapest and easiest to implement, easier to interpose or remove objects from reality, and brightness and disparity of virtual objects correspond easily with the real environment (Van Krevelen & Poelman, 2010). The real environment is captured as a digital video image using a video camera placed in the front face in the display device (Schmalstieg & Hollerer, 2016), and the virtual objects are superimposed or blended into the video feed (Figure 2.8) (Peddie, 2017). Disadvantages of VST include: restricting the Field of View (FoV) of the user (Peddie, 2017), a low resolution of reality, and disorientation of user due to parallax (Van Krevelen & Poelman, 2010).

With the projective display, a light-projector generates the virtual part of the AR display; thus, the virtual image is projected directly on real-world objects (Schmalstieg & Hollerer, 2016). The projective display method presents the following advantages: no need for special eyewear, provide a wide FoV, but due to the low brightness and contrast of the projected images, this type of display is limited to indoor use only (Van Krevelen & Poelman, 2010).

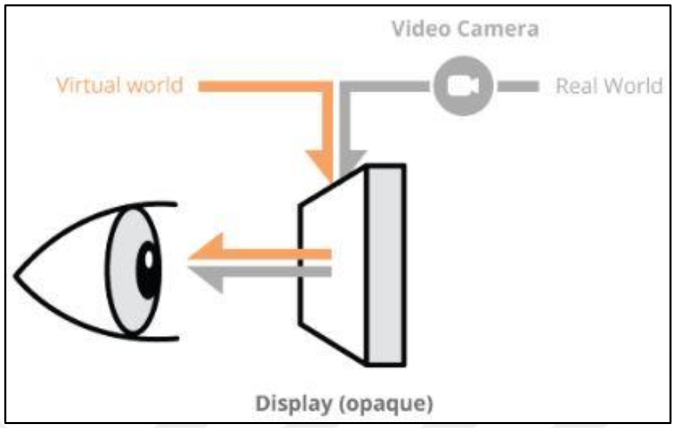

Figure 2.8. *Video See-Through Scheme (Yadav, 2018)*

Depending on their position between the spectator and the real environment, AR displays may be categorized into three groups: HMD, hand-held, and spatial (Azuma et al., 2001; Furht, 2011; Peddie, 2017; Van Krevelen & Poelman, 2010).

HMD is the most distinguished class of displays for AR (Schmalstieg & Hollerer, 2016) and the most widely used (Cheng et al., 2020b). This type of display is mounted on users' heads, which provide a display of the real and virtual environment over the user's view (Furht, 2011). Two types of HMDs exist OST and VST (Figure 2.9) (Azuma et al., 2001; Furht, 2011). Hand-held displays utilize small computing devices with a display that can be held in the user's hand (Furht, 2011).

Figure 2.9. *(a) Video see-through HMD (b) Optical see-through HMD (Yadav, 2018)*

The hand-held display category contains hand-held VST, hand-held OST displays as well as hand-held projectors. This group of displays is larger than HMDs, but due to small production costs and ease of use, it is currently the best work-around to introduce AR to a mass-market (Van Krevelen & Poelman, 2010). The AR system currently uses three distinct classes of commercially available handheld displays: smartphones, PDAs and tablet PCs (Furht, 2011). In the spatial display, required virtual objects are projected directly on the real environment objects (Azuma et al., 2001). Spatial displays detach the technology from the user and merge it into the environment (Furht, 2011). Based on the way of augmenting the environment, there are three approaches to spatial displays: screen-based VST, spatial OST, and projective displays (Furht, 2011; Van Krevelen & Poelman, 2010). Enabling the collaboration between a group of users with this type of device led to more interest in such systems in exhibitions, museums, universities, and labs (Furht, 2011). Spatial OST displays produce digital information that is aligned within the real environment (Furht, 2011). Head-up displays (HUDs) are a form of spatial OST and are becoming a standard extension for production cars to project navigational directions in the windshield (Figure 2.10) (Van Krevelen & Poelman, 2010).

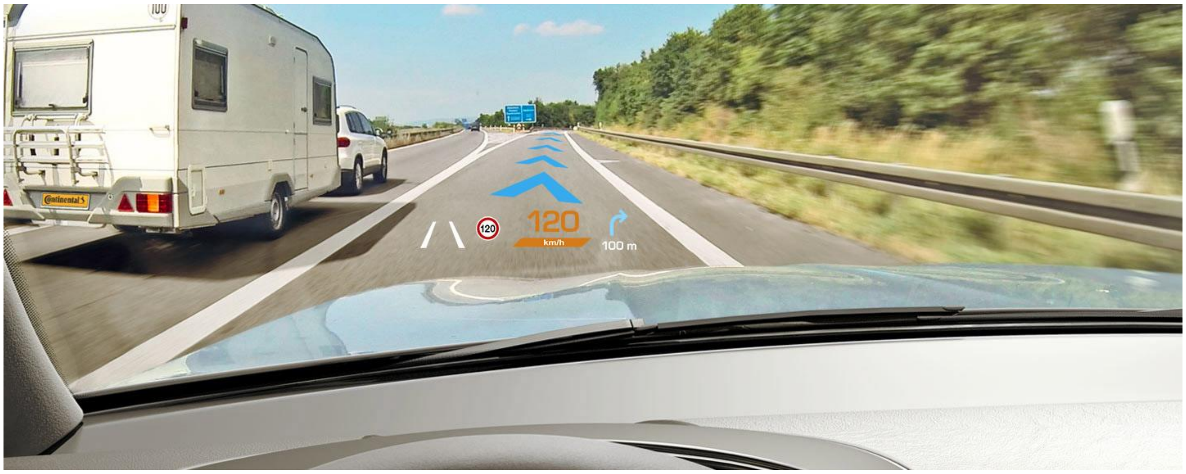

Figure 2.10. *AR head-up display (Knaflewski, 2019)*

2.3 AR in Construction Industry

AR technology is becoming more variable and implemented in many industries and practical programs such as education (Chen, Chi, Hung, & Kang, 2011; Liarokapis et al., 2004), design (Schranz, 2014; Wang & Dunston, 2008, 2011), manufacturing (Nee, Ong, Chryssolouris, & Mourtzis, 2012; Ong, Yuan, & Nee, 2008), entertainment (Zhang, Wu, Yang, & Wang, 2011), healthcare (Khor et al., 2016) and construction (Behzadan & Kamat, 2007; Schall et al., 2009; Wang, 2007; Yabuki, Miyashita, & Fukuda, 2011). The construction industry is one of the least digitized industries around. Over the years, the construction industry has developed extremely, and its future depends on the ability of construction firms to adjust their operating modes, regulations, and skill sets to flourish in the information and technology-driven world (Bademosi & Issa, 2018). AR technology found its way into the AEC industry more recently (Piroozfar et al., 2017b). AEC industry is moving to adopt more AR for improvement in different stages of construction projects (Rankohi & Waugh, 2013). The increased need of the AEC industry for visualization technologies such as AR and VR arises from the complex nature of the industry and its high demand for information access for assessment, communication and collaboration (Rankohi & Waugh, 2013). AR offers several opportunities for construction companies to properly deal with the complexities of the construction environment (Oesterreich & Teuteberg, 2017). AR applications have shown the ability to address the main issues in the field of the AEC industry, such as a lack of information for field managers, gaps between planned solutions and practical implementations, and inadequate coordination between relevant project members (Chi et al., 2013a). AR systems can be implemented in various stages throughout a construction project's lifecycle such as design review and visualization, building analysis and optimization, safety management, construction management, facility maintenance management, facility assembling, building operations (Cheng et al., 2020b), defects management, quality management, projects scheduling, and construction progress evaluation and monitoring (Piroozfar et al., 2017b). The use of AR as a stand-alone solution or in combination with other supporting technologies provide several benefits for construction industry (Bademosi & Issa, 2018), includes but not limited to:

- The essential benefit of AR is that it enables the user to receive computer-mediated contextual information that is not otherwise easily accessible (Wang & Schnabel, 2008).
- Enables all project parties to collaborate effectively throughout the construction process (Oesterreich & Teuteberg, 2017).

- Improves the health and safety of the work environment (Piroozfar et al., 2017b), for instance, by reducing the user-machine interaction (Bademosi & Issa, 2018).
- Provides a significant cost and time saving through identifying clashes at the early stages of design and construction, especially in complex projects (Ahmed, Hossain, & Hoque, 2017).

In the last decade, AEC researchers have paid a massive amount of attention to AR technology (Dunston, 2008; Wang et al., 2013a), where there have been numerous research studies on the application of AR in the field of engineering (Chi et al., 2013a). Chi et al. (2013a) proposed a research study that discusses trends and opportunities of AR in the AEC industry. Wang et al. (2013a) provided a state-of-the-art review on AR applications in the built environment with a time frame (2005-2011). Rankohi and Waugh (2013) provided a statistical review on AR technology in AEC. The study included 133 articles found in eight well-known journals in the AEC community. According to their results approximately half of studies had a principle focused on visualization/simulation or communication/collaboration as an application area of AR, while education/training and safety/inspection were the least application areas. Wang (2009) provided a detailed review on how MR and AR has been and could be applied in architecture and design. AR applications in the AEC industry includes, but is not limited to the following:

- **Building and Inspecting:** From the early exploration of the potential applications of AR concerning construction tasks, it was figured out that one of the central potential applications of AR is to provide a visual aid to oversee the construction process and then inspect the finished product (Wang, 2009). AR is implemented in facilitating inspections on some specific tasks in construction (Cheng et al., 2020b). Zhou, Luo, and Yang (2017) presented an AR-based system to assist the inspection of segment displacement during tunnelling construction. The system enables on-site quality inspectors to overlay a virtual quality control baseline model onto the real segment displacement in AR and measure the differences. Shin and Dunston (2009) evaluated the benefits of AR prototype system for inspection "ARCam" over a conventional method for steel column inspection.

- **Scheduling and construction progress monitoring:** AR will significantly improve the scheduling aspect of the construction industry; it can monitor the construction progress by comparing an as-planned vs as-built status of a project. Construction progress monitoring is considered one of AR's most used functions (Ahmed et al., 2017; Behzadi, 2016). Golparvar-Fard, Peña-Mora, and Savarese (2009) developed a 4-dimensional AR model (D4AR) for visualizing construction progress monitoring. The D4AR enables the managers to visualize the progress conflicts between the as-planned and as-built status of a project through superimposing 4D as-planned models over daily progress photographs using different visualization techniques (Golparvar-Fard et al., 2009).
- **Quality and defect management:** AR now plays a major role in global construction in order to incorporate automation into the quality and defect management system (Ahmed et al., 2017). In order to develop a defect management process and to reduce the workload of site managers, Kwon, Park, and Lim (2014) utilized BIM, image-matching, and AR to develop two types of defect management systems that would result in enabling quality inspection without visiting the real work site, and enabling managers and workers to automatically detect dimension errors and omissions on the jobsite. Park, Lee, Kwon, and Wang (2013) presented a construction defect management system framework that integrates ontology and AR with BIM. One of the technical solutions that proposed in the system framework is a Defect Inspection System based AR to support field defect management (Park et al., 2013).
- **Communication and information retrieval:** In the construction industry, effective communication and information retrieval from the construction site are considered as an essential key to achieving success for all projects (Ahmed et al., 2017; Behzadi, 2016). AR programs significantly improve information retrieval during construction (Behzadi, 2016; Davila Delgado et al., 2020). Chu, Matthews, and Love (2018) evaluated the effectiveness of integrating BIM and

AR systems to consolidate task productivity by improving the information retrieval process during construction. The integration of BIM and AR resulted in improving information retrieval on-site and reducing workers' mental workload, which can reduce the tendency of workers to commit cognitive failures (Chu et al., 2018). Supporting communication and collaboration is an increasingly common use of AR (Wang, 2009). AR might facilitate communication and information sharing between project team members and provide better spatial perception than conventional design and visualization tools (Bademosi & Issa, 2018). Dong, Behzadan, Chen, and Kamat (2013) proposed a software program named ARVita as a collaborative visualization method that enables multiple users to observe and interact with simulated construction operations.

- **Safety management and workers training:** Safety management and training of construction workers are very concerning issues in the construction industry (Ahmed et al., 2017). Safety issues have attracted widespread attention worldwide, and companies around the world are now implementing safety management systems to prevent injuries, reduce diseases and provide a safe working environment (Cheng et al., 2020b). Several studies exist on AR-based safety management (Cheng et al., 2020b). Pereira, Gheisari, and Esmaeili (2018) used panoramic AR to enhance construction workers' hazard recognition skills in real construction projects. Han, Peña-Mora, Golparvar-Fard, and Roh (2009) used the D4AR model to introduce a visualization framework for site safety management; the framework is introduced through superimposing a 4D as-planned model on safety site photographs. Safety visualization acts as an efficient communication tool to facilitate interactions between workers and managers and provides useful spatial information (Han et al., 2009).

With the rapid evolution and adoption of AR applications, numerous opportunities exist for incorporating AR and improving traditional methods used in the construction industry.

3 VIRTUAL REALITY

VR refers to a computer simulation that generates a view that appears to the user's senses in much the same way that perceives the real world (Craig et al., 2009). VR is composed of an interactive computer simulation that allows users to physically participate in a synthetic world through sensing the user's position and actions and change or augments sensory feedback information to one or more senses (Craig et al., 2009; Mihelj, Novak, & Beguš, 2014). The term "virtual reality" was introduced in the 80s (Fuchs, Moreau, & Guitton, 2011), and its definition is still in flux (Sherman & Craig, 2018). Fuchs et al. (2011) proposed a technical definition of VR as it is a scientific and technical domain that uses behavioural interfaces and computer science to emulate the behaviour of 3D entities in a virtual world, which interact with each other in real-time and with one or more users through sensorimotor channels in pseudo-natural immersion. Sherman and Craig proposed a more formal definition for VR as "A medium composed of interactive computer simulations that sense the participant's position and actions, providing synthetic feedback to one or more senses, giving the feeling of being immersed or being present in the simulation" (Craig et al., 2009). It is also described as a computer simulation of a real or imaginary system that allows a participant to execute operations on a virtual system and displays the results in real-time (Kim, Wang, Love, Li, & Kang, 2013).

Confusion exists between VR and AR, which is a long-running issue (Piroozfar et al., 2017b). Both technologies have a similar approach and shares some underlying technologies, yet they display distinctly diverse experiences (Peddie, 2017). VR differs from AR in a way that in VR, the real elements are removed, and the user is immersed in a virtual environment with virtual objects (Piroozfar et al., 2017b), while AR provides the user additional visual information overlaid on the real world (Peddie, 2017). (Figure 3.1) illustrates the difference in a user's view between AR and VR concerning a construction project site.

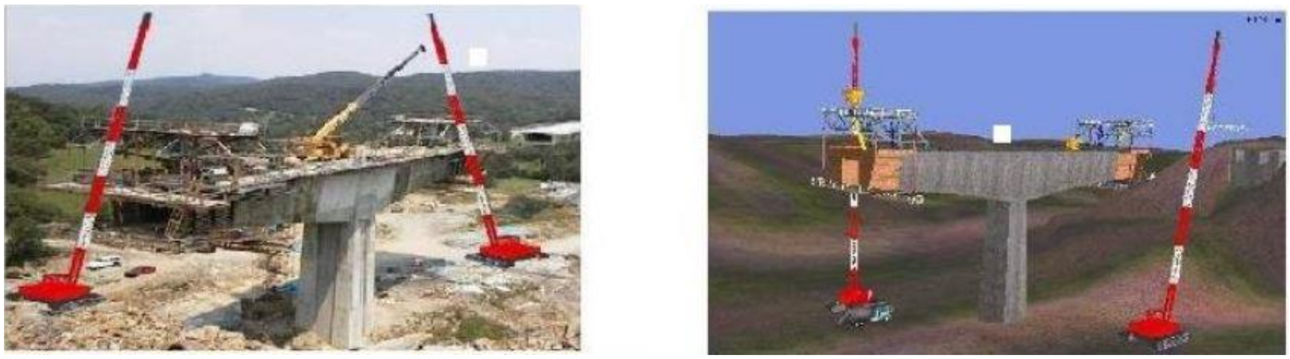

Figure 3.1. *Difference between AR (left) and VR (right) for a construction project (Piroozfar, Essa, & Farr, 2017a)*

3.1 A Brief History of VR

This section illustrates some of the outstanding historical contributions to VR. There is debate about the origins of the concept of VR, mainly because no definitive timeline determines what a VR attempt would look like. One of the reasons it is difficult to determine an origin is the lack of a cohesive term to describe the earlier work for those who were trying to create VR (Pope, 2018). The formal term of VR was coined in 1989 by Jaron Lanier, although the work was done far earlier (Li et al., 2018; Pope, 2018). For decades, the notion of VR has been around, although the public only really became aware of it in the early 1990s (Strickland, 2007). In 1957, Morton Heilig, considered by some as the father of VR, began designing a practical implementation of VR (Mihelj et al., 2014). Morton Heilig developed and patented the Sensorama (Burdea & Coiffet, 2003; Craig et al., 2009; Mihelj et al., 2014; Sherman & Craig, 2018), which is considered as the first step in the actual development of VR (Mihelj et al., 2014). Sensorama is a multimodal experience display system that has a 3D video feedback, wind effects, stereo sound, motion, colour, aromas, and a vibrated seat (Figure 3.2) (Burdea & Coiffet, 2003; Craig et al., 2009; Mandal, 2013; Mihelj et al., 2014; Sherman & Craig, 2018). Sensorama was a viewing cabinet that offered a virtual bicycle riding experience (Craig et al., 2009; Mihelj et al., 2014; Sherman & Craig, 2018), where a user would be immersed in the environment by having most of their other senses cut off from the outside world (Pope, 2018). Sensorama lacked a major component of the modern VR system, which is interactivity based on user’s actions (Craig et al., 2009; Mandal, 2013). Also, Heilig developed the first headset television display called the Telesphere Mask in the 1950s (Burdea & Coiffet, 2003; Pope, 2018; Sherman & Craig, 2018). Telesphere Mask bears a striking similarity to HMDs (Sherman & Craig, 2018) but had no motion tracking (Pope, 2018). In 1961, Philco Corporation engineers Comeau and Bryan developed the first HMD called the Headsight (Mihelj et al., 2014; Pope, 2018; Sherman & Craig, 2018; Strickland, 2007). The Headsight included a remote video camera and tracking system (Pope, 2018; Sherman & Craig, 2018). it enabled the users to observe a real environment from a distant location (Mihelj et al., 2014; Strickland, 2007), which can be considered the first example of telepresence, an application of VR still popular today (Mihelj et al., 2014).

Figure 3.2. *Sensorama virtual reality system (Kock, 2008)*

In 1965, Ivan Sutherland presented his paper called "The Ultimate Display" that proposed the ultimate solution of VR (Mandal, 2013; Mihelj et al., 2014; Sherman & Craig, 2018): a synthetic environment construction concept (Mandal, 2013) that included the presentation of aural, visual, and haptic feedback response based on the user’s actions (Craig et al., 2009). In 1968, Ivan Sutherland developed the first MHD connected to a virtual environment and was attached to a computer rather than a camera. Sutherland’s device, called the Sword of Damocles, consisted of two displays visible from a pair of half-silvered mirrors with appropriate head tracking. It projected computer graphics images through the headset according to the user’s head position and orientation. That was a significant step to form the blueprint for modern VR. In 1976, University of Wisconsin researcher Myron Krueger developed the first environment that reacted to the user’s actions called VIDEO PLACE (Mihelj et al., 2014; Pope, 2018; Sherman & Craig, 2018). The system could recognize users’ activities and move virtual objects in the virtual environment accordingly (Mandal, 2013;

Mihelj et al., 2014). The Sayre Glove was developed in 1976 at the Electronic Visualization Lab using built-in sensors to detect finger motions. Jaron Lanier is the founder of VPL company and the most famous VR industrial pioneer. During the late 1980s and early 1990s, VPL company focused extensively on VR devices and accessories. VPL company was the first company to sell VR products. In 1985, VPL manufactured the first sensing glove called the DataGlove, which enabled the user's body to become part of the virtual world. Also, in 1988 VPL produced the first commercial HMD called EyePhones, and in 1989 announced the first commercial VR system called Reality built for 2 (RB-2). The first academic conference oriented specifically for the VR community was held in 1993 in Seattle, known as VRAIS '93 (Sherman & Craig, 2018). In the same year, the Institute of Electrical and Electronics Engineers (IEEE) organized its first VR conference (Burdea & Coiffet, 2003). The two events were merged in 1995, forming the IEEE VRAIS conference, later known simply as IEEE VR (Sherman & Craig, 2018). The 1990s were a promising time for VR. The most popular VR product of the nineties was Cave Automatic Virtual Environment (CAVE), developed by Daniel Sandin and Thomas DiFanti in 1991 (Dixon, 2006; Mihelj et al., 2014). In 2013, The Oculus Rift kit was released, which was considered the first actual VR headset to hit the consumer market. The Oculus Rift was one of the first truly immersive experiences where users had most of their senses obscured (Pope, 2018). In 2014, Facebook bought the Oculus VR company for $2 billion, which was a decisive moment in the history of VR because VR gained momentum rapidly after this (Barnard, 2019).

3.2 VR Systems

One of the key elements in experiencing VR is immersion (Sherman & Craig, 2018). Immersion might be considered as to how strongly the user's attention is concentrated on a task. Virtual immersion can be roughly categorized into physical (sensory) and mental immersion. It represents the sensation of being in an environment (Mihelj et al., 2014; Sherman & Craig, 2018). Physical immersion is the central characteristic of virtual reality and is considered as entering the user's body physically into the medium (Mihelj et al., 2014; Sherman & Craig, 2018), while mental immersion is referred to as having a sense of presence within an environment (Sherman & Craig, 2018). Based on the level of immersion and the degree of presence that a system provides, the VR systems can be categorized into two groups immersive and non-immersive systems (Whyte, 2002).

Immersive VR (IVR) systems can be described as a system that totally immerses or surrounds the user in a computer-generated world (Li, 2010; Mandal, 2013; Whyte, 2002). These systems achieve immersion with the help of HMDs that supports a stereoscopic view of the scene accordingly to the user's orientation and position (Mandal, 2013). An immersive VR system's key benefit is that it provides users with a sense of presence and size by viewing and engaging with realistic computer-generated objects. The need to use many hardware devices such as HMDs, data gloves, stereo glasses and so on, which are considered too expensive for common people to afford, limits the development of immersive VR systems (Li, 2010).

Regards to non-immersive VR (non-IVR) systems, and as the name suggests, represent the least level of immersion among VR systems, it enables the user to see the virtual environment through one or more computer screens (Mandal, 2013), while the user is not totally immersed in the environment and the display device does not take up their total FOV (Mandal, 2013; Whyte, 2002). This type of system is also known as Desktop VR systems or Window on World (WoW) systems (M. Li, 2010; Mandal, 2013; Whyte, 2002), using a conventional monitor or PC as display devices. This type of system is the cheapest and most straightforward of VR systems (Li, 2010; Mandal, 2013), where it can be easily implemented in many applications without the need for other sensory output. Due to its ability to provide real-time interaction and visualization that is close to a real-world, non-IVR, has a high reputation in modern education (Mandal, 2013).

3.3 VR Display

Display technology is essential for any VR system and helps to classify emerging configurations (Vince, 2004). Since the visual system is the prevalent means of communication for most people, the visual display part of a VR display has the most influence on the VR system's overall design (Craig et al., 2009). According to Craig et al. (2009), the paradigms of visual display of VR can be categorized into three groups: stationary displays, head-based displays, and hand-based displays. Each group has its advantages, which are influenced by technological developments and the number of financial resources available (Craig et al., 2009).

The essential advantage of the stationary displays represented in filling a relatively large portion of the FOV for one or more users, where it uses fixed-position screens that wrap around the users in order to surround them with the visual representation of the world as much as possible. Also, the reduced amount of hardware worn by users represents another advantage of the paradigm, which improves the ability to see the other participant physically standing due to the reduced negative impact of latency, which also improves the system's safety (Craig et al., 2009). Several examples of stationary displays exist, such as wall displays, virtual tables, desk displays, and CAVE (Craig et al., 2009). CAVE systems is a prevalent paradigm of the VR stationary displays (Vince, 2004), which was presented in 1992 at the Electronic Visualization Laboratory of the University of Illinois at Chicago (Burdea & Coiffet, 2003; Peddie, 2017; Vince, 2004). CAVE system provides a high-resolution, multi-user (Hamzeh et al., 2019), covers wider FOV, and overcome some of the limitations of HMDs (Giraldi, Silva, & Oliveira, 2003; Mandal, 2013). CAVE system projects stereoscopic images on the room walls (Mandal, 2013), consisting of a number of back-projection screens with external projectors (Figure 3.3) (Vince, 2004). A user is head-tracked and must wear shutter glasses to see a stereoscopic view wherever the user looks (Vince, 2004).

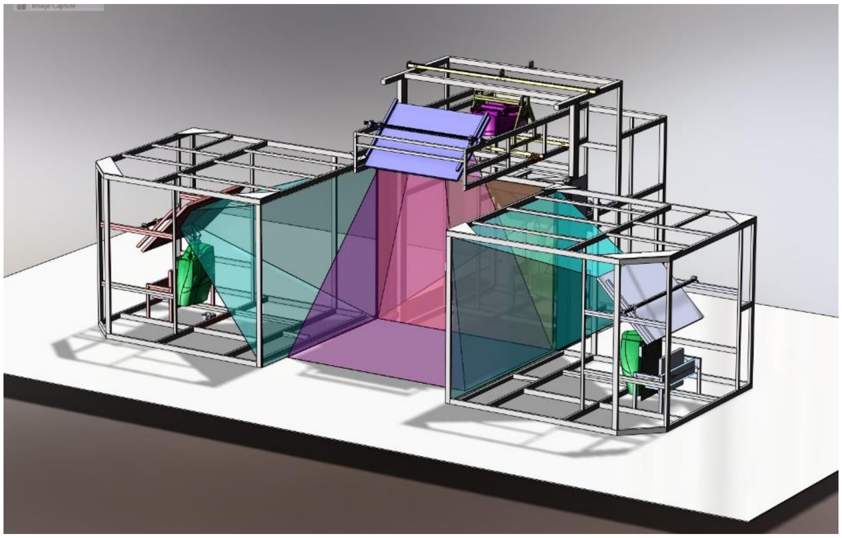

Figure 3.3. *CAVE system*

Hand-based displays have not been widely used as a component of VR systems. It is usually used under circumstances of a specific VR experience with a specific need that must be fulfilled (Craig et al., 2009). In this type of display, the user holds the device in one or both hands to present a synthetic scene (Burdea & Coiffet, 2003). According to Craig et al. (2009), two styles of hand-based display exists; the first and most intuitive style is a pair of binoculars that contain two small screens instead of the typical lenses. In the case of using special optics to project a virtual image in front of a user, this style is similar to HMDs (Burdea & Coiffet, 2003). The other style relies on using screens or devices approximately the size of a hand's palm. The image on this screen shows the virtual world from where the user’s eyes are through the small window. The hand-based displays are ideally suited when a VR experience has a natural interface, but it does not work well when the application requires a reasonable amount of FOV because both the binocular and palm-sized devices provide very limited FOV (Craig et al., 2009).

Head-based displays (HBDs) are the most commonly known type of VR display. The early forms of HBDs were often superimposed onto the helmets of fighter-pilot. These devices were heavy headsets with attached screens placed in front of the user's eyes. Later the abbreviation HMDs was also used for head-mounted displays (Craig et al., 2009). HMDs generally consist of a headgear that provides a base for mounting other components, two special optics which presents an image to the user, and a tracking system to detect the precise user's head location and orientation in real-time (Giraldi et al., 2003; Veron, Hezel, & Southard, 1994). HMDs provides the user with a total sense of immersion (Mandal, 2013). HMDs, view true-stereo 3D objects through small monitors mounted in front of a user's eyes and linking the VR viewpoint using head tracking (Kim, Wang, et al., 2013). Another type of HBDs is a mechanical arm-mounted display that the viewer pulls up to his face to offload the weight of the display device from the user (Craig et al., 2009). Burdea and Coiffet (2003) labelled this type of device as “Floor-supported displays”. This device offers larger FOV and superior graphics resolution than HMDs or Hand-based displays (Burdea & Coiffet, 2003). The Binocular Omni-Orientation Monitor (BOOM) represents the origin of this type of display device (Craig et al., 2009). BOOM was produced in 1989 by Fakespace Labs (Burdea & Coiffet, 2003; Mandal, 2013). BOOM is a small box supported by a counterbalanced arm and employs high-resolution CRT technology (Mandal, 2013; Vince, 2004). The user pulls up the box to the eyes level and moves through the virtual world (Figure 3.4) (Mandal, 2013).

Figure 3.4. *A Binocular Omni-Orientation Monitor (BOOM) (Onyesolu & Eze, 2011)*

3.4 VR in Construction Industry

Over the past two decades, VR technology implemented and offered solutions to existing and futuristic challenges in many fields, such as entertainment, education, industrial applications, driving and military applications, and medical visualization (Kim, Wang, et al., 2013; Li, 2010; Noghabaei et al., 2020). As the AEC industry relies heavily on visual communication, the advances in VR technology offers considerable benefits to the industry (Kim, Wang, et al., 2013), such as risk minimization, cost reduction, better communication between stakeholders, and clashes detection (Woksepp, 2007). The construction industry requires developed capabilities to visualize complex activities and objects, which perfectly aligns with the capability VR provides to visualize concepts that are difficult or impossible to visualize in other ways (Li, 2010). VR environment affords workers and construction professionals an interactive visualization with a project in advance of its building, which is considered the most potent and unique characteristic of VR environments for the construction industry (Ahmed et al., 2017; Li, 2010). The visualization capabilities offered by VR technology have attracted the attention of an increasing number of researchers from the AEC domain (Kim, Wang, et al., 2013). For all phases of the construction process, VR provides significant potential benefits, from conceptual design and initial planning to FM and operations (Woksepp & Tullberg, 2002). Kim, Wang, et al. (2013) presented a critical review of VR applications in the field of the built environment. The review included 150 journal papers with a time span from 2005 to 2011. The study aimed to provide a classification framework for VR knowledge in the built environment and to reveal research concentration areas and knowledge gaps in this field. One of the parts that the classification framework consists of is identifying the VR application areas in the built environment, where the results indicated that the VR application areas in the built environment in that period are: architecture and design, construction, training and education, landscape and urban planning, engineering, facility management, and lifecycle integration respectively (Kim, Wang, et al., 2013). Davila Delgado et al. (2020) presented one of the first systematic studies with a detailed analysis of the factors that drive and limit the adoption of VR and AR in the construction industry. Forty-two driving and limiting factors were identified using a mixed research method. The identified factors were grouped into a small number of factors using Principal Component Analysis (PCA), where four types of driving factors and four types of limiting factors were identified. The results indicated that the major driving factor of adopting VR and AR in the construction industry is that these technologies can improve the delivery of construction projects, also it can contribute to improve project understanding, productivity, communication and collaboration. The major limitation factor of adopting VR and AR in the construction industry is the perception that these technologies are still immature that cannot be fully used in practice yet (Davila Delgado et al., 2020). Noghabaei et al. (2020) conducted a survey to understand the trends on adopting VR and AR technologies in AEC industry. The survey findings indicated that industry experts expect strong growth over the next 5 to 10 years in the use of VR and AR technologies. Also, the study proved that AEC industry's adoption of these technologies is growing significantly (Noghabaei et al., 2020). Ahmed et al. (2017) conducted a literature review that aimed to identify the potential application areas of VR and AR in the construction industry. Results revealed that VR and AR technologies are used in different stages of the construction process, where VR is used as a safety management tool, worker training, visualization tool, and quality and defects management tool. In contrast, AR technology is successfully used in progress monitoring, safety and training, scheduling and clash detection, and quality and defects management (Ahmed et al., 2017).

Visualization and Collaboration: VR technologies enable building a virtual project model that simulates real-world effects before the project starts physically, providing many benefits and solutions for construction practitioners and stakeholders (Ahmed et al., 2017). VR as a visualization tool is used at different stages of the construction process, where it improves decision-making in the planning phase (Ahmed et al., 2017), supports design review sessions and constructability analysis meetings (Davila Delgado et al., 2020), and it reduces the cost and effort that associated with maintenance and facilities management in the post-construction phase. Over the last three decades, many studies have been conducted on construction visualization using VR technologies (Ahmed et al., 2017). Bouchlaghem, Shang, Whyte, and Ganah (2005) presented a review study of visualization applications in the design and construction process followed by the results of applying various technologies at different stages of design and construction (for collaborative working during the concept design stage, for design development and marketing in the house building sector, and for the modelling of design details during the construction stage) in three case study projects. The results indicated that during conceptual design, visualization could improve collaboration and communication among design team members, in housing development, site layout models can be used as marketing tools or for planning consultations with planners, and it facilitates information flow for buildability problems which can bridge the gap between designers and site teams (Bouchlaghem et al., 2005). Li (2010) presented a brief summary of early developments of VR technology and explored the potential applications of VR technology as a visualization tool in two main areas: visualization of building design and construction and visualization of building structural behaviour. Boton (2018) used IVR-based collaborative 4D simulation to support constructability analysis meetings. Wolfartsberger (2019) described the development and evaluation of a VR-based tool to support engineering design review. The developed tool was compared to a CAD software-based design review approach, and the results indicated that VR-based design review enables users to see slightly more faults than the traditional method, and it has a significant potential to accelerate the design review process (Wolfartsberger, 2019). In order to facilitate interpersonal project communication Du, Shi, Zou, and Zhao (2018) presented a cloud-based multiuser VR system called collaborative virtual reality (CoVR).CoVR enables remote stakeholders to have face-to-face conversations in the virtual world. The usability of the system was tested in a real case followed by a building inspection experiment, and the results indicated that the system improves communications in construction projects and provided a better perform in a building inspection task than in the case of using a single-person VR system (Du, Shi, et al., 2018).

Construction Safety Management: Safety management is a concerning issue for the construction industry since the construction industry is considered the most hazardous industry (Ahmed et al., 2017), and fatal accidents tend to be higher than in other industries (Li et al., 2018). Previous research reported that lack of preventive and proactive measures such as safety awareness and education, workforce training, risk identification and control, lead to the most accidents associated with construction projects (Li et al., 2018). VR technology is proposed as a valuable tool to advance the current safety management practices. Li et al. (2018) presented a critical review of VR and AR applications in construction safety and offered a taxonomy contains technologies characteristics and application areas, safety enhancement mechanisms, and safety assessment methods. The results indicated that the main application areas of VR and AR in construction safety management are safety planning, safety training and education, and safety inspection (Li et al., 2018). Albert, Hallowell, Kleiner, Chen, and Golparvar-Fard (2014) presented a study that aims to develop and evaluate a platform for hazard recognition in construction sites called System for Augmented Virtuality Environment Safety (SAVES). The results indicated that the developed platform could improve construction workers' hazard identification skills and reduce construction accidents (Albert et al., 2014). Moore, Eiris, Gheisari, and Esmaeili (2019) developed and compared hazard identification training scenarios using VR techniques and 360-degree panorama. Fang and Teizer (2014) proposed a virtual training approach that simulates collaborative tasks in crane lifting operations to enhance efficiency and safety in crane blind lifting operations. With a view of integrating safety with construction education methods, (Pedro, Le, & Park, 2016) developed a virtual safety-education system for university students, where students access virtual content through textbook-based QR codes by utilizing VR and smart devices.

Construction Engineering Education and Training: VR technology has been rapidly known and applied in CEET in recent years due to its provided benefits, such as creating an engaging and immersive environment (Wang et al., 2018). Wang et al. (2018) conducted a critical review regarding VR use in the CEET domain; 66 journal articles were included with a time span from 1997 to 2017. The study identified the used technologies, application areas, and future research directions. Regarding the application areas, the authors categorized the application areas of VR in the CEET domain into four groups: almost 50% of the included studies are related to applying VR in architecture visualization and design education, where VR allows students to grasp architectural design concepts in a significant way and provides the comparison of different designs at the same time, the second-largest application area is construction safety training where VR provides an interactive and immersive environment contrary to in case of using traditional methods that provided in a classroom with videos or slide presentations that usually do not represent real construction site conditions, the third group is equipment and operational task training, and the final group is teaching structural analysis subject (Wang et al., 2018). Kamath, Dongale, and Kamat (2012) developed a VR tool to improve architectural design education and prepare students for the practical experience of real industrial environments. The developed tool expands that CAD modelling results into 3D spaces that enable students to explore and interact with different virtual spaces (Kamath et al., 2012). Li, Chan, and Skitmore (2012a) proposed a Multiuser Virtual Safety Training System (MVSTS) that enable trainees to participate in a crane dismantling virtual process. The system provides a virtual experience for trainees that helps them learn the correct dismantling procedure, working location, and cooperating with other trainees in a risk-free environment. To demonstrate how the system works and its practical implementation, a case study was provided, and the results indicated that the trainees who used the proposed system got better learning than those using the traditional method (Li et al., 2012a). Kiral and Comu (2017) aimed to develope a virtual environment based safety training tool to simulate the scaffolding and formwork activities. The developed tool called V-SAFE.v2 proved that it can help the trainees to improve their safety skills such as improving hazard recognition level, hands-on practice experience, safety behavior patterns, etc. The results also demonstrated that the developed tool is an effective tool of safety training for the scaffolding and formwork activities (Kiral & Comu, 2017).

4 KNOWLEDGE SYNTHESIS: LITERATURE REVIEW METHODS

4.1 Knowledge Synthesis

The evolution of knowledge synthesis methods over time and their application within various disciplines has led to many labels and terms that are frequently used inconsistently by academics (Paré, Trudel, Jaana, & Kitsiou, 2015). Knowledge synthesis includes different forms of literature review methods and guidelines for reporting results. These methods and guidelines continue to be revised to improve the rigour of knowledge synthesis methods and the applicability and translucence of findings. Researchers and scientists benefit from knowledge about the nature and strengths of different forms of review; improving the proper and accurate reporting of the individual studies, determining the appropriate review method when carrying out a literature review, considering quality and bias of studies, and interpreting reviews (Whittemore et al., 2014). This section aims to give an overview of the knowledge synthesis, provide descriptive insight into a sample of literature review types and highlight in detail the characteristics of the used method in this study.

The considerable growth and increased volume of information system research require researchers to find a way to quickly synthesize the extent of the literature on various topics of interest and deal with all the relevant gaps (Paré et al., 2015). ‘‘Knowledge synthesis’’ is not a modern notion, with references dating back to the early 1900s (Chalmers, Hedges, & Cooper, 2002; Grant & Booth, 2009; Tricco, Tetzlaff, & Moher, 2011). In the 1960s, knowledge syntheses were prevalent throughout social science, education, and psychology (Paré et al., 2015).

Knowledge synthesis is an expression used to characterize the literature review methods that synthesize results from individual studies (Straus, Tetroe, & Graham, 2013) and interpreting these results within the context of the totality of the evidence (Kastner et al., 2012). Knowledge synthesis is central to knowledge translation, where it attempts to summarize all pertinent studies on a specific question, improve the understanding of inconsistencies in diverse evidence, and identify gaps to define future research endeavours (Kastner et al., 2012; Tricco et al., 2011). Since this time, knowledge syntheses have become increasingly important due to the fact that focusing on the results of individual studies may be misleading due to bias in their conduct or random variations in findings (Kastner et al., 2012; Straus et al., 2013; Tricco et al., 2011).

4.2 Literature Review Definition and Purpose

Knowledge accumulation and refinement are essential for the growth and advancement of "scientific" fields (King & He, 2005; Paré et al., 2015). In order to help practitioners, scholars, and graduate students to find, evaluate and synthesize the contents of many empirical and conceptual papers, rigour knowledge syntheses are becoming indispensable (Lau & Kuziemsky, 2016). More specifically, it is essential to conduct effective literature reviews in order to advance knowledge and understand the breadth of research on a subject of interest, synthesize the empirical evidence, develop theories or provide a conceptual background for subsequent research, and identify the topics or research areas that require further investigation (Paré et al., 2015). All literature review methods must include a systematic approach to affirm that included individual studies have trustworthy findings and that the synthesized findings accurately represent the aggregation or synthesis of individual studies, as the validity of the review process depends on the validity of the primary studies included and on the review process itself (Tricco et al., 2011; Whittemore et al., 2014). Methodological guidelines for many types of the literature review are available. Guidelines identify the type of research design needed for a type of review, search strategies and data collection methods, quality assessment tools, data extraction and analysis procedures, and reporting recommendations (Whittemore et al., 2014).

Several definitions have been put forward for the literature review. Webster and Watson (2002) define the literature review process as one of the platforms that provide a firm foundation for advancing knowledge. That promotes the development of theory, closes areas where an abundance of research exists, and uncovers areas where research is required (Webster & Watson, 2002). Marshall describes a literature review as a methodical method for identifying, appraising, and explaining work generated by academics, scholars, and practitioners (Baker, 2016). Common to all literature review's definitions is their notion that they are "not based primarily on new facts and findings but on publications containing such primary information, whereby the latter is digested, sifted, classified, simplified, and synthesized" (Cooper, Hedges, & Valentine, 2019).

Students, trainees, and many others who have only recently embarked on the field of research consider that literature review is merely a summary of papers or an extended bibliography annotated. However, there is much more to the actual value of a literature review than this (Samnani, Vaska, Ahmed, & Turin, 2017). Objectively, literature reviews should report the existing knowledge on a subject and provide outlines of the best available research from previously published studies related to a particular subject (Baker, 2016). The literature reviews are considered to serve the following functions:

- To differentiate what has been done from what needs to be done and recognize the essential methodologies and research techniques previously used.
- Identify what has been written on a topic, provide a theoretical framework, and rationalize the significance of the problem for the topic under study.
- Identifying topics and areas that require further investigation and demonstrating gaps in the literature.
- Provide a synthesized summary of existing evidence supporting hypotheses and opinions.
- Determining the extent to which any interpretable trends or patterns are revealed within a specific research area (Baker, 2016; Jaidka, Khoo, & Na, 2013; Lau & Kuziemsky, 2016).

4.3 Literature Review Types

Literature reviews can take two primary forms. The most prevalent one is commonly labelled as the "literature review" or "background" section (Lau & Kuziemsky, 2016; Paré et al., 2015), which exemplify a fundamental first step and provides the theoretical foundations when undertaking a research project (Baker, 2016). More precisely, the mentioned form assists the researchers to understand the existing evidence and frames the proper research methodologies, techniques, goals and research questions for a proposed study (Paré et al., 2015). The second form of literature review frames an original and useful piece of research in and of itself. Rather than presenting a foundation for the researcher's own work, it makes a robust starting point for all academic community members interested in a specific field or subject (Lau & Kuziemsky, 2016; Paré et al., 2015). This form of review can be undertaken for several reasons, such as analysing the advance of a particular flow of research, revising the application of a theoretical model or a methodological approach, evolving a new theory or research approach and providing a critical analysis of prior research on a particular research area (Paré et al., 2015). High-quality reviews become considerably quoted pieces of work that researchers look for as a robust starting point of the literature when undertaking empirical studies. The reason for the popularity of this form of reviews may be that reading the review allows one to get an overview, if not a detailed information of the area concerned, and references to the most valuable primary sources (Lau & Kuziemsky, 2016).

Many types of literature reviews can cover a wide range of topics at diverse levels of perfection and exhaustivity (Library, 2020). Six characteristics that usefully distinguish through literature reviews and review authors are used to describe their work (Focus, Goal, Perspective, Coverage, Organization, Audience) (Cooper et al., 2019; Cooper, 1988). The most crucial feature that choosing the review type dependent on is the goal of the literature review (Library, 2020). Based on the taxonomy of the literature reviews, there are three general goals of reviews (Cooper et al., 2019; Cooper, 1988). The most frequent goal for a review is to integrate or aggregate prior empirical findings (Cooper et al., 2019; Paré et al., 2015), and as an example for the literature reviews that aim to integrate or aggregate the prior studies: Systematic review, Meta-analysis review and Umbrella review (Paré et al., 2015). The second goal for literature reviews can be to critically analyse the existent literature on a broad subject to detect weaknesses, contradictions, controversies. A critical review is a case in point (Paré et al., 2015). Contrary to reviews that follow an integrative manner, critical reviews do not necessarily summarize conclusions or compare the covered works with each other. Instead, it holds each works up against a criterion and finds it more or less acceptable (Cooper et al., 2019; Paré et al., 2015). The third goal for literature reviews is to identify issues centric to a particular field. These issues may include questions that prompted past work, questions that should motivate future work, or methodological problems or problems in logic and conceptualization that have impeded progress within a topic area or field (Cooper et al., 2019; Cooper, 1988). The following sections present an overview for a sample of the most common review methods, and the last section highlights the used method in this study.

4.3.1 Narrative review

The narrative review is often called a “traditional literature review” (Stratton, 2019). A narrative review aims to synthesize or epitomize what was published on a particular subject but does not seek generalization or accumulative knowledge from what is reviewed (Lau & Kuziemsky, 2016; Paré et al., 2015). The primary purpose of this type of review is to provide a comprehensive background for understanding existing knowledge and identifying new research areas (Lau & Kuziemsky, 2016). Narrative reviews are used to introduce and rationalize research where it is commonly found in the “introduction” or “background” sections and may also be published as detached papers (Stratton, 2019). Narrative reviews can inspire research intellects by identifying knowledge gaps or contradictions and thus help researchers identify research questions or formulate hypotheses (Lau & Kuziemsky, 2016). Importantly, narrative reviews usually do not provide any explanations of how the review process was conducted, and often include an author’s assumptions and biases, where the selection of information from the primary studies may be made subjectively in order to make a point, which can lead to biased interpretations and inferences (Lau & Kuziemsky, 2016; Paré et al., 2015; Stratton, 2019). The lack of explicit criteria and the lack of information on how the review process was conducted make replication by other researchers impossible and has been identified as a key weakness of narrative reviews (Paré et al., 2015). Sherafat et al. (2020) presents an example of a narrative review. The study provides a comprehensive review of recent studies about automated activity recognition of construction resources (Sherafat et al., 2020).

4.3.2 Critical review

Critical reviews endeavour to provide a critical appraisal and interpretive analysis of the effectiveness and quality of existing literature on a certain subject of interest (Lau & Kuziemsky, 2016; Samnani et al., 2017). Rather than providing a simple description of identified studies, the central focus of the critical review is a critical analysis using appraisal instruments or critical interpretive methods to reveal strengths, weaknesses, contradictions, inconsistencies, the validity of cited resources, and/or other important issues with respect to theories, hypotheses, research methods or results (Lau & Kuziemsky, 2016; Paré et al., 2015; Samnani et al., 2017). The ‘critical’ component of this type of review is key to its value (Grant & Booth, 2009), and the ability to highlight issues, contradictions, or areas where current knowledge of a topic is untrustworthy is considered as the strength of critical review. On this wise, it can constructively inform other scholars and strengthen knowledge growth by providing a 'launch pad' for a new conceptual development phase (Paré et al., 2015). As an example of critical review, Li et al. (2018) provided a critical review of the evolution of VR/AR-CS in the academic field, which in turn established a robust platform for scientists and professionals to obtain a useful understanding of the applications of VR and AR in construction safety.

4.3.3 Systematic review

The systematic review is one of the most widely used types of review (Samnani et al., 2017). Systematic reviews can be broadly defined as a type of knowledge synthesis used to identify and retrieve evidence of multiple studies by defining relevant research, evaluating study quality, and summarizing results (Munn et al., 2018; Stratton, 2019; Whittemore et al., 2014). Systematic reviews seek to discover "all" of the evidence relevant to a topic in order to provide a comprehensive, unbiased synthesis in a single document using rigorous and transparent methods (Aromataris & Munn., 2020). In order to provide reliable data and minimize bias, systematic reviews follow a structured research process and utilize explicit, systematic, transparent methods (Munn et al., 2018; Samnani et al., 2017; Stratton, 2019; Whittemore et al., 2014). The development of a review protocol is a crucial step in the early development of a systematic review. A protocol predefines the goals and methods of the systematic review, which grant the process transparency, enabling the reader to see how the results and recommendations have been reached (Aromataris & Munn., 2020). The usefulness of systematic review in producing scientific inferences and conclusions depends on the quality and consistency of reporting process (Whittemore et al., 2014). To boost reporting standardization in systematic reviews, it is recommended that the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) be followed to improve reporting transparency and improve consistency across systematic reviews (Whittemore et al., 2014). The PRISMA Statement involves a 27-item checklist and a four-phase flow diagram. The PRISMA Statement aims to upgrade the reporting of systematic reviews and meta-analyses (Moher, Liberati, Tetzlaff, & Altman, 2010). Siraj and Fayek (2019) provide an example of a systematic review that discusses prevalent risk identification tools and techniques, risk classification methods, and common risks for construction projects. The study conducted a systematic review and detailed content analysis of 130 articles published in well-regarded and relevant academic journals with a time span limited to twenty-seven years (1990-2017) (Siraj & Fayek, 2019).

4.3.4 Meta-analysis

Meta-analysis is a subset of a systematic review that gathers evidence using statistical techniques (Stratton, 2019; Whittemore et al., 2014). Meta-analysis requires the same attention that is invested in the systematic review, with an additional requirement that meta-analysis should be reserved for homogeneous results of the included studies so that standard statistical methods or qualitative analysis can be applied to the pooled data (Stratton, 2019). Meta-analyses employ specified data extraction techniques and statistical methods to collect quantitative data in the form of standard effect measures (e.g., risk ratios, odds ratios, mean differences, correlation coefficients), taking into account the relative sample size of each study (Paré et al., 2015; Whittemore et al., 2014). Meta-analyses are seen as a robust knowledge synthesis method that enables researchers to draw meaningful inferences by resolving established disputes resulting from conflicting empirical studies (Paré et al., 2015). The ability to inspect homogeneity between critical studies is an advantage of meta-analysis over other review types (Stratton, 2019). The guideline for improving meta-analyses reporting is the same that used for systematic reviews (Whittemore et al., 2014), and the same PRISMA Checklist used for systematic review should be followed for a meta-analysis as previously discussed (Stratton, 2019). Akkoyun and Dikbas (2008) provide an example of a meta-analysis that presents a preliminary taxonomy for performance research in the construction management discipline. The identification process of relevant studies focused on peer-reviewed articles published in a number of central construction management journals with a time span limited to ten years (1999-2008). The included studies were analyzed and classified through a structured meta-analysis framework with the aim to identify the aspects and features of performance studied in different contexts (Akkoyun & Dikbas, 2008).

4.3.5 Umbrella review

Systematic reviews became prevalent due to the rising number of primary research studies. The increased number of systematic reviews has prompted many to conduct reviews of existing systematic reviews, allowing comparison and contrasting of the findings of independent reviews (Aromataris et al., 2015; Grant & Booth, 2009; Paré et al., 2015; Pollock, Fernandes, Becker, Pieper, & Hartling, 2018; Whittemore et al., 2014). Reviews of existing systematic reviews are called umbrella reviews, also referred to by several different names in the scientific literature, including overviews of reviews, reviews of reviews, a meta-reviews (Aromataris et al., 2015; Paré et al., 2015; Pollock et al., 2018; Whittemore et al., 2014). The principle purpose for conducting an umbrella review is to integrate relevant evidence from multiple systematic reviews (qualitative or quantitative) into one accessible and usable summary in order to compare and contrast the results on a variety of different levels (e.g., outcomes, interventions, population) (Aromataris et al., 2015; Paré et al., 2015; Whittemore et al., 2014). Guidelines for managing umbrella reviews and reporting the outcomes are available from The Joanna Briggs Institute (JBI) (Joanna Briggs, 2014) and Cochrane (referred to as overviews of reviews) (Pollock et al., 2018; Whittemore et al., 2014). Anwar, Xiao, Abbas, and Ali (2018) provide an example of an umbrella review that developed a risk factors checklist for Public-Private Partnerships (PPP) projects. The study identified several critical common risk factors using a questionnaire based on 20 years Meta review of literature on PPP projects, case studies, interviews from public/private sector, and academicians (Anwar et al., 2018).

4.3.6 Scoping review

Scoping reviews have become an increasingly common approach for synthesizing the literature on a particular topic (Colquhoun et al., 2014; Daudt, van Mossel, & Scott, 2013; Levac, Colquhoun, & O'Brien, 2010; Pham et al., 2014). Scoping reviews endeavour to provide a preliminary indication of the potential size and scope of the available body of literature relevant to a particular topic as well as an overview of its focus (Arksey & O'Malley, 2005; Daudt et al., 2013; Grant & Booth, 2009; Munn et al., 2018; Paré et al., 2015; Teare & Taks, 2020). Scoping reviews are a comparatively new approach, and despite the efforts among researchers that seek clarification, there is no universally agreed-upon definition or purpose for scoping reviews (Colquhoun et al., 2014; Daudt et al., 2013; Levac et al., 2010; Pham et al., 2014). Arksey and O'Malley (2005) argued that scoping reviews' definitions are sparse. Levac et al. (2010) affirm this opinion in their work, presenting a group of recent reliable scoping sources, each presenting a different definition or purpose (Daudt et al., 2013). A scoping review of scoping reviews found out that most of the included reviews defined scoping review as a type of literature review that identifies and characterizes or maps the available studies relevant to a particular subject (Pham et al., 2014). One of the scoping review's most commonly cited definitions of scoping review is the one suggested by Arksey and O'Malley (Colquhoun et al., 2014): “scoping studies aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available, and can be undertaken as standalone projects in their own right, especially where an area is complex or has not been reviewed comprehensively before” (Arksey & O'Malley, 2005). Daudt et al. (2013) suggested a revised definition as follows: “scoping studies aim to map the literature on a particular topic or research area and provide an opportunity to identify key concepts, gaps in the research; and types and sources of evidence to inform practice, policymaking, and research” (Colquhoun et al., 2014). Colquhoun et al. (2014) suggested the use of the following definition: “A scoping review or scoping study is a form of knowledge synthesis that addresses an exploratory research question aimed at mapping key concepts, types of evidence, and gaps in research related to a defined area or field by systematically searching, selecting, and synthesizing existing knowledge”.

4.3.6.1 *Why a scoping review?*

Scoping reviews tend to not focus on the depth of coverage but on the breadth of coverage of the available literature (Arksey & O'Malley, 2005; Paré et al., 2015; Rumrill, Fitzgerald, & Merchant, 2010). The purpose of a scoping review defines to what extent the in-depth coverage that a scoping review seeks to provide (Arksey & O'Malley, 2005). As it is for the definition, no universal recognized scoping review's purpose (Levac et al., 2010; Munn et al., 2018). There are several reasons why a scoping review might be conducted. Arksey and O'Malley (2005) identified four common reasons why a scoping review might be conducted:

1. To examine the size, scope, and quality of research activity: in such an approach, describing research results in any detail might not be provided. However, this is a useful way to map study areas where it is difficult to visualize the range of available materials.

2. To define the importance of conducting a full systematic review.
3. To summarize and publicize research outcomes: in this type of scoping review, a description in more detail of research outcomes in a particular area of study might be provided.
4. To identify research gaps in the existing literature.

Levac et al. (2010) suggested that researchers might have a comprehensive study purpose with multiple objectives indicated by Arksey and O'Malley that is required in order to assist achieve their overall purpose. Tricco et al. (2016) carried out a review on the conduct and reporting of scoping reviews and found that the most common scoping review purpose was to examine the breadth of research activity. A scoping review of scoping reviews found that most reported purposes of the scoping review were: to identify, describe, and summarize research findings on a subject, including identification of research gaps and the least reported purpose was to identify questions for a systematic review (Pham et al., 2014). Munn et al. (2018) suggested a set of purposes for undertaking a scoping review as follows:

- To identify the sorts of available evidence in a particular field
- To illustrate basic concepts/ definitions in the literature
- To examine research techniques and methodologies on a particular subject
- To identify basic features or factors related to a notion
- As a precursor to a systematic review
- To identify and analyze knowledge gaps

Munn et al. (2018) explained that these purposes were listed as discrete reasons in order to provide needed clarity, and they alerted researchers to not interpret the list of purposes as a discrete list where only one purpose can be identified.

4.3.6.2 *Scoping review compared to other types of review*

Scoping reviews and systematic reviews are similar in following a structured process, but they are conducted for different purposes and have some key methodological differences (Arksey & O'Malley, 2005; Levac et al., 2010; Munn et al., 2018). The key differences among scoping reviews and systematic reviews include the research question nature (Munn et al., 2018), whereas scoping review has less depth but is broad in nature which is considered to provide a breadth of coverage more than systematic reviews besides more expansive inclusion criteria (Arksey & O'Malley, 2005; Levac et al., 2010; Munn et al., 2018; Peterson, Pearce, Ferguson, & Langford, 2017; Tricco et al., 2016). Conversely, the systematic review questions are targeting a relatively narrow range of studies based on very precise inclusion criteria (Arksey & O'Malley, 2005; Peters et al., 2020; Peterson et al., 2017; Tricco et al., 2016). Furthermore, scoping reviews aim to provide a breadth coverage of the available data on a particular topic rather than producing the best available evidence to answer a narrow specific question related to policy and practice (Arksey & O'Malley, 2005; Munn et al., 2018), therefore scoping reviews do not address the issues of quality appraisal or quality assessment of the included studies (Arksey & O'Malley, 2005; Peters et al., 2015), as in the case of the systematic reviews, which considered as a limitation of scoping reviews (Arksey & O'Malley, 2005; Levac et al., 2010). While (Peters et al., 2015) explained that the lack of performing a quality assessment of the included studies could be considered a limitation in conducting a scoping review as a precursor to systematic reviews, otherwise a formal assessment of methodological quality is not conducted within the scoping review (Munn et al., 2018; Peters et al., 2015). Furthermore, the lack of quality assessment in the scoping review results in a more expanded range of study methodologies and designs being addressed than in the systematic review (Arksey & O'Malley, 2005).

A scoping review differs from traditional systematic reviews and meta-analysis in that it provides for more flexibility and is capable of restricting a variety of relevant literature using different methodologies (Arksey & O'Malley, 2005; Levac et al., 2010; Peterson et al., 2017). Traditional literature reviews have many shared characteristics with scoping reviews (Stratton, 2019), but considering the fundamental differences, scoping reviews should no longer be confused with traditional literature reviews. The main differences include the subjectivity nature of traditional literature reviews in selecting information from primary studies as discussed earlier and the lack of prior review protocols or a pre-defined analysis approach (Munn et al., 2018; Stratton, 2019). Scoping reviews and mapping reviews have many similarities, including identifying and analyzing gaps in the knowledge base, with perhaps the main difference that distinguishes mapping reviews is the production of a visual database or schematic (i.e. map), that used as an assistance tool in interpreting where evidence exists and where there are gaps (Munn et al., 2018).

4.3.6.3 *Scoping review framework*

In order to provide guidance to researchers interested in scoping review, the first methodological framework was proposed in 2005 by Arksey and O'Malley to provide needed clarity on how and when a scoping review might be undertaken (Arksey & O'Malley, 2005). Tricco et al. (2016) found that out of 494 included scoping reviews, Arksey and O'Malley's framework was the most frequently cited guide for conducting the scoping review. Along with this, a scoping review of scoping reviews found that within the included studies that reported using a framework (109/174), the Arksey and O'Malley's framework was the most frequently used as a guide for conducting scoping review (Pham et al., 2014). The developed framework is considered not a linear but iterative process consisting of five stages and an optional sixth stage (Arksey & O'Malley, 2005). The first stage includes identifying the research question. Within this stage, considering the important aspects of the research question, such as study population, interventions, or outcomes, would help researchers shape the review parameters (Arksey & O'Malley, 2005). The second stage identifying relevant studies should be aligned with the whole point of this type of review, which is to be as comprehensive as possible. The research team has to make decisions related to the coverage and breadth of the review in terms of data sources, search methods, inclusion criteria, time span, and language to limit the scope of the review (Arksey & O'Malley, 2005). In the third stage that called study selection, inclusion and exclusion criteria are applied to identify relevant studies to be included and eliminate studies that do not address the research question (Arksey & O'Malley, 2005). Once the articles are identified, the fourth stage called "charting the data", involves charting and sorting the obtained information according to key items and issues (Arksey & O'Malley, 2005; Daudt et al., 2013). The fifth stage includes collating, summarizing, and reporting results. The last and optional stage includes consulting with stakeholders to inform consulting with stakeholders to report or support study results (Arksey & O'Malley, 2005; Colquhoun et al., 2014; Levac et al., 2010). Arksey and O'Malley (2005) encouraged other researchers to revise their framework to develop the methodology (Daudt et al., 2013; Levac et al., 2010). Levac et al. (2010) provided more explicit recommendations regarding each stage of the framework and addressed the framework's strengths and limitations. Both of these frameworks have supported the development of the formal guidance for conducting scoping reviews produced by JBI in 2015 (Peters et al., 2020). Daudt et al. (2013) presented particular recommendations such as being flexible regarding the research questions and sharing the whole review team throughout every step of the framework. Engebø et al. (2020) provided a recent example of a scoping review that aims to provide an overview of collaborative project delivery methods and identifying knowledge gaps by creating a summary of the body of evidence. Engebø et al. (2020) implemented the framework outlined by (Arksey & O'Malley, 2005) and the contribution to the framework made by (Colquhoun et al., 2014; Daudt et al., 2013; Levac et al., 2010).

The scoping review method is used in this study due to the consistency of the study objectives with the method, the broad nature of the research questions (Arksey & O'Malley, 2005; Daudt et al., 2013; Levac et al., 2010; Peters et al., 2015), the diverse nature of the topic, and the flexibility in the selection and inclusion of literature, which is essential for literature assessment within the CPM field where there is no consistent paradigm regarding the study design (Engebø et al., 2020).

5 METHODOLOGY

The methodology of this study was guided by the proposed framework outlined by (Arksey & O'Malley, 2005), in addition to the enhanced recommendations made by (Colquhoun et al., 2014; Daudt et al., 2013; Levac et al., 2010). The methodology followed up the following five stages while the optional component of the framework "consultation exercise" was not included :

1. Identify the research questions

2. Identify relevant studies

3. Study selection

4. Chart the data

5. Collate, summarize and report the results.

5.1 Identifying the Research Questions

As a starting point for conducting a review, appropriate broad research questions with a clearly articulated scope of inquiry were identified and linked to the purpose at the outset of the review as proposed by (Daudt et al., 2013; Levac et al., 2010), which led to establishing an effective search strategy. Consequently, this study was conducted to systematically map the development and trends of AR and VR in the CPM sector to explore the size, range, and nature of the existing literature about the AR and VR applications in the CPM, and identifying the key application areas and the future research trends of these technologies in the CPM. The following formulated questions guided this study:

- What researches have been conducted on AR and VR in CPM?
- What is known from the existing literature about the applications of AR and VR in CPM?
- What are the key application areas of AR and VR in CPM?
- What are the types and characteristics of AR and VR technologies used in the CPM?

5.2 Search Strategy: Identifying Relevant Studies

After identifying the research questions and aims, methodical guidelines were set to guide the following stages (Table 5.1). The stage of Identifying relevant studies requires to be as comprehensive as possible for covering the field to identify the existing literature suitable for answering the central research questions (Arksey & O'Malley, 2005; Daudt et al., 2013; Levac et al., 2010; Peters et al., 2015). Therefore, the research strategy adopted different sources to identify relevant studies (Arksey & O'Malley, 2005; Daudt et al., 2013). Which are the following:

- Electronic databases
- Hand-searching of key journals
- Relevant conference

Some limits related to the time span and the language were placed on the search strategy to balance comprehensiveness, breadth, and feasibility (Arksey & O'Malley, 2005; Daudt et al., 2013; Levac et al., 2010). Initially, our search was started through two databases (Web of Science and ASCE library) that are supposed to compromise master journals and publishers regarding the scientific field of construction management in an unbiased manner (Engebø et al., 2020). The search was targeting the published studies in peer-reviewed journals and conference proceedings that have been published between 2008 and 2020. Only the studies that have been published in English were targeted due to the time and cost involved in the translation process. The keywords "augmented reality" and "virtual reality" was used. The initial search generated an unmanageable amount (>35000) of hits, so to narrow the search towards the CPM field, a combination of technical topics and sub-headings such as (construction management, project management, construction) were used to fit the databases of Web of Science and ASCE library respectively. The reference lists from a set of relevant key papers (such as review articles) were scanned to identify other potential papers that may not be included in the databases. Afterwards, a hand-search was conducted for a set of key journals that have demonstrated a high number of relevant papers within the initial search in the databases. Also, the proceedings of the International Council for Research and Innovation in Building and Construction (CIB W78) conference were searched using the ITC Digital library as it is a relevant conference to the advanced technology in construction.

Table 5.1 *Methodical guidelines used in the study*

General guidelines	Sources	Extracted data	Reporting the results
• Sources: electronic databases, selected journals, relevant conference • English language • Time span: (2008-2020) • Sources must be peer-reviewed journals or conference proceedings	• Web of Science • ASCE Library • ITC Digital library for proceedings of CIB W78 conference	• Title, author(s), publication year, country/region, • Journal/Conference • Reported study design • Type of technology • Technology features • Application areas • Key findings	• Descriptive summaries • Statistical summaries • Visual illustrations (charts and graphs) and tables

5.3 Study Selection

A two-stage screening process was used to evaluate the relevance of the identified citations to the research questions. In the first screening stage, a screening process of the title, abstract, and keywords for all the generated hits was conducted using a prepared relevance screening form (Appendix 1) to remove irrelevant studies. In case of existing ambiguity about the relevance of the study after screening the abstract, an investigation of the full-text article was conducted. Titles for which an abstract was not available were included for the subsequent stage of screening full text. In the second screening stage, a full-text eligibility screening was conducted for all the studies (that were deemed relevant in the first stage) using an eligibility screening form (Appendix 2) to make the final decision about including the studies in the review. The included studies must fit the following criteria: only studies that were published between 2008 and 2020, available in English, full-text available, and published in peer-reviewed journals or conference proceedings were included. The included studies must deal with the application of AR or VR in areas of the CPM, where those studies regarding solely to AR or VR rather than their applications in CPM were not included. The study was excluded if the full text was not available (e.g. conference abstracts). All the identified citations from the databases were imported into bibliographic citation management software Endnote X9 to manage bibliographies, organize and cross-check the data, and remove duplicates. Furthermore, the software was compatible with the used Microsoft Word package, which provided a quick and easy task to produce lists of references for inclusion in the final thesis report.

5.4 Charting the Data

'Charting' depicts a manner for synthesizing and explaining qualitative data by means of sifting, charting and sorting materials on the basis of main issues and themes (Arksey & O'Malley, 2005). This stage involved extracting the important data and variables from the full-text records (that included in the review for the final analysis) to address the research questions (Levac et al., 2010). A data charting form was developed based on numerous dimensions that would answer the research question (Appendix 3). The data extraction process was iterative, and the data-charting form was continually updated as proposed by (Levac et al., 2010). The final data-charting form contained the following data when available: general information regarding study (title, author(s), publication year, country/region, type of article/study, journal/conference); reported study design (quantitative, qualitative, mixed); type of technology (AR, VR); technology features; application area; and key findings. All the included studies in the final review were imported to Nvivo 12 software to identify, code, and extract the units of text related to the key components of the data charting form.

5.5 Collating, Summarizing, and Reporting the Results

In order to analyse the size, range, and nature of the existing studies, descriptive numerical summaries were used to describe the characteristics of the included studies (Arksey & O'Malley, 2005; Daudt et al., 2013; Levac et al., 2010). The description of these characteristics includes the process of identifying and selecting studies, classification of studies by date, journal, geographical distribution, and the reported study design. Later, the extracted units related to the application areas of AR and VR technologies in CPM, and the types and characteristics of these technologies were analysed and organized thematically under thematic categories (Arksey & O'Malley, 2005; Daudt et al., 2013; Levac et al., 2010), where the results will be reported as a combination of tables, charts, and narrative summaries.

6 RESULTS AND DISCUSSION

6.1 Search and Selecting of Studies

The research strategy initially identified 5207 potentially relevant articles through the search of the electronic databases, and 32 articles were identified as proceedings of the CIB W78 conference through the search in the ITC Digital library. Through removing duplicates and the first stage of screening title, abstract, and keywords, 5065 articles were excluded, while 174 articles were retrieved for the next stage of screening, addition to 20 articles was identified through the hand-search. The screening of the full-text records of the remaining articles excluded 100 studies for not meeting the eligibility criteria or being duplicated, while 94 articles were included in the final analysis. The flow of articles from the initial identification to the final inclusion is demonstrated in (Figure 6.1). The final included studies are classified as 42 studies related to AR, 46 studies related to VR, and six studies related to both AR and VR.

6.2 Classification of Studies by Publication Year

Figure 6.2 depicts the number of studies by publication year. From 2008 to 2012, relevant studies were published in series of low numbers with an average of 2.8 publications per year. 2013 represents the first peak of the publication rate where there was a rapid and significant increase in the publication number (11), about four times more than the average number of publications in previous years. The publication rate between 2013-2020 has an average number of 10 publications per year. 2018 represents the highest number of publications within the review time frame, with 20 publications per year, about four times more than the average (5.1) in previous years. Despite the drop in the publication number in 2019 and 2020 compared to 2018, it is still more than the total average of the publication rate. This substantial increase in the publication rate may indicate that the interests and efforts in AR and VR research in the CPM domain have increased, and this trend will continue.

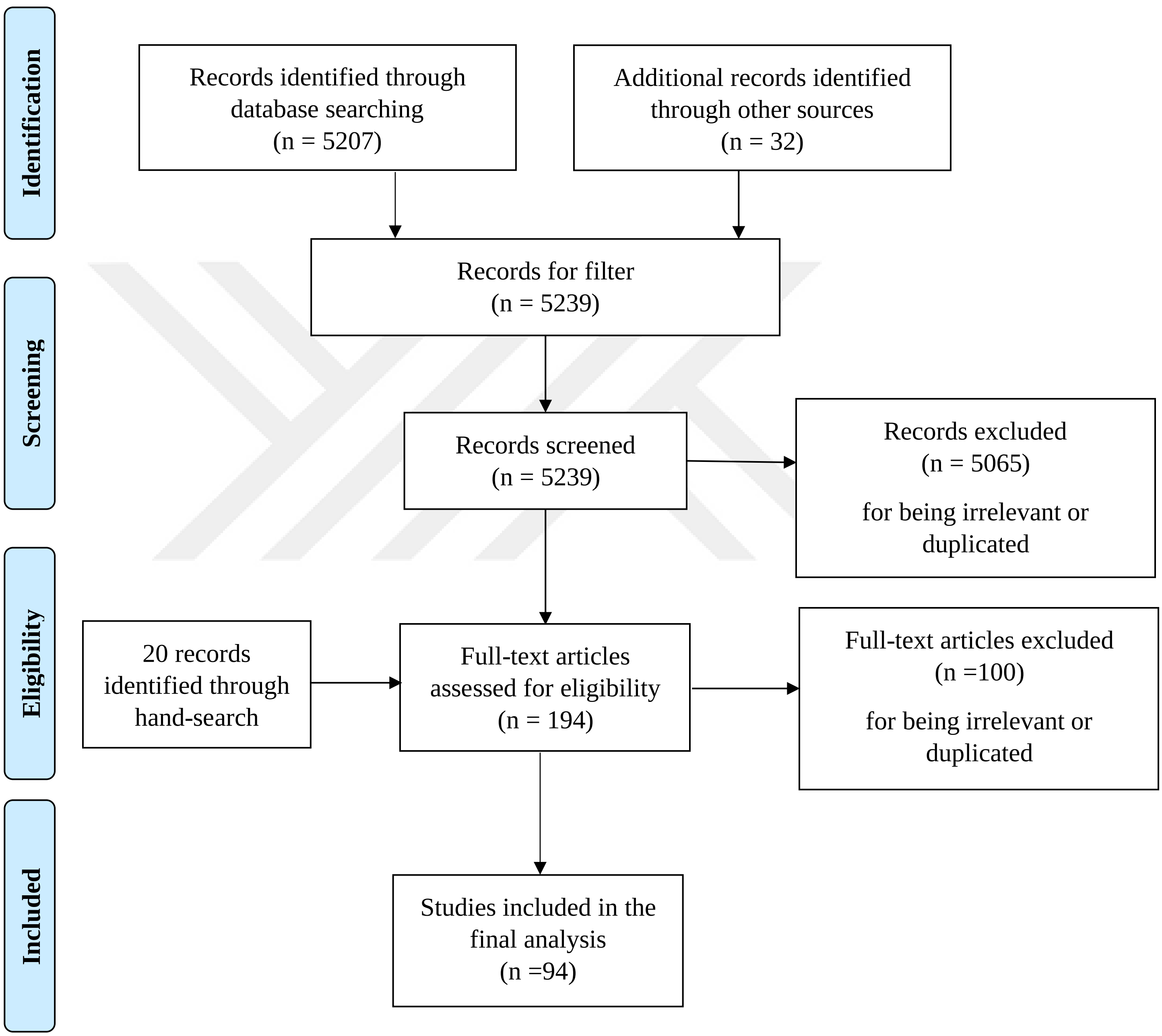

Figure 6.1. *Scoping review flowchart*

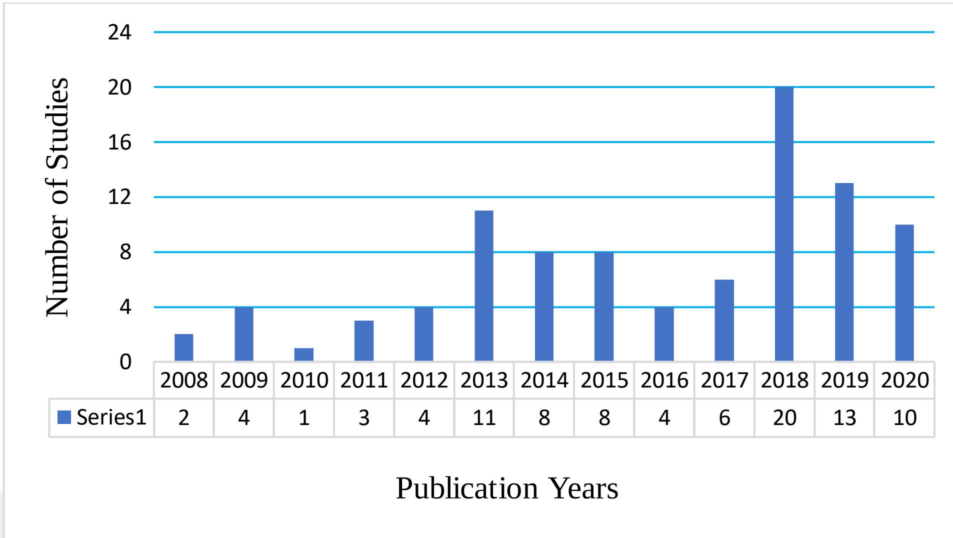

Figure 6.2. *Publications per year*

6.3 Classification of Studies by Publication Venue and Study Design

The included studies are classified according to the publication venue and the reported study design in this section. Of the 94 included studies, 70 (74%) studies were identified as a journal paper and 24 (26%) studies as a conference proceeding (Figure 6.3). The high percentage of the identified studies as journal papers may lay the assumption that authors would prefer publication in peer-reviewed journals than conference proceedings. Table 6.1 presents the distribution of identified studies categorized based on publication venue. The results demonstrate that 50% of the identified studies are published in the following sources: "Automation in Construction", "Journal of Computing in Civil Engineering", and "American Society of Civil Engineering (ASCE) Conferences", where the "Automation in Construction" journal contributes with the highest publication rate (21%) to the research topic with 20 studies. Furthermore, the publication distribution reveals multidisciplinary research efforts of AR and VR in the CPM aspects, where the identified studies were mainly published in technology-related journals and conferences and within the area of construction engineering and management. This observation represents a valuable clue for the academics and researchers interested in the AR and VR applications in the CPM where it provides an important indicator of where to find relevant research and where to submit research.

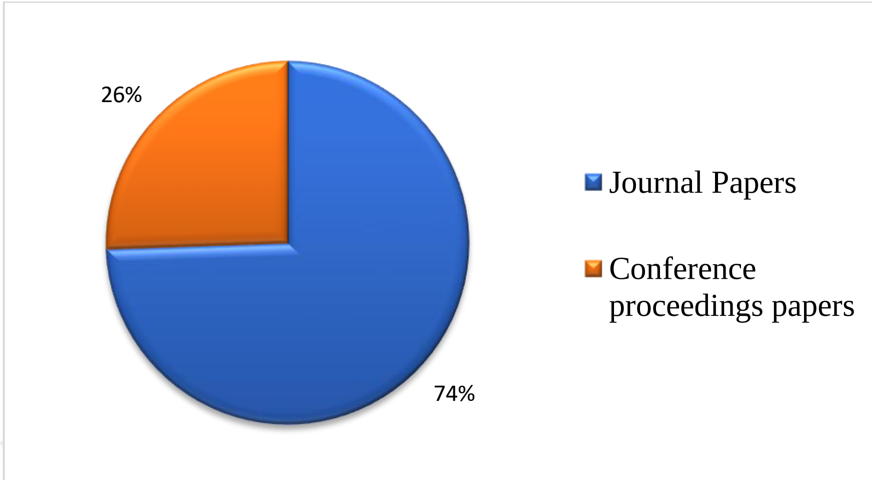

Figure 6.3. *Reference type*

The studies were also categorized according to the reported study design as either "Quantitative", "Qualitative", or "Mixed Method". Figure 6.4 illustrates the classification of the studies by the methodology, where the quantitative method represents the dominant approach with the highest proportion (66%) as a used methodology within the classified studies, followed by the mixed-method methodology (25%), and the qualitative methodology appears with the lowest proportion (9%). It should be mentioned that three studies were not classified due to the lack of sufficient information about the used methodology.

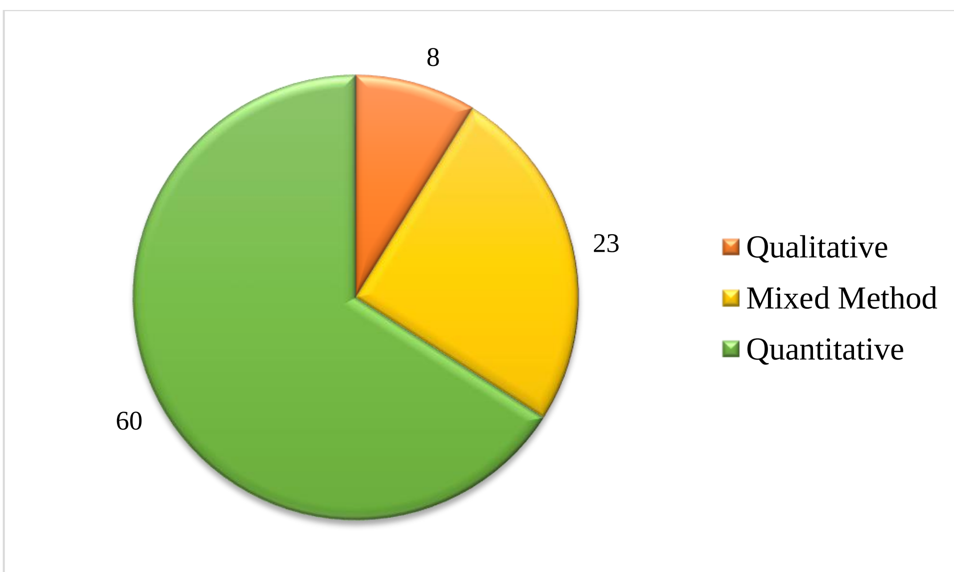

Figure 6.4. *Methodical distribution*

Table 6.1. *Distribution of the identified studies by publication venue*

Journal List	Number of Studies	Percentage
Automation in Construction	20	21%
Journal of Computing in Civil Engineering	12	13%
Journal of Construction Engineering and Management	4	4%
Visualization in Engineering	4	4%
Safety Science	3	3%
Journal of Information Technology in Construction	3	3%
KSCE Journal of Civil Engineering	3	3%
International Journal of Engineering Education	3	3%
Construction Innovation	2	2%
Construction Management Economics	2	2%
Journal of Civil Engineering and Management	2	2%
Engineering, Construction and Architectural Management	2	2%
Advances in Civil Engineering	1	1%
Building a Sustainable Future	1	1%
Buildings	1	1%
Journal of Architectural Engineering	1	1%
Journal of Intelligent & Robotic Systems	1	1%
Journal of Management in Engineering	1	1%
Journal of Professional Issues in Engineering Education and Practice	1	1%
Teknik Dergi	1	1%
Organization Technology and Management in Construction	1	1%
International Journal of Environmental Research Public Health	1	1%
Conference List		
American Society of Civil Engineering (ASCE) Conferences	16	17%
International Council for Research and Innovation in Building and Construction (CIB W78)	5	5%
International Conference Structures and Architecture (ICSA)	1	1%
Winter Simulation Conference (WSC)	1	1%
International Symposium on System Integration (SII)	1	1%
Total	94	100%

6.4 Classification of Studies by Country

In this part, the identified studies were classified based on the geographical location of the institution or university belonging of the authors or the main author in the case of multinationalism of the authors. Figure 6.5 illustrates the sorting of publications according to the geographical location. The geographical distribution of the publications represents almost 10% of all countries recognized by the UN. The low distribution can be interpreted as an immaturity of this research field, at least regarding global reach (Engebø et al., 2020); moreover, it could be due to the concentration of this study on publications written in English. As can be noted, USA comes first in terms of the number of publications 42 studies by a large percentage (45%) and by a large margin in comparing with the rest of the presented countries this reflecs the interest of academics and researchers in USA with AR and VR implementations, where it is expected that AR and VR will promote gross domestic product (GDP) in the U.S. by 49 billion U.S. dollars in 2021. South Korea came next with 13 publications (14%), followed by Taiwan with six publications (6%), and both Australia and Italy with four publications (4%) and the rest of the publications came from miscellaneous countries with a number of publications ranging from 3 to 1.

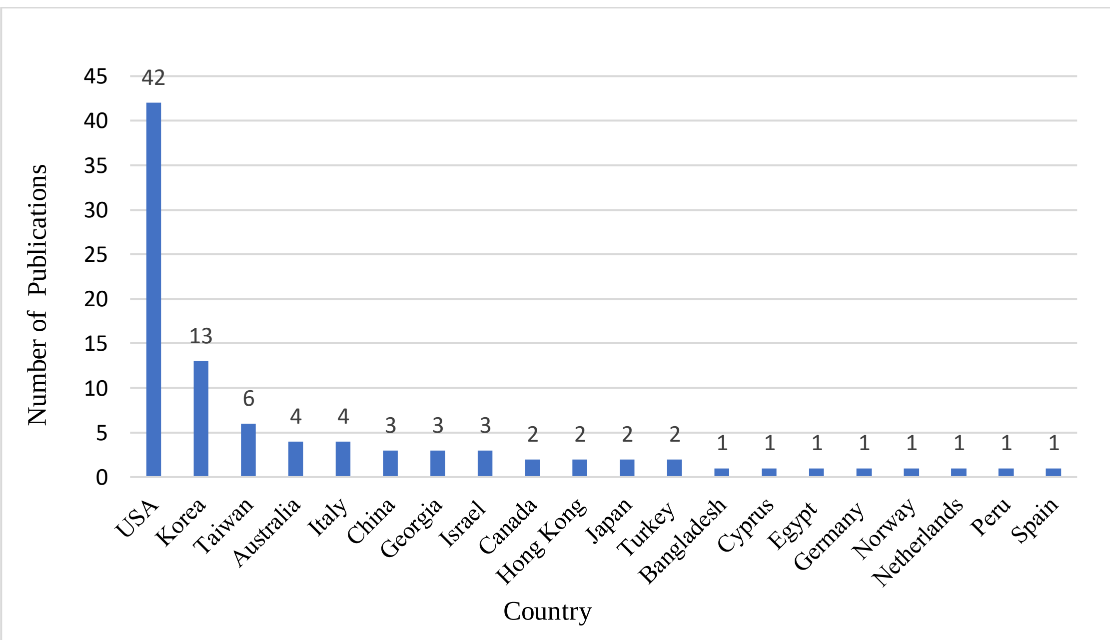

Figure 6.5. *Countries and publications*

6.5 Technology features

According to the used technology, the identified studies are classified to 42 studies related to AR technology, 46 studies related to VR technology, and six studies related to AR and VR. This section will answer the research question regarding AR and VR technologies' features implemented in the CPM domain. The main features of each technology system were extracted and classified, where the identified features of AR technology are spatial registration method, display method, user interaction device, while for VR technology are: display method, user interaction device, and level of immersion.

Display technology is an essential part of any AR or VR system, and as mentioned in the previous chapters, several types of display technology existed today, including HMDs, desktop displays, hand-held displays, and stationary displays. Table 6.2 illustrates the identified display methods for both AR and VR technologies and the number of applications within this review.

Among all display methods of AR technology, hand-held displays, which mainly refer to tablets and smartphones was the most widely used at 18 in number. This result may reflect the growing interest in improving and using mobile AR applications (Rankohi & Waugh, 2013); furthermore, this growing interest may be due to several factors, including the improving performance of this display method, recent solutions to technical issues such as tracking, small production costs, and ease of use (Rankohi & Waugh, 2013; Van Krevelen & Poelman, 2010). HMDs came secondly as a used display method of AR technology where it was identified in 16 studies, followed by the desktop display method.

As for the used display methods in VR technology, HMDs were the most widely used at 18 in number; this result aligns with what was mentioned that the HMDs are the most commonly known method of VR display. Desktop display and projection-based display were identified in 13 and 8 studies, respectively. According to the previously mentioned taxonomy, both methods are categorized under the stationery displays (Craig et al., 2009). The high use of these displays may be explained by its providing of a relatively large portion of the FOV for one or more users, the reduced amount of hardware worn by users, which result in improving the safety of the system, and its ease of accessibility (Craig et al., 2009; Wen & Gheisari, 2020). Hand-held displays came with the least number of use (4) as a VR display method which also aligns with what was mentioned previously that hand-held displays had not been widely used as a component of VR systems.

Table 6.2. *AR and VR identified display methods*

Display method	**Number of applications**	
	AR	**VR**
HMD	16	18
Hand-held display	18	4
Desktop display	8	13
Projection-based display	1	8
Not mentioned	4	6

Real-time Interaction with a composite environment in the case of AR or with a virtual environment in the case of VR is one of the main features of AR and VR technologies (Azuma et al., 2001; Craig, 2013; Mihelj et al., 2014). The used interaction devices in AR and VR systems were identified and illustrated in (Table 6.3). The touch screen is the most used interaction device among all interaction methods of AR systems, at 18 in number. This aligns with the high use of hand-held display devices, as mentioned previously. Next comes the traditional input method with keyboard and mouse at 9 in number, which were used mainly in conjunction with the desktop display; in addition to that, in some cases, HMDs used keyboard and mouse as interaction devices. Regarding VR systems, the controller, keyboard and mouse were identified as the most used interaction devices in 11 and 10 studies, respectively.

Table 6.3. *Interaction devices*

Interaction device	Number of applications	
	AR	VR
Keyboard and mouse	9	10
Touch screen	18	3
Joystick	2	4
Controller	2	11
Smart glove	1	0
Not mentioned	11	19

The level of immersion is considered one of the key elements of any VR system that distinguishes this technology from conventional computer-generated technologies. Based on the level of immersion, the identified VR-related studies in this review were classified into three categories: least-immersive, semi-immersive, and full-immersive (Li et al., 2018). Figure 6.6 presents the distribution of the VR system based on the level of immersion. The full-immersive VR system came firstly with the highest rate of use at 35% (18 studies), which returns to the popularity of HMDs as the most widely used display method for VR systems. Despite the expensive cost of such a system, it is preferred because of its ability to provide the highest level of immersion. It gives the user the feeling of being part of the virtual environment (Li et al., 2018). The least-immersive systems, also called Desktop VR systems, were also used highly at 33% (17 studies). This high use of such a system may be returned to its simplicity of display, ease of accessibility, less need for hardware components, and it is considered the least expensive VR system (Craig et al., 2009; Li et al., 2018; Wen & Gheisari, 2020). The semi-immersive system has the lowest rate of use at 15% (8 studies). These systems are characterized by providing a higher level of immersion than the least-immersive systems whilst maintaining the desktop VR's simplicity (Li et al., 2018). CAVE is an example of such a system mainly used regarding safety management and education (Leder, Horlitz, Puschmann, Wittstock, & Schutz, 2019; Perlman, Sacks, & Barak, 2014).

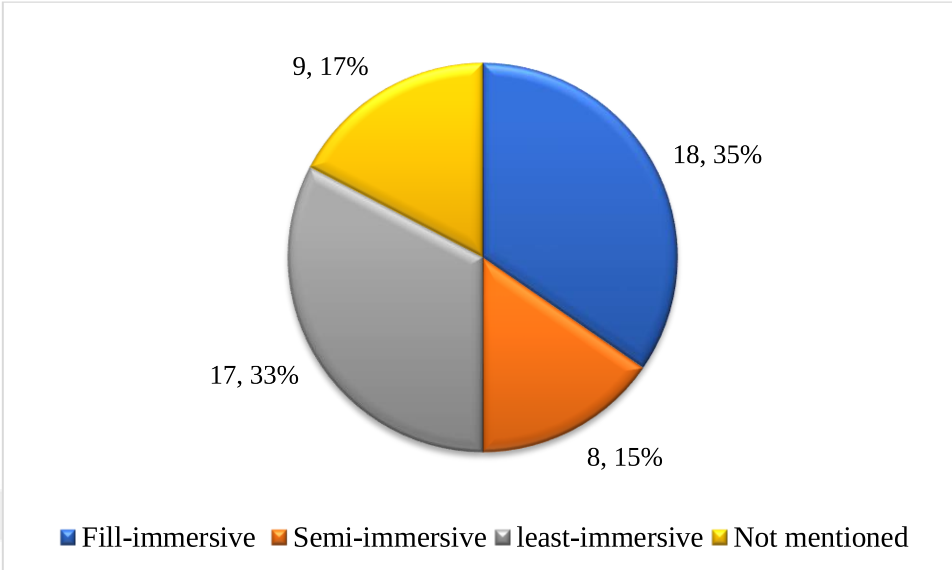

Figure 6.6. *Distribution of studies based on the immersion level*

Spatial registration is one of the most important technical aspects of an AR system and is considered a core part of AR functionality (Azuma et al., 2001; Chi et al., 2013a; Silva et al., 2003). Spatial registration is responsible for the imposing process of the virtual objects into the real environment view by calculating the user's correct spatial position and orientation in accordance with the real-world coordinate systems (Cheng et al., 2020a; Chi et al., 2013a). The Spatial registration methods of the included AR-related studies were extracted and classified into two categories: "marker-based" and "marker-less" methods, as shown in (Table 6.4). The marker-based “image recognition” method is considered the most widely used spatial registration method within the included studies, as it represents more than 50% (20 out of 38) of the identified methods. The high use of this method may be returned to the simplicity, efficiency, and convenience of image recognition for superimposing virtual objects to the real world, where the image recognition method relies on extracting features from images instead of using complicated algorithms for calculating the relationship of relative positions (Cheng et al., 2020a). Among the AR marker-less registration methods, GPS came first, where it was identified in 9 studies. The notable use of GPS may be explained by its suitability for use in a large open area such as a construction site and the ease of its signal receiving by common mobile devices (Cheng et al., 2020a).

Table 6.4. *AR spatial registration methods*

Spatial registration method	Number of applications
Marker-based	**-**
2D image recognition	20
3D object recognition	3
Marker-less	**-**
GPS	9
IMU	3
RFID	1
VIO	2
Not mentioned	10

6.6 AR and VR application areas in CPM

This part provides the answer to the research question related to identifying the application areas of AR and VR technologies in the CPM domain. The application areas within the included studies were extracted and classified under themes that represent the CPM aspects. The following sections illustrate a descriptive summary that includes a set of main studies for each application area.

6.6.1 AR

It is believed that AR technology is an important tool for bringing automation in the construction industry, where it has a significant contribution in changing the culture of the industry to a fully automated soon (Ahmed, 2019). Various application areas of AR technology in the CPM domain were identified, as shown in (Table 6.5).

Table 6.5. *AR application areas in the CPM domain*

Application area	**Number of publications**	**%**
Safety management	17	36%
Communication and data acquisition	9	19%
Visualization	7	15%
Construction management education	4	9%
Scheduling and project progress tracking	4	9%
Defect and quality management	3	6%
Facility management	3	6%

6.6.1.1 *Scheduling and project progress tracking*

As illustrated in (Table 6.5), the contribution of the AR technology as a tool for scheduling and project progress tracking represents 9% among the identified studies. AR technology can enhance the scheduling and project progress tracking aspects remarkably; it provides an integrated visualization of as-built and as-planned forms. Golparvar-Fard, Pena-Mora, and Savarese (2011) developed a modelling system called D^4AR that registries spatial as-planned and as-built models to measure, analyze, and communicate the construction progress. A set of experiments were conducted to validate the proposed system, and it has been proven not only can it be used as a scheduling management and progress tracking tool, but it can also be used as a robust on-site tool for defect and quality control, site layout management, and off-site safety management and education (Golparvar-Fard et al., 2011). Kim, Kim, Borrmann, and Kang (2018) proposed an AR-based 4D CAD system that provides 4D and 5D simulation objects based on real-time construction information. Instead of analyzing the schedule progress based on the fieldwork reports and digital photos, the proposed system enables the construction participants to examine the progress remotely. Kim et al. (2018) suggested using their system as a tool to observe fieldwork and support decision-making and collaboration between remote managers and workers. Zaher, Greenwood, and Marzouk (2018) proposed a system that integrates AR with BIM, generates 4D and 5D models to track construction progress and cost and time control. The proposed system was developed using various tools such as Primavera P6 to develop time schedules, Autodesk Revit to develop BIM models, Autodesk Naviswork to develop the 5D models, and Metaio creator to create and deploy AR scenarios. The effectiveness of the proposed system was evaluated through semi-structured interviews, and the results demonstrated that the system might reduce the time of construction and explaining information, decrease errors comparing with using paperwork, increase the effectiveness of decision-making (Zaher et al., 2018). AR as a scheduling and construction progress tracking tool is going to be one of the most used technologies in advanced CPM (Ahmed, 2019).

6.6.1.2 *Quality and defect management*

Using AR technology as a defect management tool represents 6% among the identified studies, as depicts in (Table 6.5). Quality and defect management is an initial aspect of CPM where the repeated and inevitable defects are considered one of the important causes of project cost and schedule overruns in the construction process. AR can play a significant role to bring automation in quality and defect management aspects. AR technology could be used as a useful tool for field inspection. The use of such technology leads to the proactive prevention of dimension deviation and commission error of many defects in a construction site (Park et al., 2013). Park et al. (2013) proposed a system framework that integrates AR, BIM, and ontology-based data, for proactive defect management. It is expected that the proposed system would improve the existing manual inspection practices (Park et al., 2013). Kwon et al. (2014) addressed using marker-based AR, BIM, and image matching techniques to evolve two defect management systems; a mobile AR-based defect management app that automatically detects dimension errors and omissions on construction sites, and an image-matching system that enables managers to inspect quality remotely. **Error! Reference source not found.** illustrates an inspection process for window positioning errors by using the mobile AR-based defect management system. The study results demonstrated the usability of the proposed system at real job sites. The AR-based defect management system provides proactive prevention of defects by enabling workers to augment component position information in advance of installation work. Furthermore, the system would highly progress the existing manual-based defect management process by enabling inspectors and site managers to check errors more efficiently and remotely (Kwon et al., 2014).

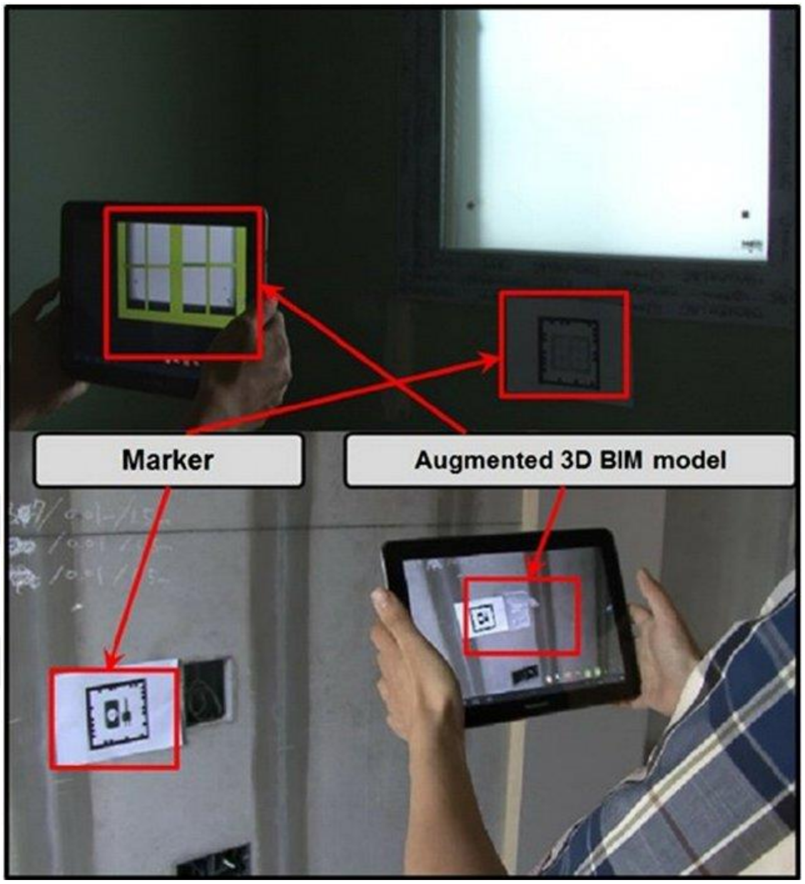

Figure 6.7. *Inspection of windows positioning errors using mobile AR (Kwon et al., 2014)*

6.6.1.3 *Construction management education*

The traditional teaching techniques or even called passive teaching techniques, such as coursework in core subjects and in-class instruction, lack to effective preparation of students to handle the complexities of real projects, which results in limited opportunities for hands-on experience (Bademosi, Blinn, & Issa, 2019; Behzadan, Iqbal, & Kamat, 2011). From this point came the need to use advanced visualization technologies as teaching techniques to enhance the educational experience of the CPM students (Bademosi, Blinn, et al., 2019). AR technology has the potential to become an advantageous pedagogical tool in CPM education and benefit students by assisting them in comprehending complex construction processes (Bademosi, Blinn, et al., 2019). Furthermore, the AR technology has the ability to enhance the traditional learning experience as it provides: an interactive learning environment that engages students in teamwork and brainstorming activities resulting in improving communication and problem-solving skills, supporting discovery-based learning where students take control of their learning process, and the ability to make mistakes that in real-site would lead to safety and health-related problems (Behzadan et al., 2011). Behzadan et al. (2011) proposed a collaborative AR system as a supportive learning tool for the existing education methods in order to help students to gain an in-depth understanding of equipment operation and related operational safety. The study developed the first generation MagicBook (GEN-1), an AR-based enhanced book that enables students to manipulate and observe imposed 3D virtual objects while reading the corresponding information. **Error! Reference source not found.** illustrates the major steps of the proposed system and GEN-1. Bademosi, Blinn, et al. (2019) assessed the effectiveness of using AR technology as a novel pedagogical technique to enhance CPM students' understanding of the Spatio-temporal constraints of several construction assemblies. The proposed pedagogical relies on the superimposing of virtual construction elements and objects using AR technology on real-time site videos to bring job site experiences to the classroom. The results indicated that CPM students anticipated in AR-based lectures were better able to identify the construction components when compared to those students who anticipated in traditional in-class lectures. Furthermore, the results revealed that incorporating AR as a supplement tool in the classroom is the best tactic to promote the educational experience of CPM students (Bademosi, Blinn, et al., 2019). Wu et al. (2019) explored the potential use of AR and VR as a construction education tool and workforce development through conducting a comparative analysis between student novices and professional experts in terms of design review and assessment. The results indicated no statistically significant differences between students and experts, despite students' apparent lack of experience. Wu et al. (2019) proposed using AR and VR to bridge experience gaps in existing construction education and training, thereby accelerating the development of experience among students and refine a skilled workforce.

Figure 6.8. *(left) The first generation Magicbook (right) Major steps of the system (Behzadan et al., 2011)*

6.6.1.4 *Facility management*

Within the scope of facility management, managers often need to connect physical objects to database-like text-based information (Irizarry, Gheisari, Williams, & Walker, 2013). Access to the location or equipment-related information is supposed as the basis of the facility management system (Baek, Ha, & Kim, 2019). AR technology is, therefore, an excellent candidate to assist facility managers with their routine tasks where it provides an integrated interface for a live view of a space supplemented by database information (Irizarry et al., 2013). Few studies related to the application of AR technology in facility management as its activities start after the construction phase and usually in an indoor environment (Irizarry et al., 2013; Williams, Gheisari, Chen, & Irizarry, 2015). As (Table 6.5) illustrates, three studies have been identified within our search scope as an AR application in facility management. Irizarry et al. (2013) presented the first mobile AR as a data-access tool for facility management called InfoSPOT (Information Surveyed Point for Observation and Tracking). Williams et al. (2015) proposed a cost-effective and efficient tool called BIM2MAR that aims to assist managers in accessing information related to their tasks within the scope of facility management. The proposed tool relies on a process of bringing BIM data to a mobile AR environment. Baek et al. (2019) integrated AR technology and image-based indoor localization to develop facility management systems. The system assesses a user's orientation and position by comparing the user's perspective to BIM data based on a deep learning computation. The proposed system was evaluated through an expert interview and a real case study. The case study scenario represented a general facility management situation when a current location and related information of sanitary pipe was needed for a facility manager **Error! Reference source not found.**. The results revealed an agreement that AR is a powerful and effective tool for displaying facility management information and expected that the proposed system would effectively ease communication among on-site workers than using verbal explanation (Baek et al., 2019).

Figure 6.9. *Detection of sanitary pipe location using AR and image-based indoor localization (Baek et al., 2019)*

6.6.1.5 *Visualization*

The identified AR-related studies as a visualization tool contribute by 15% (7 studies) among the analyzed studies. The identified aspects for AR as a visualization tool in the CPM domain were including "Design Review" (Wang & Dunston, 2008; Wang & Dunston, 2013), "Design and Constructability Review" (Alsafouri & Ayer, 2019a, 2019b; Wang & Dunston, 2013), and "Visualization of Simulated Construction Operations" (Chen, Chi, Kang, & Hsieh, 2016; Hammad, Wang, & Mudur, 2009). Using AR as visualization for collaborative design review assists in completing tasks much faster than the paper-based method, provides a higher level of immersion than paper drawing, could better facilitate problem-solving and creativity, and increase the productivity of work in a given amount of time (Wang & Dunston, 2008; Wang & Dunston, 2013). Alsafouri and Ayer (2019a) investigated how different mobile display devices presenting the same AR environment may affect users' behaviours in a design review context. The study guides practitioners and academics when planning for what devices to purchase for AR-based design review sessions (Alsafouri & Ayer, 2019a). Alsafouri and Ayer (2019b) found out that mobile AR can enable most of the actions and outcomes reported by prior works that used VR-based mock-ups or physical mock-ups. Furthermore, it was suggested that using different mobile computing devices presents the same AR environment led to different behaviours among users. Augmented Reality can help to precisely visualize the suggested excavation area as well as digitizing existing underground utilities. Figure 6.10 showed an x-ray view of the underground utilities in a digging machine’s vicinity, enabling excavation operators to avoid accidental utility strikes consciously (Dong & Kamat, 2013). Operation simulation could enable construction engineers to improve and estimate equipment productivity by modifying equipment composition and logistics. The development of AR technology brings high opportunities for interactive and collaborative construction equipment operation modelling (Kim, Kim, & Kim, 2012). Kim et al. (2012) proposed an AR-based system for identifying the optimum equipment operation scenario within dynamic, changeable construction progress. The study results demonstrate that the system has a robust prospect for significant advances in the construction planning process (Kim et al., 2012). Behzadan and Kamat (2009) proposed a method that could automatically create operation-level construction animations in outdoor AR.

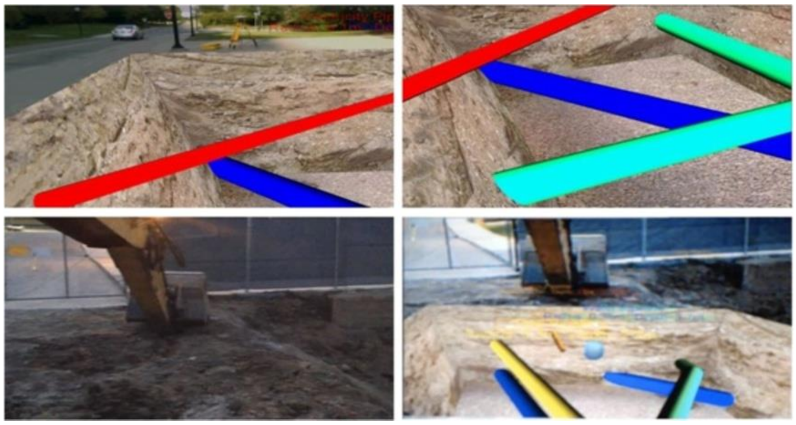

Figure 6.10. *An x-ray of the underground utilities using AR (Dong & Kamat, 2013)*

6.6.1.6 *Communication and data acquisition*

Effective communication and information management are crucial issues to the successful delivery of construction projects (Ahmed, 2019; Bae, Golparvar-Fard, & White, 2015). Communication and data acquisition as an application area for AR technology was identified in 9 studies. AR has been proposed as a technology to enhance the information retrieval process from BIMs to improve the effectiveness and efficiency of workers' tasks. Chu et al. (2018) used AR technology and BIM to enhance the workers' productivity by improving the information retrieval process. Using the proposed system enabled the participants to complete their tasks about 50% faster than using 2D paper-based documentation, decreased the participants' mental workload, and reduced learning curve times compared to paper manuals (Chu et al., 2018). Bae et al. (2015) proposed a system that integrates markerless AR technology and image-based localization techniques to conduct field reporting and access project information. The study results revealed that the proposed system indeed could enhance the on-site information retrieval process and prompt field reporting (Bae et al., 2015). Kim, Park, Lim, and Kim (2013) developed an AR-based on-site management system focused on three main functions: real-time information sharing, task management, and site monitoring (Figure 6.11). The results indicated that the proposed system has the potential to enhance the existing on-site management process. Furthermore, the results revealed the following benefits of the proposed system: a reduction in construction time; through providing real-time access to the project information databases, through providing effective information sharing and the appropriate work order the system can minimize the possibilities of rework, and improving the quality of a construction project through providing work task information for site engineers (Kim, Park, et al., 2013). Various researchers have also investigated the implementation of AR technology as a communication and information retrieval tool (Bae, Golparvar-Fard, & White, 2013; Lin, Liu, Tsai, & Kang, 2015; Ratajczak, Riedl, & Matt, 2019; Tsai & Yau, 2014; Yeh, Tsai, & Kang, 2012).

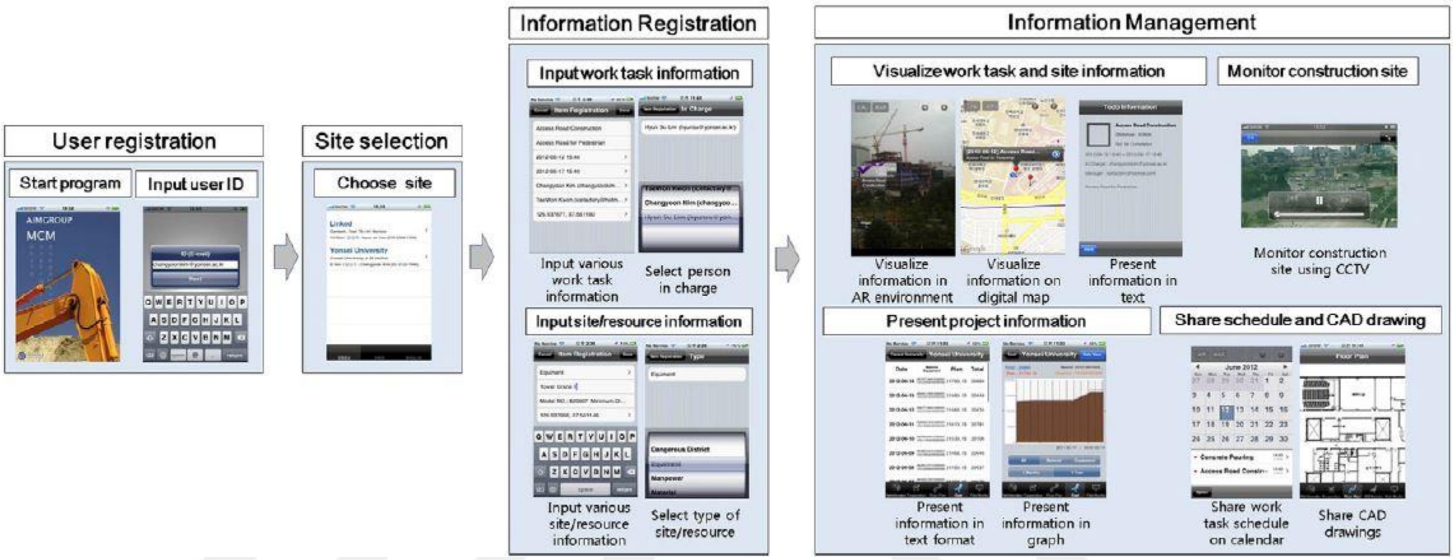

Figure 6.11. *User interface flow (Kim, Park, et al., 2013)*

6.6.1.7 *Safety Management*

The construction industry is one of the most dangerous industries where serious accidents and high death rates are still encountered, resulting in serious cost overruns and project delays (Getuli, Capone, Bruttini, & Isaac, 2020; Le, Pedro, Lim, et al., 2015). As illustrated in (Table 6.5), the results demonstrate a strong focus on developing AR-based systems to enhance construction safety management practices. Safety management represents the highest rate (36%) as an application area of AR technology among the identified application areas.

Many researchers investigated the efficiency of using AR technology as a safety training tool, especially regarding the hazard identification aspect and heavy equipment operator training (Eiris, Gheisari, & Esmaeili, 2018; Han et al., 2009; Sekizuka et al., 2017). Park and Kim (2013) proposed a framework called safety management and visualization system (SMVS), integrating AR and BIM for reflecting the processes of safety planning, education and inspection. It is believed that the proposed framework has a significant potential to enhance the identification of safety risks and could enhance the real-time communication between managers and workers (Park & Kim, 2013). Pereira, Moore, Gheisari, and Esmaeili (2019) presented in their study that panoramic AR can provide an immersive safety training experience for construction professionals and workers. Using 360-degree AR panoramic as a safety training tool provides comparable outcomes to the traditional Occupational Safety and Health Administration (OSHA) training interventions while using AR reduces the required time for risk perception and hazard identification significantly (Eiris, Jain, Gheisari, & Wehle, 2020). Kim, Kim, and Kim (2017) proposed a construction hazard avoidance system using AR technology and image-based localization technique (**Error! Reference source not found.**). The proposed system involves three modules: site monitoring module, safety assessment module, and visualization module. The system enables workers to avoid hazards by proactively providing hazard information (Kim et al., 2017).

Safety education is one of the important aspects of safety management to provide a safe and healthy work environment in construction. Le, Pedro, Lim, et al. (2015) presented a framework for using mobile AR and VR for experiential construction safety education. The study results revealed that the proposed framework could enrich safety education in terms of hazard recognition skills and awareness of safety procedures (Le, Pedro, Lim, et al., 2015). Chen et al. (2016) integrated AR technology, BIM, and path planning to develop an assistive interface for a teleoperated crane to overcome many problems associated with crane operation and ensure the quality and safety of the erection tasks.

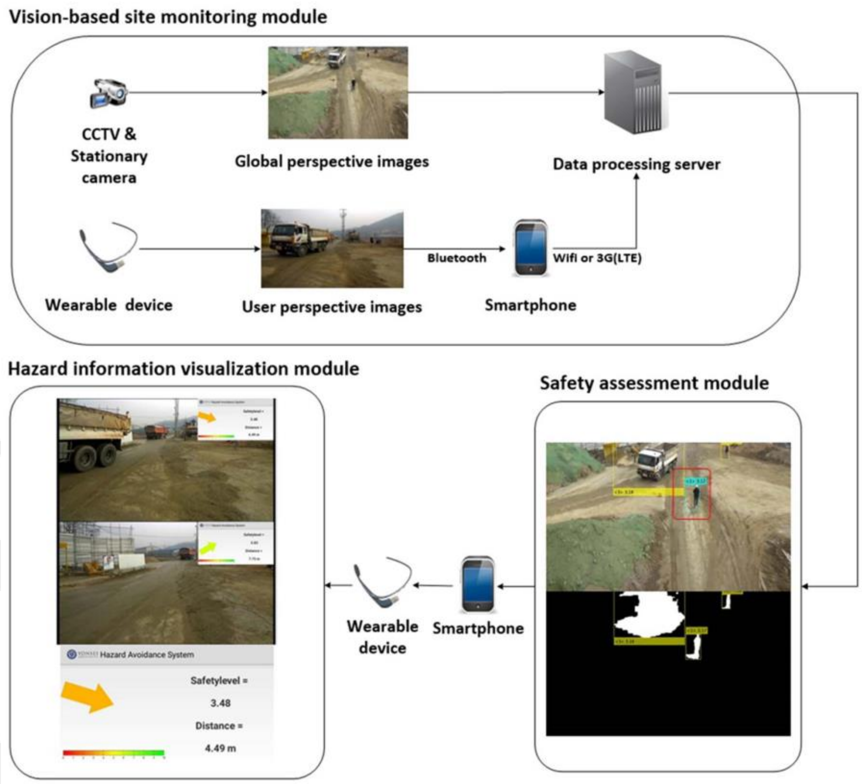

Figure 6.12. *Information flow in the proposed hazard avoidance system (Kim et al., 2017)*

6.6.2 VR

Table 6.6 illustrates the identified application areas of VR technology in the CPM domain.

Table 6.6. *VR application areas in the CPM domain*

Application area	Number of publications	%
Construction safety management	26	51%
Visualization	9	18%
Communication and data acquisition	6	12%
Construction management education	5	10%
Scheduling and project progress tracking	5	10%

6.6.2.1 *Construction safety management*

VR technology has attracted great attention as a valuable construction safety management tool. As indicated in Table 6.6, about 50 % of the included VR-based studies concerned safety management aspects. The typical aspects of VR-based construction safety management can be generally classified as safety planning and safety training and education. Li, Chan, and Skitmore (2012b) used VR to develop an interactive construction safety assessment system called Virtual Safety Assessment System (VSAS). The safety assessment system could assess workers' awareness in identifying unsafe working environments, unsafe working attitudes, and unsafe working methods (Li et al., 2012b). Getuli et al. (2020) integrated IVR with BIM to facilitate the sharing of safety-related information, enhancing construction workspace planning.

Construction safety education and training programs have proven to affect construction job sites' safety performance (Pedro et al., 2016). These programs are crucial for providing solid knowledge and cultivating skills for novices or students before entering the construction industry, which aids reduce injuries and fatal accidents rates on construction sites (Pham et al., 2018). Safety knowledge is usually gained through traditional education or training methods, which in many cases were found inadequate to engage and motivate learners or trade workers to learn about safety and health matters and unable to provide realistic and practical experiences (Le, Pedro, Lim, et al., 2015; Pedro et al., 2016). VR technology affords new opportunities for effective construction safety education and training of students and workers, providing higher risk cognition and fewer hazard exposure (Li et al., 2018). In order to improve the construction safety experiential learning, (Le, Pedro, & Park, 2015) proposed a social VR-based system that enables learners to implement role-playing, dialogic learning, and social interaction for construction safety education. In order to enrich the construction safety experiential learning, (Le, Pedro, Lim, et al., 2015) proposed a framework of using mobile VR and AR technologies that reflects the typical safety education process. The proposed system involves three modules that enable transferring safety knowledge to students, cementing students ability to recognize risks and hazards, and assessing the gained safety knowledge (Le, Pedro, Lim, et al., 2015). In order to improve traditional construction education, (Pedro et al., 2016) proposed a Virtual Construction Safety Education (VSES) framework that incorporates safety content to current construction safety management curricula. It is suggested that the proposed framework can enhance students' ability to identify hazards and improve their safety knowledge (Pedro et al., 2016). Pham et al. (2018) used panoramic VR to develop a construction safety education system called Virtual Field Trip System (VIFITS). VIFITS is considered a powerful pedagogical tool that brings construction field trips to classrooms, provides practical safety experience, and improves students' safety knowledge compared with traditional education methods (Pham et al., 2018). Li et al. (2012a) developed a Multiuser Virtual Safety Training System (MVSTS) that provides close-to-reality training for workers involved in tower crane dismantlement. The results revealed valuable advantages of the proposed system: it provides totally risk-free training compared to traditional training. It motivates trainees to learn and enables trainees to identify their weakness areas (Li et al., 2012a). Sacks, Perlman, and Barak (2013) investigated the efficiency of using IVR for workers training and found out that IVR provides more effective safety training and maintains a higher level of trainees' awareness and concentration than conventional training methods. In order to improve the safety training of crane operators, (Fang, Teizer, & Marks, 2014) proposed a VR-based framework for an as-built virtual environment. The system aimed to provide a free-risk environment for crane operators to expose them to potential hazards and train them for developing timely and reasonable responses to these hazards (Fang et al., 2014). For safety managers, the safety planning gets high priority to identify hazards in advance of work on site (Li et al., 2018). Several VR-based systems have been developed to enhance hazard identification and recognition (Jeelani, Han, & Albert, 2017; Jeelani, Han, & Albert, 2020; Lu & Davis, 2018). Results revealed that using VR technology for hazard identification enhances users' perception of risks and assessing higher risk levels compared with traditional methods of hazard identification (Li et al., 2018; Perlman et al., 2014).

6.6.2.2 *Visualization*

As illustrated in (Table 6.6), VR technology as a visualization tool was found at 18% with nine studies. Recent researches proposed VR technology as a highly valued tool for collaborative decision-making in the design review process (Boton, 2018; Liu, Lather, & Messner, 2014; Zaker & Coloma, 2018). Paes and Irizarry (2018) evaluated the usability of

IVR technology as a visualization tool for design review from the users' standpoint. The results revealed the efficiency of VR in communicating design ideas and enhancing the communication in design review meetings among stakeholders (Paes & Irizarry, 2018). Calderon-Hernandez, Paes, Irizarry, and Brioso (2019) found that VR technology as a visualization tool could perform more effectively in terms of user's perception accuracy and memory and comprehension of objects compared with 2D paper-based drawings. Berg, Hartmann, and Graaf (2017) provided in-depth insights into how clients and designers could use VR to support the design review process with pre-meetings using VR environments. The Walk-through VR model enabled clients to visualize a project in advance and detect problematic design issues; moreover, the clients who used VR were empowered to contribute to the discussion related to identified design issues and participating feedback on a design proposal (Berg et al., 2017). Liu, Castronovo, Messner, and Leicht (2020) evaluated the impact of VR on design review meetings and provided to project teams valuable insights into the pros and cons of adopting VR to support design review meetings. To overcome one of the most technical problems with the existing VR, which is the difficulty and time consuming of converting design data into VR displays, (Du, Zou, Shi, & Zhao, 2018) proposed a BIM-VR based system called BVRS that enables real-time automation of the updates of design information in VR displays automatically and simultaneously (Figure 6.13).

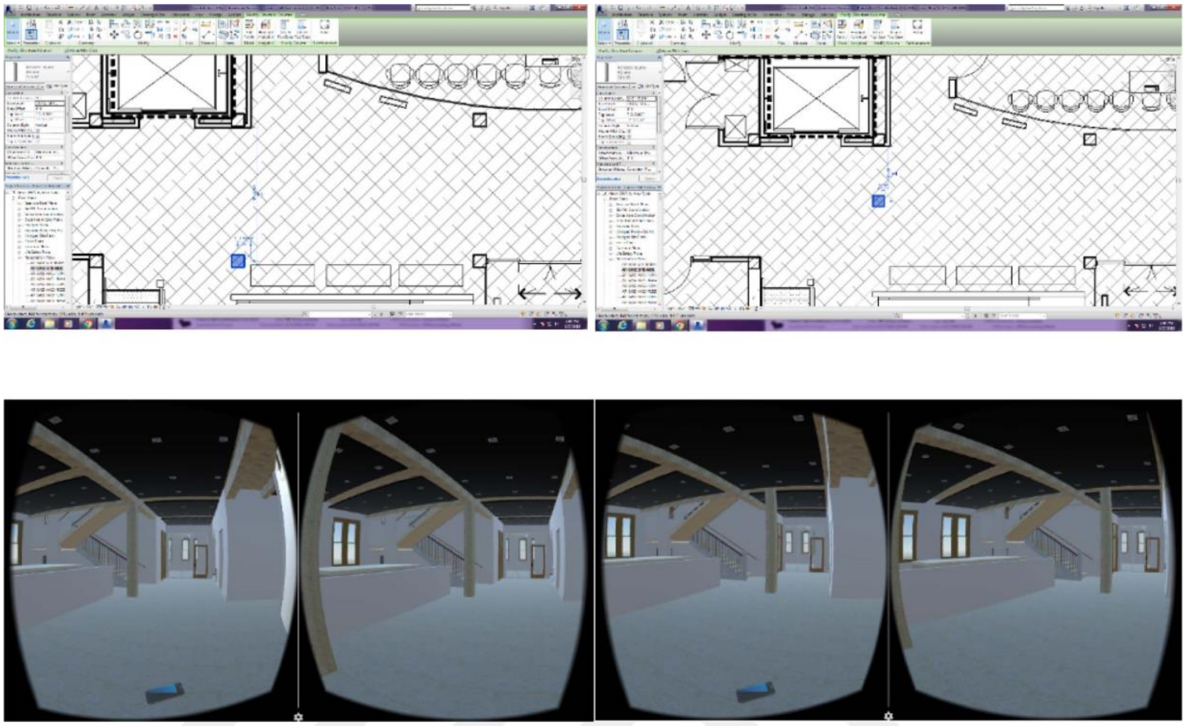

Figure 6.13. *Synchronization of location changes of a column via BVRS (Du, Zou, et al., 2018)*

6.6.2.3 ***Construction management education***

As illustrated in (Table 6.6), VR technology as a pedagogical tool for teaching construction management concepts was found at 10% with five studies. The value of VR technology as a pedagogical tool returns to providing students with the opportunity to explore and visualize 3D construction information in real-time and dynamic environments (Nikolic, Jaruhar, & Messner, 2011). Le, Pedro, Pham, and Park (2016) proposed a VR-based system to provide an experiential learning experience to prevent defects and enhance construction quality knowledge. The results revealed that the proposed system compared with the traditional lectures is more interactive and engaging, proving its simplicity and ease to follow. Furthermore, the results showed the system's capability to improve the learners' defect identification abilities and risk cognition (Le et al., 2016). Three generations of virtual construction simulators were developed for teaching construction management concepts VCS 1 (Lee, Scholar, & Messner, 2010), VCS 2 (Nikolic et al., 2011), VCS 3 (Lee, Nikolic, & Messner, 2015). The developed simulators enabled learners to create, visualize, and review construction schedules. The results showed the ability of the simulators to enhance the learners' knowledge of time, cost, resource management, as well as factors that affect construction progress (Lee et al., 2015).

6.6.2.4 *Communication and data acquisition*

Recently the construction industry has paid great attention to VR technology as a project communication tool (Du, Shi, et al., 2018). Houck, Hassan, Thiis, and Solheim (2013) assessed the use of VR technology as a multidisciplinary communication tool in an early phase of projects and found out that VR technology should be considered as a useful multidisciplinary communication tool for both professionals and non-professionals. Du, Shi, et al. (2018) proposed a VR-based system called Collaborative Virtual Reality (CoVR) as an interactive project communication tool. The proposed system enhances communication in construction tasks and reduces the number of change orders and requests for information (Du, Shi, et al., 2018). Using VR technology and on-site cameras, (Liu, Wu, Tsai, & Kang, 2018) developed a novel method for retrieving spatial information. Based on geometric information such as dimensions and position data of construction objects retrieved from on-site videos, the developed model allows to create and update real-time virtual construction scene reflecting site conditions which enable engineers to distinguish safe areas and hazard areas, to re-plan construction operations on a virtual environment instead of risking them in a real construction site (Liu et al., 2018). Abbas, Choi, Seo, Cha, and Li (2019) assessed the effectiveness of using IVR technology as a project communication tool through a comparative analysis between IVR-based communication and traditional face-to-face (FtF) discussion and found out that both methods provided effective communication regarding communication richness, communication openness, and discussion quality.

6.6.2.5 *Scheduling and project progress tracking*

Kim and Kano (2008) proposed a new method of construction progress control by comparing photo images of a real construction site, which reflects the exact site situation, with the planned VR images simulated in a virtual environment (Figure 6.14). The comparing process of both real and virtual images enables observing the differences between as-planned and as-built models. It enables retrieving of useful information with feedback on the planning of the construction process (Kim & Kano, 2008). Change orders are one of the most common reasons for construction delays. Balali, Noghabaei, Heydarian, and Han (2018) integrated the

IVR technology with BIM and cost database to develop a cost estimating approach that enables engineers and stakeholders to visualize and interact with models in realistic virtual environments and comprehend the dollar amount changes resulting from change orders. The results revealed that the proposed system could be considered a cost estimation tool that allows conducting change orders virtually and assessing alternative designs and construction methods to present the cost impacts with each change (Balali et al., 2018; Balali, Zalavadia, & Heydarian, 2020). Bademosi, Tayeh, and Issa (2019) proposed a framework for integrating technology and BIM to streamline the construction cost estimation process.

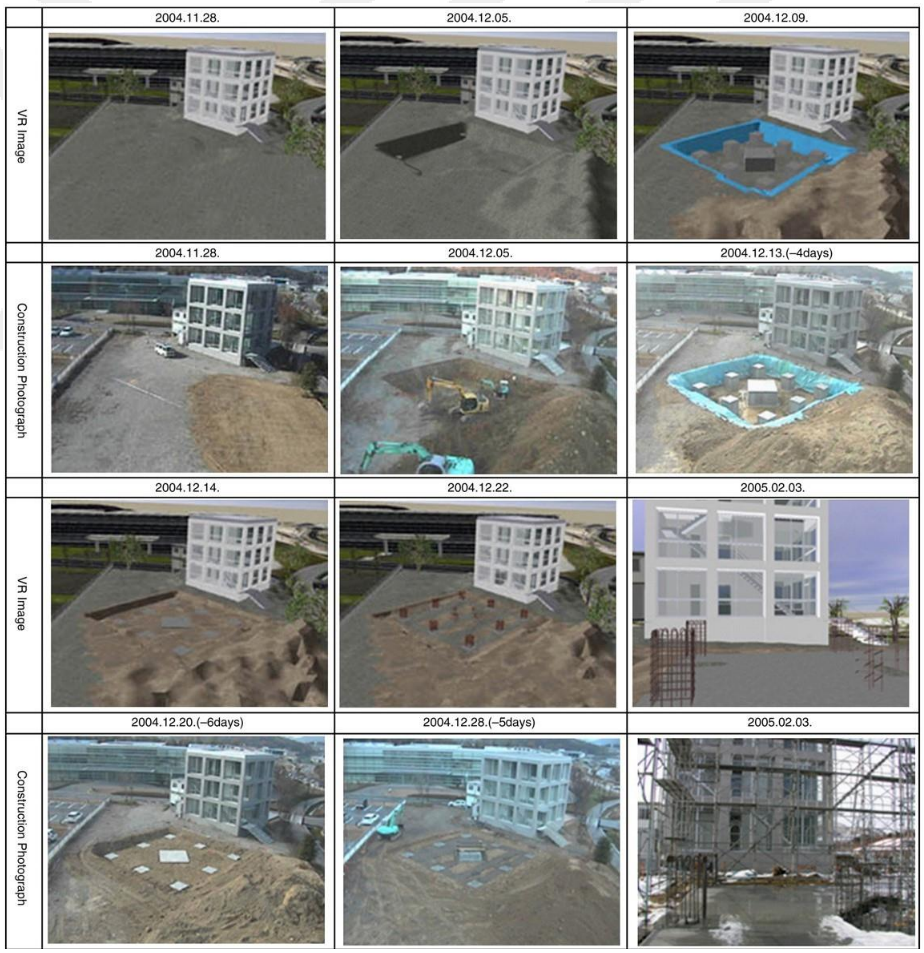

Figure 6.14. *Comparison of VR images and construction photographs (Kim & Kano, 2008)*

7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The AEC industry is increasingly moving towards embracing digitally managed information and visualization platforms (Chi, Kang, & Wang, 2013b). Recently, many researchers have paid considerable attention to the implementations of AR and VR technologies in the AEC industry due to the rapid growth of application areas and the advancement of computational software and hardware of these technologies (Chi et al., 2013b; Liu & Seipel, 2018; Shin & Dunston, 2008). In recent years, many researchers have focused on the implementation of AR and VR technologies concerning CPM aspects, where these technologies have shown promising futures to advance the CPM domain and have shown a significant contribution to the advancement of this sector in many areas such as cost and time management, defect management, safety management, education and training, progress monitoring and tracking, and on-site information access (Ahmed, 2019). However, there is a lack of a structured review that synthesizes the existing knowledge body about the implementation of AR and VR technologies in the various aspects of CPM. Therefore, this study tries to fill this gap by introducing a structured, comprehensive scoping review to reflect these technologies' present status in the CPM domain. This study provides a breadth of coverage of the available literature about AR and VR technologies in the CPM, which provides a better understanding of the nature, size, and scope of research activity in this field. Furthermore, this study aims to identify the main application areas of AR and VR technologies in the CPM and the characteristics of these technologies, which in turn provides a comprehensive platform for the researchers and practitioners to explore the potential application areas, understand the effective use of these technologies, and propose new use cases.

This study presents a scoping review on the application areas of AR and VR technologies in the CPM domain. The review aims to exploring the size, range, and nature of the existing literature about the AR and VR applications in the CPM and identifying the key application areas of these technologies in the CPM domain. The review methodology followed the main five steps proposed by (Arksey & O'Malley, 2005), which are: identifying a research question, identifying relevant studies, Study selection, Charting the data, Collating, summarizing and reporting the results. Firstly, appropriate broad research questions that aligned with the research aims were identified. Secondly, identifying the relevant studies process was started from different sources. Thirdly, the study selection process was conducted through a two-stage screening process, which yielded to including 94 relevant studies in the final analysis. The fifth step includes extracting the important data and variables from the full-text records to address the research questions. The last step provides descriptive summaries about classifying studies by publication date, publication source, country, Study Design, and technology features; furthermore, it provides narrative summaries of the identified application areas. The main results can be concluded as follows:

Publication year: Within the study's timespan, 2018 represents the peak year according to the number of publications with 20 publications per year.

Publication venue and study design: "Automation in Construction" journal has the highest publication rate (21%) among the identified journals, and "American Society of Civil Engineering (ASCE) Conferences" has the highest publication rate (17%) among the identified conferences. The quantitative method with 66% is the most frequent research method among included studies.

Geographical location: the USA with 42 studies comes first as the geographical location of the institution or university belonging to the authors.

Display method and interaction devices: The hand-held displays and touch screens were the most used display method and interaction displays for AR hardware. For VR hardware HMDs and controllers were the most used display method and interaction display.

VR level of immersion: The full-immersive VR system has the highest use rate in 18 studies among the VR-related included studies. Despite the expensive cost of such systems, it is preferred because of its ability to provide the highest level of immersion.

AR spatial registration methods: The marker-based “2D image recognition” method was the most widely used spatial registration method for AR systems within the included studies. It represents more than 50% (20 out of 38) of the identified methods. The high use of this method may be returned to the simplicity, efficiency, and convenience of image recognition for superimposing virtual objects to the real world.

AR application areas: the potential application areas of AR technology in the CPM domain were identified as: Safety management, Communication and data acquisition, Visualization, Construction management education, Scheduling and project progress tracking, Defect and quality management, Facility management.

VR application areas: the potential application areas of VR technology in the CPM domain were identified as: Construction safety management, Visualization, Communication and data acquisition, Construction management education, Scheduling and project progress tracking.

It is clear from the recent researches that there is a massive contribution to developing AR and VR systems for use in the construction safety management aspects. Many studies have proven the efficiency of these technologies for use in many aspects regarding safety management such as hazard recognition, safety training and education, and construction equipment operator training. AR and VR technologies implementations regarding project scheduling and construction progress tracking has a great potential to enhance the traditional methods, and it is proposed to have a promising role in the advanced CPM domain. AR and VR are proven tools for improving communication and data acquisition. AR technology has proved its ability to enhance on-site information retrieval, improving the effectiveness and efficiency of workers' tasks, and prompting field reporting, while VR technology proposed as a valuable tool for a multidisciplinary communication tool in early phase of projects. AR is greatly appreciated by researchers for its efficiency in defect and quality management aspects, as it is distinguished from traditional methods by playing an important role by providing proactive prevention of many defects in a construction site and enabling inspectors and site managers to check errors more efficiently and remotely. Both AR and VR technologies are highly proposed as a pedagogical tool for teaching CPM aspects and concepts, where both technologies have proven their efficiency compared to the traditional learning methods in teaching CPM concepts. The advantages of both VR and AR played an important role in using it for the purpose of visualization. Both technologies are proven tools for supporting design and constructability review meetings by enhancing decision making in the design review process and enhancing the communication among stakeholders.

7.2 Recommendations

It is recommended to explore the limitations and drivers of the adoption of AR and VR technologies in the CPM domain.

It is recommended to critically compare each technology's proposed systems and prototypes under each identified application area.

8 REFERENCES

Abbas, A., Choi, M., Seo, J., Cha, S. H., & Li, H. (2019). Effectiveness of Immersive Virtual Reality-based Communication for Construction Projects. *KSCE Journal of Civil Engineering, 23*(12), 4972-4983. doi:10.1007/s12205-019-0898-0

Ahmed, S. (2018). A review on using opportunities of augmented reality and virtual reality in construction project management. *Organization, technology and management in construction*, *10*(1), 1839-1852.

Ahmed, S. (2019). A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management. *Organization Technology and Management in Construction*, *11*(1), 1839-1852. doi:10.2478/otmcj-2018-0012

Ahmed, S., Hossain, M. M., & Hoque, M. I. (2017). A brief discussion on augmented reality and virtual reality in construction industry. *Journal of System Management Sciences, 7*(3), 1-33.

Akkoyun, I., & Dikbas, A. (2008). Performance in construction: A literature review of research in construction management journals. *Project Management Centre, Istanbul Technical University, Turkey*.

Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., & Golparvar-Fard, M. (2014). Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality. *Journal of Construction Engineering and Management, 140*(7), 04014024. doi:doi:10.1061/(ASCE)CO.1943-7862.0000860

Alsafouri, S., & Ayer, S. K. (2019a). Leveraging Mobile Augmented Reality Devices for Enabling Specific Human Behaviors in Design and Constructability Review. *Advances in Civil Engineering*, *2019*, 11. doi:10.1155/2019/3951986

Alsafouri, S., & Ayer, S. K. (2019b). Mobile Augmented Reality to Influence Design and Constructability Review Sessions. *Journal of Architectural Engineering, 25*(3), 11. doi:10.1061/(asce)ae.1943-5568.0000362

Anwar, B., Xiao, Z., Abbas, H. W., & Ali, Z. (2018). Meta review of critical risk factors in PPP projects of emerging nations in South Asia. *The Journal of Developing Areas, 52*(1), 183-209.

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International journal of social research methodology*, *8*(1), 19-32.

Aromataris, E., Fernandez, R., Godfrey, C. M., Holly, C., Khalil, H., & Tungpunkom, P. (2015). Summarizing systematic reviews: methodological development, conduct and reporting of an umbrella review approach. *International journal of evidence-based healthcare, 13*(3), 132-140.

Aromataris, E., & Munn., Z. (2020). Chapter 1: JBI Systematic Reviews. *JBI Manual for Evidence Synthesis.* Retrieved from https://wiki.jbi.global/display/MANUAL/Chapter+1%3A+JBI+Systematic+Reviews

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *IEEE computer graphics and applications, 21*(6), 34-47.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments, 6*(4), 355-385.

Bademosi, F., Blinn, N., & Issa, R. R. A. (2019). USE OF AUGMENTED REALITY TECHNOLOGY TO ENHANCE COMPREHENSION OF CONSTRUCTION ASSEMBLIES. *Journal of Information Technology in Construction, 24*, 58-79.

Bademosi, F., & Issa, R. R. A. (2018). *Business Value of Augmented Reality in the Construction Industry*. New York: Amer Soc Civil Engineers.

Bademosi, F. M., Tayeh, R., & Issa, R. R. A. (2019). *An Immersive Approach to Construction Cost Estimating.* Paper presented at the Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation, New York.

Bae, H., Golparvar-Fard, M., & White, J. (2013). High-Precision and Infrastructure-Independent Mobile Augmented Reality System for Context-Aware Construction and Facility Management Applications. In *Computing in Civil Engineering (2013)* (pp. 637-644).

Bae, H., Golparvar-Fard, M., & White, J. (2015). Image-Based Localization and Content Authoring in Structure-from-Motion Point Cloud Models for Real-Time Field Reporting Applications. *Journal of Computing in Civil Engineering, 29*(4), B4014008. doi:doi:10.1061/(ASCE)CP.1943-5487.0000392

Baek, F., Ha, I., & Kim, H. (2019). Augmented reality system for facility management using image-based indoor localization. *Automation in Construction, 99*, 18-26. doi:10.1016/j.autcon.2018.11.034

Baker, J. D. (2016). The Purpose, Process, and Methods of Writing a Literature Review. *AORN journal, 103*(3), 265-269. doi:10.1016/j.aorn.2016.01.016

Balali, V., Noghabaei, M., Heydarian, A., & Han, K. (2018). *Improved Stakeholder Communication and Visualizations: Real-Time Interaction and Cost Estimation within Immersive Virtual Environments.* Paper presented at the Construction Research Congress 2018: Construction Information Technology, New York.

Balali, V., Zalavadia, A., & Heydarian, A. (2020). Real-Time Interaction and Cost Estimating within Immersive Virtual Environments. *Journal of Construction Engineering and Management, 146*(2), 10. doi:10.1061/(asce)co.1943-7862.0001752

Barnard, D. (2019). History of VR - Timeline of Events and Tech Development. Retrieved from https://virtualspeech.com/blog/history-of-vr

Behzadan, A., & Kamat, V. R. (2007). Georeferenced registration of construction graphics in mobile outdoor augmented reality. *Journal of computing in civil engineering, 21*(4), 247-258.

Behzadan, A. H., Iqbal, A., & Kamat, V. R. (2011). A COLLABORATIVE AUGMENTED REALITY BASED MODELING ENVIRONMENT FOR CONSTRUCTION ENGINEERING AND MANAGEMENT EDUCATION. In S. Jain, R. Creasey, & J. Himmelspach (Eds.), *Proceedings of the 2011 Winter Simulation Conference* (pp. 3568-3576). New York: Ieee.

Behzadan, A. H., & Kamat, V. R. (2009). Automated Generation of Operations Level Construction Animations in Outdoor Augmented Reality. *Journal of Computing in Civil Engineering, 23*(6), 405-417. doi:10.1061/(asce)0887-3801(2009)23:6(405)

Behzadi, A. (2016). Using augmented and virtual reality technology in the construction industry. *American journal of engineering research, 5*(12), 350-353.

Berg, M., Hartmann, T., & Graaf, R. (2017). SUPPORTING DESIGN REVIEWS WITH PRE-MEETING VIRTUAL REALITY ENVIRONMENTS. *Journal of Information Technology in Construction, 22*(16), 305-321.

Boton, C. (2018). Supporting constructability analysis meetings with Immersive Virtual Reality-based collaborative BIM 4D simulation. *Automation in Construction, 96*, 1-15. doi:10.1016/j.autcon.2018.08.020

Bouchlaghem, D., Shang, H., Whyte, J., & Ganah, A. (2005). Visualisation in architecture, engineering and construction (AEC). *Automation in Construction, 14*(3), 287-295.

Burdea, G. C., & Coiffet, P. (2003). *Virtual reality technology*: John Wiley & Sons.

Calderon-Hernandez, C., Paes, D., Irizarry, J., & Brioso, X. (2019). Comparing Virtual Reality and 2-Dimensional Drawings for the Visualization of a Construction Project. In *Computing in Civil Engineering 2019* (pp. 17-24).

Chalmers, I., Hedges, L. V., & Cooper, H. (2002). A Brief History of Research Synthesis. *Evaluation & the Health Professions, 25*(1), 12-37. doi:10.1177/0163278702025001003

Chen, Y.-C., Chi, H.-L., Hung, W.-H., & Kang, S.-C. (2011). Use of tangible and augmented reality models in engineering graphics courses. *Journal of Professional Issues in Engineering Education Practice, 137*(4), 267-276.

Chen, Y. C., Chi, H. L., Kang, S. C., & Hsieh, S. H. (2016). Attention-Based User Interface Design for a Tele-Operated Crane. *Journal of Computing in Civil Engineering, 30*(3), 12. doi:10.1061/(asce)cp.1943-5487.0000489

Cheng, J., Chen, K., & Chen, W. (2020a). State-of-the-Art Review on Mixed Reality Applications in the AECO Industry. *Journal of Construction Engineering and Management, 146*(2), 12. doi:10.1061/(asce)co.1943-7862.0001749

Cheng, J. C., Chen, K., & Chen, W. (2020b). State-of-the-art review on mixed reality applications in the AECO industry. *Journal of Construction Engineering and Management, 146*(2), 03119009.

Chi, H.-L., Kang, S.-C., & Wang, X. (2013a). Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. *Automation in Construction, 33*, 116-122.

Chi, H. L., Kang, S. C., & Wang, X. (2013b). Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. *Automation in Construction, 33*, 116-122. doi:10.1016/j.autcon.2012.12.017

Chu, M., Matthews, J., & Love, P. E. D. (2018). Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study. *Automation in Construction, 85*, 305-316. doi:10.1016/j.autcon.2017.10.032

Colquhoun, H. L., Levac, D., O'Brien, K. K., Straus, S., Tricco, A. C., Perrier, L., . . . Moher, D. (2014). Scoping reviews: time for clarity in definition, methods, and reporting. *Journal of clinical epidemiology, 67*(12), 1291-1294.

Cooper, H., Hedges, L. V., & Valentine, J. C. (2019). *The handbook of research synthesis and meta-analysis*: Russell Sage Foundation.

Cooper, H. M. (1988). Organizing knowledge syntheses: A taxonomy of literature reviews. *Knowledge in society, 1*(1), 104.

Craig, A. B. (2013). *Understanding augmented reality: Concepts and applications*: Newnes.

Craig, A. B., Sherman, W. R., & Will, J. D. (2009). *Developing virtual reality applications: Foundations of effective design*: Morgan Kaufmann.

Daudt, H. M. L., van Mossel, C., & Scott, S. J. (2013). Enhancing the scoping study methodology: a large, inter-professional team’s experience with Arksey and O’Malley’s framework. *BMC medical research methodology, 13*(1), 48.

Davila Delgado, J. M., Oyedele, L., Beach, T., & Demian, P. (2020). Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *Journal of Construction Engineering and Management, 146*(7), 04020079.

Delgado, J. M. D., Oyedele, L., Beach, T., & Demian, P. (2020). Augmented and Virtual Reality in Construction: Drivers and Limitations for Industry Adoption. *Journal of Construction Engineering and Management, 146*(7), 17. doi:10.1061/(asce)co.1943-7862.0001844

Dixon, S. (2006). A history of virtual reality in performance. *International Journal of Performance Arts & Digital Media, 2*(1).

Dong, S., Behzadan, A. H., Chen, F., & Kamat, V. R. A. i. E. S. (2013). Collaborative visualization of engineering processes using tabletop augmented reality. *Advances in Engineering Software, 55*, 45-55.

Dong, S., & Kamat, V. R. (2013). SMART: scalable and modular augmented reality template for rapid development of engineering visualization applications. *Visualization in Engineering, 1*(1), 1. doi:10.1186/2213-7459-1-1

Du, J., Shi, Y. M., Zou, Z. B., & Zhao, D. (2018). CoVR: Cloud-Based Multiuser Virtual Reality Headset System for Project Communication of Remote Users. *Journal of Construction Engineering and Management, 144*(2), 19. doi:10.1061/(asce)co.1943-7862.0001426

Du, J., Zou, Z. B., Shi, Y. M., & Zhao, D. (2018). Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making. *Automation in Construction, 85*, 51-64. doi:10.1016/j.autcon.2017.10.009

Dunston, P. S. J. A. i. C. (2008). Identification of application areas for Augmented Reality in industrial construction based on technology suitability. *Automation in Construction, 17*(7), 882-894.

Eiris, R., Gheisari, M., & Esmaeili, B. (2018). PARS: Using augmented 360-degree panoramas of reality for construction safety training. *International journal of environmental research public health, 15*(11), 2452.

Eiris, R., Jain, A., Gheisari, M., & Wehle, A. (2020). Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context. *Safety Science, 127*, 14. doi:10.1016/j.ssci.2020.104703

Engebø, A., Lædre, O., Young, B., Larssen, P. F., Lohne, J., & Klakegg, O. J. (2020). Collaborative project delivery methods: a scoping review. *Journal of Civil Engineering and Management, 26*(3), 278-303.

Fang, Y., & Teizer, J. (2014). A Multi-User Virtual 3D Training Environment to Advance Collaboration Among Crane Operator and Ground Personnel in Blind Lifts. In *Computing in Civil and Building Engineering (2014)* (pp. 2071-2078).

Fang, Y., Teizer, J., & Marks, E. (2014). *A framework for developing an as-built virtual environment to advance training of crane operators.* Paper presented at the Construction Research Congress 2014: Construction in a Global Network.

Fuchs, P., Moreau, G., & Guitton, P. (2011). *Virtual reality: concepts and technologies*: CRC Press.

Furht, B. (2011). *Handbook of Augmented Reality*: Springer, New York, NY.

Getuli, V., Capone, P., Bruttini, A., & Isaac, S. (2020). BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach. *Automation in Construction, 114*, 20. doi:10.1016/j.autcon.2020.103160

Giraldi, G., Silva, R., & Oliveira, J. (2003). Introduction to virtual reality. *LNCC Research Report, 6*.
Golparvar-Fard, M., Pena-Mora, F., & Savarese, S. (2011). Integrated Sequential As-Built and As-Planned Representation with D(4)AR Tools in Support of Decision-Making Tasks in the AEC/FM Industry. *Journal of Construction Engineering and Management, 137*(12), 1099-1116. doi:10.1061/(asce)co.1943-7862.0000371
Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2009). D4AR–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication. *Journal of Information Technology in Construction (ITcon), 14*(13), 129-153.
Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal, 26*(2), 91-108. doi:10.1111/j.1471-1842.2009.00848.x
Hammad, A., Wang, H., & Mudur, S. P. (2009). Distributed Augmented Reality for Visualizing Collaborative Construction Tasks. *Journal of Computing in Civil Engineering, 23*(6), 418-427. doi:10.1061/(asce)0887-3801(2009)23:6(418)
Hamzeh, F., Abou-Ibrahim, H., Daou, A., Faloughi, M., & Kawwa, N. (2019). 3D visualization techniques in the AEC industry: the possible uses of holography. *Journal of Information Technology in Construction (ITcon), 24*, 239-255.
Han, S., Peña-Mora, F., Golparvar-Fard, M., & Roh, S. (2009). Application of a Visualization Technique for Safety Management. In *Computing in Civil Engineering (2009)* (pp. 543-551).
Houck, L., Hassan, L., Thiis, T., & Solheim, K. (2013). *Virtual Reality as a multidisciplinary communication tool.* Paper presented at the Structures and architecture. ICSA2013 conference proceedings. Taylor & Francis.
Irizarry, J., Gheisari, M., Williams, G., & Walker, B. N. (2013). InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. *Automation in Construction, 33*, 11-23. doi:10.1016/j.autcon.2012.09.002
Jaidka, K., Khoo, C. S. G., & Na, J. C. (2013). Literature review writing: how information is selected and transformed. *Aslib Proceedings, 65*(3), 303-325. doi:10.1108/00012531311330665
Jeelani, I., Han, K., & Albert, A. (2017). Development of Immersive Personalized Training Environment for Construction Workers. In *Computing in Civil Engineering 2017* (pp. 407-415).
Jeelani, I., Han, K., & Albert, A. (2020). Development of virtual reality and stereo-panoramic environments for construction safety training. *Engineering, Construction Architectural Management*.
Joanna Briggs, I. (2014). The Joanna Briggs Institute. Joanna Briggs Institute Reviewers' Manual: 2014 edition. *The Joanna Briggs Institute*.
Kamath, R. S., Dongale, T. D., & Kamat, R. K. (2012). Development of Virtual Reality Tool for Creative Learning in Architectural Education. *International Journal of Quality Assurance in Engineering Technology Education, 2*(4), 16-24.
Kastner, M., Tricco, A. C., Soobiah, C., Lillie, E., Perrier, L., Horsley, T., . . . Straus, S. E. (2012). What is the most appropriate knowledge synthesis method to conduct a

review? Protocol for a scoping review. *BMC medical research methodology, 12*(1), 114.
Khor, W. S., Baker, B., Amin, K., Chan, A., Patel, K., & Wong, J. (2016). Augmented and virtual reality in surgery—the digital surgical environment: applications, limitations and legal pitfalls. *Annals of translational medicine, 4*(23).
Kim, B., Kim, C., & Kim, H. (2012). Interactive Modeler for Construction Equipment Operation Using Augmented Reality. *Journal of Computing in Civil Engineering, 26*(3), 331-341. doi:doi:10.1061/(ASCE)CP.1943-5487.0000137
Kim, C., Park, T., Lim, H., & Kim, H. (2013). On-site construction management using mobile computing technology. *Automation in Construction, 35*, 415-423. doi:10.1016/j.autcon.2013.05.027
Kim, H., & Kano, N. (2008). Comparison of construction photograph and VR image in construction progress. *Automation in Construction, 17*(2), 137-143. doi:10.1016/j.autcon.2006.12.005
Kim, H. S., Kim, S. K., Borrmann, A., & Kang, L. S. (2018). Improvement of Realism of 4D Objects Using Augmented Reality Objects and Actual Images of a Construction Site. *KSCE Journal of Civil Engineering, 22*(8), 2735-2746. doi:10.1007/s12205-017-0734-3
Kim, K., Kim, H., & Kim, H. (2017). Image-based construction hazard avoidance system using augmented reality in wearable device. *Automation in Construction, 83*, 390-403. doi:10.1016/j.autcon.2017.06.014
Kim, M., Wang, X., Love, P., Li, H., & Kang, S.-C. (2013). Virtual reality for the built environment: a critical review of recent advances. *Journal of Information Technology in Construction (ITcon), 18*(2013), 279-305.
King, W. R., & He, J. (2005). Understanding the role and methods of meta-analysis in IS research. *Communications of the Association for Information Systems, 16*(1), 32.
Kiral, I. A., & Comu, S. (2017, 4-7 July). *Safety training for scaffolding and formwork construction by using virtual environment.* Paper presented at the 34th International Conference of CIB W78, Heraklion, Crete, Greece.
Knaflewski, J. (2019). All That You Should Know About Augmented Reality (From a Business Perspective). Retrieved from https://www.itgenerator.com/augmented-reality-for-business/
Kock, N. (2008). E-collaboration and e-commerce in virtual worlds: The potential of Second Life and World of Warcraft. *International Journal of e-Collaboration, 4*(3), 1-13.
Kwon, O. S., Park, C. S., & Lim, C. R. (2014). A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality. *Automation in Construction, 46*, 74-81. doi:10.1016/j.autcon.2014.05.005
Lau, F., & Kuziemsky, C. (2016). *Handbook of eHealth evaluation: an evidence-based approach*.
Le, Q. T., Pedro, A., Lim, C. R., Park, H. T., Park, C. S., & Kim, H. K. (2015). A framework for using mobile based virtual reality and augmented reality for experiential construction safety education. *International Journal of Engineering Education, 31*(3), 713-725.
Le, Q. T., Pedro, A., & Park, C. S. (2015). A Social Virtual Reality Based Construction Safety Education System for Experiential Learning. *Journal of Intelligent & Robotic Systems, 79*(3), 487-506. doi:10.1007/s10846-014-0112-z

Le, Q. T., Pedro, A., Pham, H. C., & Park, C. S. (2016). A virtual world based construction defect game for interactive and experiential learning. *Int. J. Eng. Educ, 32*, 457-467.

Leder, J., Horlitz, T., Puschmann, P., Wittstock, V., & Schutz, A. (2019). Comparing immersive virtual reality and powerpoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making. *Safety Science, 111*, 271-286. doi:10.1016/j.ssci.2018.07.021

Lee, S., Nikolic, D., & Messner, J. I. (2015). Framework of the Virtual Construction Simulator 3 for Construction Planning and Management Education. *Journal of Computing in Civil Engineering, 29*(2), 05014008. doi:doi:10.1061/(ASCE)CP.1943-5487.0000388

Lee, S., Scholar, P.-D., & Messner, J. I. (2010, 16-18 November). *THE VIRTUAL CONSTRUCTION SIMULATOR: EVALUATING AN EDUCATIONAL SIMULATION APPLICATION FOR TEACHING CONSTRUCTION MANAGEMENT CONCEPTS.* Paper presented at the 27th I International Conference of CIB W78, Cairo, Egypt.

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: advancing the methodology. *Implementation science, 5*(1), 69. doi:10.1186/1748-5908-5-69

Li, H., Chan, G., & Skitmore, M. (2012a). Multiuser Virtual Safety Training System for Tower Crane Dismantlement. *Journal of Computing in Civil Engineering, 26*(5), 638-647. doi:10.1061/(asce)cp.1943-5487.0000170

Li, H., Chan, G., & Skitmore, M. (2012b). Visualizing safety assessment by integrating the use of game technology. *Automation in Construction, 22*, 498-505. doi:10.1016/j.autcon.2011.11.009

Li, M. (2010). *Notice of Retraction: Applications of virtual reality technology in construction industry.* Paper presented at the 2010 2nd International Conference on Computer Engineering and Technology.

Li, X., Yi, W., Chi, H. L., Wang, X. Y., & Chan, A. P. C. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction, 86*, 150-162. doi:10.1016/j.autcon.2017.11.003

Liarokapis, F., Mourkoussis, N., White, M., Darcy, J., Sifniotis, M., Petridis, P., . . . Lister, P. F. (2004). Web3D and augmented reality to support engineering education. *World transactions on engineering technology education*

3(1), 11-14.

Library, U. V. (2020). Types of Literature Review. Retrieved from https://guides.hsict.library.utoronto.ca/c.php?g=696870&p=5020041

Lin, T. H., Liu, C. H., Tsai, M. H., & Kang, S. C. (2015). Using Augmented Reality in a Multiscreen Environment for Construction Discussion. *Journal of Computing in Civil Engineering, 29*(6), 9. doi:10.1061/(asce)cp.1943-5487.0000420

Liu, C. W., Wu, T. H., Tsai, M. H., & Kang, S. C. (2018). Image-based semantic construction reconstruction. *Automation in Construction, 90*, 67-78. doi:10.1016/j.autcon.2018.02.016

Liu, F., & Seipel, S. (2018). Precision study on augmented reality-based visual guidance for facility management tasks. *Automation in Construction, 90*, 79-90. doi:10.1016/j.autcon.2018.02.020

Liu, Y., Castronovo, F., Messner, J., & Leicht, R. (2020). Evaluating the Impact of Virtual Reality on Design Review Meetings. *Journal of Computing in Civil Engineering, 34*(1), 13. doi:10.1061/(asce)cp.1943-5487.0000856

Liu, Y., Lather, J., & Messner, J. (2014). Virtual Reality to Support the Integrated Design Process: A Retrofit Case Study. In *Computing in Civil and Building Engineering (2014)* (pp. 801-808).

Lu, X. Q., & Davis, S. (2018). Priming effects on safety decisions in a virtual construction simulator. *Engineering Construction and Architectural Management, 25*(2), 273-294. doi:10.1108/ecam-05-2016-0114

Mandal, S. (2013). Brief introduction of virtual reality & its challenges. *International Journal of Scientific Engineering Research, 4*(4), 304-309.

Mihelj, M., Novak, D., & Beguš, S. (2014). *Virtual reality technology and applications* (Vol. 68): Springer Dordrecht Heidelberg New York London.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems, 77*(12), 1321-1329.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg, 8*(5), 336-341.

Moore, H. F., Eiris, R., Gheisari, M., & Esmaeili, B. (2019). *Hazard Identification Training Using 360-Degree Panorama vs. Virtual Reality Techniques: A Pilot Study.* Paper presented at the Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation, New York.

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC medical research methodology, 18*(1), 143.

Nee, A. Y., Ong, S., Chryssolouris, G., & Mourtzis, D. (2012). Augmented reality applications in design and manufacturing. *CIRP annals, 61*(2), 657-679.

Nikolic, D., Jaruhar, S., & Messner, J. I. (2011). Educational Simulation in Construction: Virtual Construction Simulator1. *Journal of Computing in Civil Engineering, 25*(6), 421-429. doi:doi:10.1061/(ASCE)CP.1943-5487.0000098

Noghabaei, M., Heydarian, A., Balali, V., & Han, K. (2020). Trend Analysis on Adoption of Virtual and Augmented Reality in the Architecture, Engineering, and Construction Industry. *Data, 5*(1), 26.

Oesterreich, T., & Teuteberg, F. (2017). *Evaluating augmented reality applications in construction–a cost-benefit assessment framework based on VoFI.* Paper presented at the 25th European Conference on Information Systems (ECIS), Guimarães, Portugal.

Ong, S., Yuan, M., & Nee, A. (2008). Augmented reality applications in manufacturing: a survey. *International journal of production research, 46*(10), 2707-2742.

Onyesolu, M. O., & Eze, F. U. (2011). Understanding virtual reality technology: advances and applications. *Adv. Comput. Sci. Eng*, 53-70.

Paes, D., & Irizarry, J. (2018). A Usability Study of an Immersive Virtual Reality Platform for Building Design Review: Considerations on Human Factors and User Interface. In *Construction Research Congress 2018* (pp. 419-428).

Paré, G., Trudel, M.-C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management, 52*(2), 183-199.

Park, C. S., & Kim, H. J. (2013). A framework for construction safety management and visualization system. *Automation in Construction, 33*, 95-103. doi:10.1016/j.autcon.2012.09.012

Park, C. S., Lee, D. Y., Kwon, O. S., & Wang, X. (2013). A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. *Automation in Construction, 33*, 61-71. doi:10.1016/j.autcon.2012.09.010

Peddie, J. (2017). *Augmented reality: Where we will all live*: Springer.

Pedro, A., Le, Q. T., & Park, C. S. (2016). Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality. *Journal of Professional Issues in Engineering Education and Practice, 142*(2), 04015011. doi:doi:10.1061/(ASCE)EI.1943-5541.0000261

Pereira, R. E., Gheisari, M., & Esmaeili, B. (2018). Using Panoramic Augmented Reality to Develop a Virtual Safety Training Environment. In *Construction Research Congress 2018* (pp. 29-39).

Pereira, R. E., Moore, H., Gheisari, M., & Esmaeili, B. (2019). Development and usability testing of a panoramic augmented reality environment for fall hazard safety training. In *Advances in informatics and computing in civil and construction engineering* (pp. 271-279): Springer.

Perlman, A., Sacks, R., & Barak, R. (2014). Hazard recognition and risk perception in construction. *Safety Science, 64*, 22-31. doi:10.1016/j.ssci.2013.11.019

Peters, M., Godfrey, C., McInerney, P., Soares, C. B., Khalil, H., & Parker, D. (2015). Methodology for JBI scoping reviews. In *The Joanna Briggs Institute Reviewers manual 2015* (pp. 3-24): The Joanna Briggs Institute.

Peters, M. D., Godfrey, C., McInerney, P., Munn, Z., Tricco, A. C., & Khalil., H. (2020). Chapter 11: Scoping Reviews (2020 version). *JBI Manual for Evidence Synthesis.* Retrieved from https://wiki.joannabriggs.org/display/MANUAL/Chapter+11%3A+Scoping+reviews

Peterson, J., Pearce, P. F., Ferguson, L. A., & Langford, C. A. (2017). Understanding scoping reviews: Definition, purpose, and process. *Journal of the American Association of Nurse Practitioners, 29*(1), 12-16.

Pham, H. C., Dao, N. N., Pedro, A., Le, Q. T., Hussain, R., Cho, S., & Park, C. S. (2018). Virtual Field Trip for Mobile Construction Safety Education Using 360-Degree Panoramic Virtual Reality. *International Journal of Engineering Education, 34*(4), 1174-1191.

Pham, M. T., Rajić, A., Greig, J. D., Sargeant, J. M., Papadopoulos, A., & McEwen, S. A. (2014). A scoping review of scoping reviews: advancing the approach and enhancing the consistency. *Research synthesis methods, 5*(4), 371-385.

Piroozfar, P., Essa, A., & Farr, E. R. (2017a). *The application of Augmented Reality and Virtual Reality in the construction industry using wearable devices.* Paper presented at the The 9th International Conference on Construction in the 21st Century (CITC-9).

Piroozfar, P., Essa, A., & Farr, E. R. P. (2017b). *The application of Augmented Reality and Virtual Reality in the construction industry using wearable devices.* Paper presented at the 9th International Conference on Construction in the 21st Century (CITC-9) Dubai, United Arab Emirates.

Pollock, M., Fernandes, R. M., Becker, L. A., Pieper, D., & Hartling, L. (2018). Chapter V: overviews of reviews. *Cochrane Handbook for Systematic Reviews of Interventions version, 6*.

Pope, H. (2018). Introduction to Virtual and Augmented Reality. *Library Technology Reports, 54*(6), 5-7.

Rankohi, S., & Waugh, L. (2013). Review and analysis of augmented reality literature for construction industry. *Visualization in Engineering, 1*(1), 9. doi:10.1186/2213-7459-1-9

Ratajczak, J., Riedl, M., & Matt, D. T. (2019). BIM-based and AR Application Combined with Location-Based Management System for the Improvement of the Construction Performance. *Buildings, 9*(5), 17. doi:10.3390/buildings9050118

Rumrill, P. D., Fitzgerald, S. M., & Merchant, W. R. (2010). Using scoping literature reviews as a means of understanding and interpreting existing literature. *Work (Reading, Mass.), 35*(3), 399.

Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management Economics, 31*(9), 1005-1017.

Samnani, S. S., Vaska, M., Ahmed, S., & Turin, T. C. (2017). Review typology: The basic types of reviews for synthesizing evidence for the purpose of knowledge translation. *Journal of the College of Physicians and Surgeons Pakistan, 27*(10), 635-641.

Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B., & Schmalstieg, D. (2009). Handheld augmented reality for underground infrastructure visualization. *Personal ubiquitous computing, 13*(4), 281-291.

Schmalstieg, D., & Hollerer, T. (2016). *Augmented reality: principles and practice*: Addison-Wesley Professional.

Schranz, C. (2014). *Augmented Reality in Design.* Paper presented at the International Conference of Design, User Experience, and Usability.

Sekizuka, R., Koiwai, K., Saiki, S., Yamazaki, Y., Tsuji, T., & Kurita, Y. (2017). *A virtual training system of a hydraulic excavator using a remote controlled excavator with augmented reality.* Paper presented at the 2017 IEEE/SICE International Symposium on System Integration (SII).

Sherafat, B., Ahn, C. R., Akhavian, R., Behzadan, A. H., Golparvar-Fard, M., Kim, H., . . . Azar, E. R. (2020). Automated Methods for Activity Recognition of Construction Workers and Equipment: State-of-the-Art Review. *Journal of Construction Engineering and Management, 146*(6), 03120002. doi:doi:10.1061/(ASCE)CO.1943-7862.0001843

Sherman, W. R., & Craig, A. B. (2018). *Understanding virtual reality: Interface, application, and design*: Morgan Kaufmann.

Shin, D., & Dunston, P. S. (2009). Evaluation of augmented reality in steel column inspection. *Automation in Construction, 18*(2), 118-129.

Shin, D. H., & Dunston, P. S. (2008). Identification of application areas for Augmented Reality in industrial construction based on technology suitability. *Automation in Construction, 17*(7), 882-894. doi:10.1016/j.autcon.2008.02.012

Silva, R., Oliveira, J. C., & Giraldi, G. A. (2003). Introduction to augmented reality. *National laboratory for scientific computation, 11*.

Siraj, N. B., & Fayek, A. R. (2019). Risk Identification and Common Risks in Construction: Literature Review and Content Analysis. *Journal of Construction Engineering and Management*, *145*(9), 03119004. doi:doi:10.1061/(ASCE)CO.1943-7862.0001685

Stratton, S. J. (2019). Literature Reviews: Methods and Applications. *Prehospital and Disaster Medicine*, *34*(4), 347-349. doi:10.1017/s1049023x19004588

Straus, S., Tetroe, J., & Graham, I. D. (2013). *Knowledge translation in health care: moving from evidence to practice*: John Wiley & Sons.

Strickland, J. (2007). How Virtual Reality Works. Retrieved from https://electronics.howstuffworks.com/gadgets/other-gadgets/virtual-reality.htm

Teare, G., & Taks, M. (2020). Extending the scoping review framework: a guide for interdisciplinary researchers. *International journal of social research methodology, 23*(3), 311-315.

Thomas, P., & David, W. (1992). *Augmented reality: An application of heads-up display technology to manual manufacturing processes.* Paper presented at the Hawaii international conference on system sciences.

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., . . . Wilson, K. (2016). A scoping review on the conduct and reporting of scoping reviews. *BMC medical research methodology, 16*(1), 15.

Tricco, A. C., Tetzlaff, J., & Moher, D. (2011). The art and science of knowledge synthesis. *Journal of clinical epidemiology, 64*(1), 11-20.

Tsai, M. K., & Yau, N. J. (2014). Using mobile disaster response system in bridge management. *Journal of Civil Engineering and Management, 20*(5), 737-745. doi:10.3846/13923730.2013.802731

Van Krevelen, D. W. F., & Poelman, R. (2010). A survey of augmented reality technologies, applications and limitations. *International journal of virtual reality, 9*(2), 1-20.

Veron, H., Hezel, P., & Southard, D. A. (1994). *Head-mounted displays for virtual reality.* Paper presented at the Helmet-and Head-Mounted Displays and Symbology Design Requirements.

Vince, J. (2004). *Introduction to virtual reality*: Springer Science & Business Media.

Wang, P., Wu, P., Wang, J., Chi, H.-L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *Int J Environ Res Public Health*, *15*(6), 1204.

Wang, X. (2007). Using augmented reality to plan virtual construction worksite. *International Journal of Advanced Robotic Systems, 4*(4), 42.

Wang, X. (2009). Augmented reality in architecture and design: potentials and challenges for application. *International Journal of Architectural Computing, 7*(2), 309-326.

Wang, X., & Dunston, P. S. (2008). User perspectives on mixed reality tabletop visualization for face-to-face collaborative design review. *Automation in Construction, 17*(4), 399-412.

Wang, X., & Dunston, P. S. (2011). Comparative effectiveness of mixed reality-based virtual environments in collaborative design. *IEEE Transactions on Systems, Man, Cybernetics, Part C, 41*(3), 284-296.

Wang, X., & Dunston, P. S. (2013). Tangible mixed reality for remote design review: a study understanding user perception and acceptance. *Visualization in Engineering, 1*(1), 8. doi:10.1186/2213-7459-1-8

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

Wang, X., & Schnabel, M. A. (2008). *Mixed reality in architecture, design, and construction*: Springer Science & Business Media.

Wang, X. Y., Kim, M. J., Love, P. E. D., & Kang, S. C. (2013b). Augmented Reality in built environment: Classification and implications for future research. *Automation in Construction, 32*, 1-13. doi:10.1016/j.autcon.2012.11.021

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *Mis Quarterly, 26*(2), XIII-XXIII.

Wen, J., & Gheisari, M. (2020). Using virtual reality to facilitate communication in the AEC domain: a systematic review. *Construction Innovation, 20*(3).

Whittemore, R., Chao, A., Jang, M., Minges, K. E., Park, C. J. H., & Lung. (2014). Methods for knowledge synthesis: an overview. *Heart & Lung, 43*(5), 453-461.

Whyte, J. (2002). *Virtual reality and the built environment*: Routledge.

Williams, G., Gheisari, M., Chen, P.-J., & Irizarry, J. (2015). BIM2MAR: An Efficient BIM Translation to Mobile Augmented Reality Applications. *Journal of Management in Engineering, 31*(1), A4014009. doi:doi:10.1061/(ASCE)ME.1943-5479.0000315

Woksepp, S. (2007). *Virtual reality in construction: tools, methods and processes.* Luleå tekniska universitet,

Woksepp, S., & Tullberg, O. (2002). *Virtual reality in construction: A state of the art report*: Chalmers tekniska högsk.

Wolfartsberger, J. (2019). Analyzing the potential of Virtual Reality for engineering design review. *Automation in Construction, 104*, 27-37.

Wu, W., Hartless, J., Tesei, A., Gunji, V., Ayer, S., & London, J. (2019). Design Assessment in Virtual and Mixed Reality Environments: Comparison of Novices and Experts. *Journal of Construction Engineering and Management, 145*(9), 14. doi:10.1061/(asce)co.1943-7862.0001683

Yabuki, N., Miyashita, K., & Fukuda, T. (2011). An invisible height evaluation system for building height regulation to preserve good landscapes using augmented reality. *Automation in Construction, 20*(3), 228-235.

Yadav, N. (2018). Understanding display techniques in Augmented Reality. Retrieved from https://blog.prototypr.io/understanding-display-techniques-in-augmented-reality-c258b911b5c9

Yeh, K. C., Tsai, M. H., & Kang, S. C. (2012). On-Site Building Information Retrieval by Using Projection-Based Augmented Reality. *Journal of Computing in Civil Engineering, 26*(3), 342-355. doi:10.1061/(asce)cp.1943-5487.0000156

Yu, D., Jin, J. S., Luo, S., Lai, W., & Huang, Q. (2009). A useful visualization technique: a literature review for augmented reality and its application, limitation & future direction. In *Visual information communication* (pp. 311-337): Springer.

Zaher, M., Greenwood, D., & Marzouk, M. (2018). Mobile augmented reality applications for construction projects. *Construction Innovation, 18*(2), 152-166. doi:10.1108/ci-02-2017-0013

Zaker, R., & Coloma, E. (2018). Virtual reality-integrated workflow in BIM-enabled projects collaboration and design review: a case study. *Visualization in Engineering, 6*(1), 4. doi:10.1186/s40327-018-0065-6

Zhang, M., Wu, L., Yang, L., & Wang, Y. (2011). A digital entertainment system based on augmented reality. In *Informatics in Control, Automation and Robotics* (pp. 787-794): Springer.

Zhou, Y., Luo, H., & Yang, Y. (2017). Implementation of augmented reality for segment displacement inspection during tunneling construction. *Automation in Construction, 82*, 112-121.

APPENDICES

Appendix 1: Relevance screening form on the basis of title, abstract, and keywords

Question	Options	Exclusion if
1) What type of source is the result?	- Journal article (go to question 2) - Conference proceedings paper (go to question 2) - Others (e.g. book chapter)	Result of category "others"
2) Is an abstract available?	- Yes (go to question 3) - No (go to question 2a)	
2a) Can it be concluded from the title that the article deals with AR OR VR?	- Yes (article will stay for further review process) - No	No
3) Does the article concern any of the Construction Project Management aspects?	- Yes (article will remain for further review process) - No	No

Appendix 2: Eligibility screening form on basis of full-text screening

Question	Options	Exclusion if	Additional notes
1) Is the full text available?	- Yes (go to question 2) - No	- No	Please do the following to find full-text: - Use Endnote/Citavi function to automate find full-texts; use available links; search university library's electronic journals; use a search engine. Only articles where full texts were not accessible after trying all of the above-mentioned methods were excluded.
2) Is the full text in English?	- Yes (go to question 3)	- No	
3) Again: What type of source is the result?	- Journal Paper (go to question 4) - Conference Paper (go to question 4) - Others (e.g. book chapter)	- Others	Screening title and abstract cannot be assumed to be representative of the full article that follows and the article type often is not identifiable. From this step on only Journal Papers and Conference Papers are included.
4) Is the article mainly concerning AR or VR?	- Yes (go to question 5) - No	- No	Exclude articles that only refer to AR, VR as an example or as these technologies are not the main scope of the study.
5) Is the article mainly concerning any of the CPM aspects?	- Yes (article will be included in the final analysis) - No	- No	

Appendix 3: The data charting form

Title	Author	Year	Journal	Country/Region	Reference Type	Methodology	Type of Technology	Application Area	Display Method	Interaction Display	Spatial Registration Method	Level of Immersion
A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management	Ahmed, S.;	2019	Organization Technology and Management in Construction	Bangladesh	Journal Article	quantitative	AR and VR	Mixed Areas	Unassigned	Unassigned	Unassigned	Unassigned
Mobile Augmented Reality to Influence Design and Constructability Review Sessions	Alsafouri, S.;Ayer, S. K.;	2019	Journal of Architectural Engineering	USA	Journal Article	mixed	AR	Visualization	Hand-held and HMD	keyboard and touch screen	marker-based 2D image recognition	Unassigned
Leveraging Mobile Augmented Reality Devices for Enabling Specific Human Behaviors in Design and Constructability Review	Alsafouri, S.;Ayer, S. K.;	2019	Advances in Civil Engineering	USA	Journal Article	qualitative	AR	Visualization	Hand-held and HMD	keyboard and touch screen	marker-based 2D image recognition	Unassigned

Interactive Augmented Reality Visualization for Improved Damage Prevention and Maintenance of Underground Infrastructure	Amir H. Behzadan;Vineet R. Kamat;	2009	Building a Sustainable Future	USA	Conference Proceedings	quantitative	AR	Safety Management And Training	Hand-held and HMD	keyboard and touch screen	markerless-GPS	Unassigned
USE OF AUGMENTED REALITY TECHNOLOGY TO ENHANCE COMPREHENSION OF CONSTRUCTION ASSEMBLIES	Bademosi, F.;Blinn, N.;Issa, R. R. A.;	2019	Journal of Information Technology in Construction	USA	Journal Article	mixed	AR	Construction Management Education	Desktop display	keyboard and mouse	marker-based 2D image recognition	Unassigned
Augmented reality system for facility management using image-based indoor localization	Baek, F.;Ha, I.;Kim, H.;	2019	Automation in Construction	Korea	Journal Article	mixed	AR	Facility Management	HMD	Unassigned	marker-based 2D image recognition	Unassigned
A COLLABORATIVE AUGMENTED REALITY BASED MODELING ENVIRONMENT FOR CONSTRUCTION ENGINEERING AND MANAGEMENT EDUCATION	Behzadan, A. H.;Iqbal, A.;Kamat, V. R.;	2011	Proceedings of the 2011 Winter Simulation Conference	USA	Conference Proceedings	quantitative	AR	Construction Management Education	HMD	smart glove	markerless-GPS	Unassigned

Automated Generation of Operations Level Construction Animations in Outdoor Augmented Reality	Behzadan, A. H.;Kamat, V. R.;	2009	Journal of Computing in Civil Engineering	USA	Journal Article	quantitative	AR	Visualization	HMD	keyboard	markerless-GPS	Unassigned
Interactive Modeler for Construction Equipment Operation Using Augmented Reality	Byungil Kim;Changyoon Kim;Hyoungkwan Kim;	2012	Journal of Computing in Civil Engineering	Korea	Journal Article	quantitative	AR	Visualization	HMD	keyboard and mouse	marker-based 2D image recognition	Unassigned
Attention-Based User Interface Design for a Tele-Operated Crane	Chen, Y. C.;Chi, H. L.;Kang, S. C.;Hsieh, S. H.;	2016	Journal of Computing in Civil Engineering	Taiwan	Journal Article	quantitative	AR	Safety Management And Training	Desktop display	keyboard and mouse	marker-based 2D image recognition	Unassigned
Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study	Chu, M.;Matthews, J.;Love, P. E. D.;	2018	Automation in Construction	Australia	Journal Article	quantitative	AR	Communication And Data Acquisition	Hand-held	Touch screen	marker-based 2D image recognition	Unassigned
SMART: scalable and modular augmented reality template for rapid development of engineering visualization applications	Dong, Suyang;Kamat, Vineet R.;	2013	Visualization in Engineering	USA	Journal Article	quantitative	AR	Visualization	HMD	Unassigned	markerless-GPS	Unassigned

PARS: Using augmented 360-degree panoramas of reality for construction safety training	Eiris, Ricardo;Gheisari, Masoud;Esmaeili, Behzad;	2018	International journal of environmental research public health	USA	Journal Article	quantitative	AR	Safety Management And Training	Desktop display	keyboard and mouse	marker-based 2D image recognition	Unassigned
The Application of Virtual Reality and Augmented Reality in Dealing with Project Schedule Risks	Fu, M. Q;Liu, R.;	2018	Construction Research Congress 2018: Construction Information Technology	USA	Conference Proceedings	qualitative	AR and VR	Scheduling And Project Progress Tracking	Unassigned	Unassigned	Unassigned	Unassigned
Integrated Sequential As-Built and As-Planned Representation with D(4)AR Tools in Support of Decision-Making Tasks in the AEC/FM Industry	Golparvar-Fard, M.;Pena-Mora, F.;Savarese, S.;	2011	Journal of Construction Engineering and Management	USA	Journal Article	quantitative	AR	Scheduling And Project Progress Tracking	Unassigned	Unassigned	marker-based 3D object recognition	Unassigned
BIM2MAR: An Efficient BIM Translation to Mobile Augmented Reality Applications	Graceline Williams;Masoud Gheisari;Po-Jui Chen;Javier Irizarry;	2015	Journal of Management in Engineering	USA	Journal Article	qualitative	AR	Facility Management	Hand-held	Touch screen	markerless-GPS	Unassigned
Distributed Augmented Reality for Visualizing Collaborative Construction Tasks	Hammad, A.;Wang, H.;Mudur, S. P.;	2009	Journal of Computing in Civil Engineering	Canada	Journal Article	quantitative	AR	Safety Management And Training	HMD	joysticks	Markerless-GPS and IMU	Unassigned

High-Precision and Infrastructure-Independent Mobile Augmented Reality System for Context-Aware Construction and Facility Management Applications	Hyojoon Bae;Mani Golparvar-Fard;Jules White;	2013	Computing in Civil Engineering (2013)	USA	Conference Proceedings	quantitative	AR	Communication And Data Acquisition	Hand-held	Touch screen	marker-based 3D object recognition	Unassigned
Image-Based Localization and Content Authoring in Structure-from-Motion Point Cloud Models for Real-Time Field Reporting Applications	Hyojoon Bae;Mani Golparvar-Fard;Jules White;	2015	Journal of Computing in Civil Engineering	USA	Journal Article	quantitative	AR	Communication And Data Acquisition	Hand-held	Touch screen	marker-based 3D object recognition	Unassigned
InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach	Irizarry, J.;Gheisari, M.;Williams, G.;Walker, B. N.;	2013	Automation in Construction	USA	Journal Article	quantitative	AR	Facility Management	Hand-held	Touch screen	markerless IMU	Unassigned
Enhancing Spatial and Temporal Cognitive Ability in Construction Education Through Augmented Reality and Artificial Visualizations	Ivan Mutis;Raja R. A. Issa;	2014	Computing in Civil and Building Engineering (2014)	USA	Conference Proceedings	quantitative	AR	Construction Management Education	Desktop display	keyboard and mouse	marker-based 2D image recognition	Unassigned

Augmented Reality Combined with Location-Based Management System to Improve the Construction Process, Quality Control and Information Flow.	J Ratajczak;A Schweigkofler;M Riedl, D T Matt.;	2018	35th International Conference of CIB W78	Italy	Conference Proceedings	mixed	AR	Communication And Data Acquisition	Hand-held	Touch screen	markerless VIO	Unassigned
On-site construction management using mobile computing technology	Kim, C.;Park, T.;Lim, H.;Kim, H.;	2013	Automation in Construction	Korea	Journal Article	quantitative	AR	Communication And Data Acquisition	Hand-held	Touch screen	markerless-GPS	Unassigned
Improvement of Realism of 4D Objects Using Augmented Reality Objects and Actual Images of a Construction Site	Kim, H. S.;Kim, S. K.;Borrmann, A.;Kang, L. S.;	2018	KSCE Journal of Civil Engineering	Korea	Journal Article	quantitative	AR	Scheduling And Project Progress Tracking	Unassigned	Unassigned	marker-based 2D image recognition	Unassigned
Image-based construction hazard avoidance system using augmented reality in wearable device	Kim, K.;Kim, H.;Kim, H.;	2017	Automation in Construction	Korea	Journal Article	quantitative	AR	Safety Management And Training	HMD	Unassigned	markerless IMU	Unassigned
Using Augmented Reality to Facilitate Construction Site Activities	Kivrak, Serkan;Arslan, Gokhan.;	2018	35th International Conference of CIB W78	Turkey	Journal Article	quantitative	AR	Defect Management	HMD	Unassigned	marker-based 2D image recognition	Unassigned

A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality	Kwon, O. S.;Park, C. S.;Lim, C. R.;	2014	Automation in Construction	Korea	Journal Article	quantitative	AR	Defect Management	Hand-held	Touch screen	marker-based 2D image recognition	Unassigned
Using Augmented Reality to Facilitate Piping Assembly: An Experiment-Based Evaluation	Lei Hou;Xiangyu Wang;Martijn Truijens;	2015	Journal of Computing in Civil Engineering	Australia	Journal Article	quantitative	AR	Safety Management And Training	Desktop display	Unassigned	marker-based 2D image recognition	Unassigned
A critical review of virtual and augmented reality (VR/AR) applications in construction safety	Li, X.;Yi, W.;Chi, H. L.;Wang, X. Y.;Chan, A. P. C.;	2018	Automation in Construction	China	Journal Article	qualitative	AR and VR	Safety Management And Training	Unassigned	Unassigned	Unassigned	Unassigned
Using Augmented Reality in a Multiscreen Environment for Construction Discussion	Lin, T. H.;Liu, C. H.;Tsai, M. H.;Kang, S. C.;	2015	Journal of Computing in Civil Engineering	Taiwan	Journal Article	quantitative	AR	Communication And Data Acquisition	Hand-held	Touch screen	marker-based 2D image recognition	Unassigned
A framework for construction safety management and visualization system	Park, C. S.;Kim, H. J.;	2013	Automation in Construction	Korea	Journal Article	quantitative	AR	Safety Management And Training	Hand-held	Touch screen	markerless-RFID	Unassigned

A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template	Park, C. S.;Lee, D. Y.;Kwon, O. S.;Wang, X.;	2013	Automation in Construction	Korea	Journal Article	quantitative	AR	Defect Management	Hand-held	Touch screen	marker-based 2D image recognition	Unassigned
Using Panoramic Augmented Reality to Develop a Virtual Safety Training Environment	Pereira, R. E.;Gheisari, M.;Esmaeili, B.;	2018	Construction Research Congress 2018: Safety and Disaster Management	USA	Conference Proceedings	Unassigned	AR	Safety Management And Training	Desktop display	keyboard and mouse	marker-based 2D image recognition	Unassigned
Development and Usability Testing of a Panoramic Augmented Reality Environment for Fall Hazard Safety Training	R. Eiris Pereira;H F Moore;M Gheisari;B Esmaeili.;	2018	35th International Conference of CIB W78	USA	Conference Proceedings	mixed	AR	Safety Management And Training	Desktop display	keyboard and mouse	marker-based 2D image recognition	Unassigned
BIM-based and AR Application Combined with Location-Based Management System for the Improvement of the Construction Performance	Ratajczak, J.;Riedl, M.;Matt, D. T.;	2019	Buildings	Italy	Journal Article	mixed	AR	Communication And Data Acquisition	Hand-held	Touch screen	markerless VIO	Unassigned

Application of a Visualization Technique for Safety Management	SangUk Han;Feniosky Peña-Mora;Mani Golparvar-Fard;Seungjun Roh;	2009	Computing in Civil Engineering (2009)	USA	Conference Proceedings	quantitative	AR	Safety Management And Training	Unassigned	Unassigned	marker-based 2D image recognition	Unassigned
A virtual training system of a hydraulic excavator using a remote controlled excavator with augmented reality	Sekizuka, Ryota;Koiwai, Kazushige;Saiki, Seiji;Yamazaki, Yoichiro;Tsuji, Toshio;Kurita, Yuichi;	2017	2017 IEEE/SICE International Symposium on System Integration (SII)	Japan	Conference Proceedings	quantitative	AR	Safety Management And Training	HMD	joysticks	Unassigned	Unassigned
Uncertainty-aware visualization and proximity monitoring in urban excavation: a geospatial augmented reality approach	Su, Xing;Talmaki, Sanat;Cai, Hubo;Kamat, Vineet R.;	2013	Visualization in Engineering	USA	Journal Article	quantitative	AR	Safety Management And Training	Unassigned	Unassigned	Unassigned	Unassigned
Streamlining Information Representation during Construction Accidents	Tsai, M. K.;	2014	KSCE Journal of Civil Engineering	Taiwan	Journal Article	quantitative	AR	Safety Management And Training	Hand-held	Touch screen	markerless-GPS	Unassigned
Using mobile disaster response system in bridge management	Tsai, M. K.;Yau, N. J.;	2014	Journal of Civil Engineering and Management	Taiwan	Journal Article	quantitative	AR	Communication And Data Acquisition	Hand-held	Touch screen	markerless-GPS	Unassigned

User perspectives on mixed reality tabletop visualization for face-to-face collaborative design review	Wang, X. Y.;Dunston, P. S.;	2008	Automation in Construction	USA	Journal Article	quantitative	AR	Visualization	HMD	controller	marker-based 2D image recognition	Unassigned
Design Assessment in Virtual and Mixed Reality Environments: Comparison of Novices and Experts	Wu, W.;Hartless, J.;Tesei, A.;Gunji, V.;Ayer, S.;London, J.;	2019	Journal of Construction Engineering and Management	USA	Journal Article	mixed	AR AND VR	Construction Management Education	HMD	Unassigned	Unassigned	Unassigned
On-Site Building Information Retrieval by Using Projection-Based Augmented Reality	Yeh, K. C.;Tsai, M. H.;Kang, S. C.;	2012	Journal of Computing in Civil Engineering	Taiwan	Journal Article	quantitative	AR	Communication And Data Acquisition	Projection-based	Touch screen	Unassigned	Unassigned
Mobile augmented reality applications for construction projects	Zaher, Mohamed;Greenwood, David;Marzouk, Mohamed;	2018	Construction Innovation	Egypt	Journal Article	mixed	AR	Scheduling And Project Progress Tracking	Hand-held	Touch screen	marker-based 2D image recognition	Unassigned
Effectiveness of Immersive Virtual Reality-based Communication for Construction Projects	Abbas, A.;Choi, M.;Seo, J.;Cha, S. H.;Li, H.;	2019	KSCE Journal of Civil Engineering	Hong Kong	Journal Article	mixed	VR	Communication And Data Acquisition	HMD	joysticks	Unassigned	IVR

Cyber-physical postural training system for construction workers	Akanmu, Abiola A.;Olayiwola, Johnson;Ogunseiju, Omobolanle;McFeeters, David;	2020	Automation in Construction	USA	Journal Article	mixed	VR	Safety Management And Training	HMD	Unassigned	markerless IMU	IVR
Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality	Akeem Pedro;Quang Tuan Le;Chan Sik Park;	2016	Journal of Professional Issues in Engineering Education and Practice	Korea	Journal Article	quantitative	VR	Safety Management And Training	Hand-held	Touch screen	Unassigned	Non-IVR
An Immersive Approach to Construction Cost Estimating	Bademosi, F. M.;Tayeh, R.;Issa, R. R. A.;	2019	Computing in Civil Engineering 2019	USA	Conference Proceedings	Unassigned	VR	Scheduling And Project Progress Tracking	HMD	Unassigned	Unassigned	IVR
Improved Stakeholder Communication and Visualizations: Real-Time Interaction and Cost Estimation within Immersive Virtual Environments	Balali, V.;Noghabaei, M.;Heydarian, A.;Han, K.;	2018	Construction Research Congress 2018: Construction Information Technology	USA	Conference Proceedings	quantitative	VR	Scheduling And Project Progress Tracking	HMD	Unassigned	Unassigned	IVR
Real-Time Interaction and Cost Estimating within Immersive Virtual Environments	Balali, V.;Zalavadia, A.;Heydarian, A.;	2020	Journal of Construction Engineering and Management	USA	Journal Article	quantitative	VR	Scheduling And Project Progress Tracking	HMD	joysticks	Unassigned	IVR

Supporting constructability analysis meetings with Immersive Virtual Reality-based collaborative BIM 4D simulation	Boton, C.;	2018	Automation in Construction	Canada	Journal Article	quantitative	VR	Visualization	Projection-based	controller	Unassigned	semi-immersive
Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications	Cheng, T.;Teizer, J.;	2013	Automation in Construction	USA	Journal Article	quantitative	VR	Safety Management And Training	Unassigned	Unassigned	Unassigned	Unassigned
Comparing Virtual Reality and 2-Dimensional Drawings for the Visualization of a Construction Project	Claudia Calderon-Hernandez;Daniel Paes;Javier Irizarry;Xavier Brioso;	2019	Computing in Civil Engineering 2019	Georgia	Conference Proceedings	quantitative	VR	Visualization	HMD	Unassigned	Unassigned	Unassigned
A Usability Study of an Immersive Virtual Reality Platform for Building Design Review: Considerations on Human Factors and User Interface	Daniel Paes;Javier Irizarry;	2018	Construction Research Congress 2018	Georgia	Conference Proceedings	mixed	VR	Visualization	HMD	keyboard	Unassigned	IVR

Educational Simulation in Construction: Virtual Construction Simulator1	Dragana Nikolic;Shrimant Jaruhar;John I. Messner;	2011	Journal of Computing in Civil Engineering	USA	Journal Article	mixed	VR	Construction Management Education	Projection-based	Unassigned	Unassigned	semi-immersive
CoVR: Cloud-Based Multiuser Virtual Reality Headset System for Project Communication of Remote Users	Du, J.;Shi, Y. M.;Zou, Z. B.;Zhao, D.;	2018	Journal of Construction Engineering and Management	USA	Journal Article	quantitative	VR	Communication And Data Acquisition	HMD	keyboard	Unassigned	IVR
Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making	Du, J.;Zou, Z. B.;Shi, Y. M.;Zhao, D.;	2018	Automation in Construction	USA	Journal Article	quantitative	VR	Visualization	HMD	controller	Unassigned	IVR
Desktop-based safety training using 360-degree panorama and static virtual reality techniques: A comparative experimental study	Eiris, R.;Gheisari, M.;Esmaeili, B.;	2020	Automation in Construction	USA	Journal Article	mixed	AR AND VR	Safety Management And Training	Desktop display	keyboard and mouse	Unassigned	Non-IVR
Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context	Eiris, R.;Jain, A.;Gheisari, M.;Wehle, A.;	2020	Safety science	USA	Journal Article	quantitative	AR	Safety Management And Training	HMD	Unassigned	Unassigned	Unassigned

A framework for developing an as-built virtual environment to advance training of crane operators	Fang, Yihai;Teizer, Jochen;Marks, Eric;	2014	Construction Research Congress 2014: Construction in a Global Network	USA	Conference Proceedings	quantitative	VR	Safety Management And Training	Desktop display	joysticks	Unassigned	Non-IVR
BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach	Getuli, V.;Capone, P.;Bruttini, A.;Isaac, S.;	2020	Automation in Construction	Italy	Journal Article	quantitative	VR	Safety Management And Training	HMD	controller	Unassigned	IVR
Virtual Reality as a multidisciplinary communication tool	Houck, L;Hassan, L;Thiis, TK;Solheim, K;	2013	Structures and architecture. ICSA2013 conference proceedings.	Norway	Conference Proceedings	quantitative	VR	Communication And Data Acquisition	Projection-based	Unassigned	Unassigned	semi-immersive
Development of Immersive Personalized Training Environment for Construction Workers	Idris Jeelani;Kevin Han;Alex Albert;	2017	Computing in Civil Engineering 2017	USA	Conference Proceedings	quantitative	VR	Safety Management And Training	HMD	Unassigned	Unassigned	IVR
Development of virtual reality and stereo-panoramic environments for construction safety training	Jeelani, Idris;Han, Kevin;Albert, Alex;	2020	Engineering, Construction and Architectural Management	USA	Journal Article	mixed	VR	Safety Management And Training	HMD	controller	Unassigned	IVR

Comparison of construction photograph and VR image in construction progress	Kim, H.;Kano, N.;	2008	Automation in Construction	Japan	Journal Article	Unassigned	VR	Scheduling And Project Progress Tracking	Unassigned	Unassigned	Unassigned	Unassigned
Safety training for scaffolding and formwork construction by using virtual environment	Kiral, Isik Ates;Comu, Semra;	2017	34th International Conference of CIB W78	Turkey	Conference Proceedings	quantitative	VR	Safety Management And Training	Desktop display	keyboard and mouse	Unassigned	Non-IVR
A framework for using mobile based virtual reality and augmented reality for experiential construction safety education	Le, Quang Tuan;Pedro, AKEEM;Lim, Chung Rok;Park, Hee Taek;Park, Chan Sik;Kim, Hong Ki;	2015	International Journal of Engineering Education	Korea	Journal Article	mixed	AR AND VR	Safety Management And Training	Hand-held	Unassigned	Unassigned	Unassigned
A Social Virtual Reality Based Construction Safety Education System for Experiential Learning	Le, Quang Tuan;Pedro, Akeem;Park, Chan Sik;	2015	Journal of Intelligent & Robotic Systems	Korea	Journal Article	mixed	VR	Safety Management And Training	Unassigned	Unassigned	Unassigned	Unassigned
A virtual world based construction defect game for interactive and experiential learning	Le, Quang Tuan;Pedro, Akeem;Pham, Hai Chien;Park, Chan Sik;	2016	Int. J. Eng. Educ	Korea	Journal Article	quantitative	VR	Construction Management Education	Desktop display	Unassigned	Unassigned	Non-IVR

Comparing immersive virtual reality and powerpoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making	Leder, J.;Horlitz, T.;Puschmann, P.;Wittstock, V.;Schutz, A.;	2019	Safety science	Germany	Journal Article	quantitative	VR	Safety Management And Training	Projection-based	controller	Unassigned	semi-immersive
THE VIRTUAL CONSTRUCTION SIMULATOR: EVALUATING AN EDUCATIONAL SIMULATION APPLICATION FOR TEACHING CONSTRUCTION MANAGEMENT CONCEPTS	Lee, Sanghoon;Scholar, Post-Doc;Messner, John I.;	2010	27th I International Conference of CIB W78	USA	Conference Proceedings	mixed	VR	Construction Management Education	Desktop display	keyboard and mouse	Unassigned	Non-IVR
Multiuser Virtual Safety Training System for Tower Crane Dismantlement	Li, H.;Chan, G.;Skitmore, M.;	2012	Journal of Computing in Civil Engineering	Hong Kong	Journal Article	quantitative	VR	Safety Management And Training	Desktop display	controller	Unassigned	Non-IVR
Visualizing safety assessment by integrating the use of game technology	Li, H.;Chan, G.;Skitmore, M.;	2012	Automation in Construction	China	Journal Article	quantitative	VR	Safety Management And Training	Desktop display	keyboard and mouse	Unassigned	Non-IVR

Image-based semantic construction reconstruction	Liu, C. W.;Wu, T. H.;Tsai, M. H.;Kang, S. C.;	2018	Automation in Construction	Taiwan	Journal Article	quantitative	VR	Communication And Data Acquisition	Desktop display	keyboard and mouse	Unassigned	Non-IVR
Priming effects on safety decisions in a virtual construction simulator	Lu, X. Q.;Davis, S.;	2018	Engineering Construction and Architectural Management	Australia	Journal Article	quantitative	VR	Safety Management And Training	Desktop display	Unassigned	Unassigned	Non-IVR
Data-Driven Approach to Scenario Determination for VR-Based Construction Safety Training	Mo, Y.;Zhao, D.;Du, J.;Liu, W. H.;Dhara, A.;	2018	Construction Research Congress 2018: Safety and Disaster Management	USA	Conference Proceedings	quantitative	VR	Safety Management And Training	Unassigned	Unassigned	Unassigned	Unassigned
Adoption of Virtual Reality (VR) for Site Layout Optimization of Construction Projects	Muhammad, A. A.;Yitmen, I.;Alizadehsalehi, S.;Celik, T.;	2020	Teknik Dergi	Cyprus	Journal Article	quantitative	VR	Communication And Data Acquisition	HMD	Unassigned	Unassigned	Unassigned
Hazard recognition and risk perception in construction	Perlman, A.;Sacks, R.;Barak, R.;	2014	Safety science	Israel	Journal Article	quantitative	VR	Safety Management And Training	projection-based	controller	Unassigned	semi-immersive

Virtual Field Trip for Mobile Construction Safety Education Using 360-Degree Panoramic Virtual Reality	Pham, H. C.;Dao, N. N.;Pedro, A.;Le, Q. T.;Hussain, R.;Cho, S.;Park, C. S.;	2018	International Journal of Engineering Education	Korea	Journal Article	quantitative	VR	Safety Management And Training	Hand-held	Touch screen	Unassigned	Non-IVR
Construction safety training using immersive virtual reality	Sacks, Rafael;Perlman, Amotz;Barak, Ronen;	2013	Construction Management Economics	Israel	Journal Article	quantitative	VR	Safety Management And Training	Projection-based	controller	Unassigned	semi-immersive
Safety by design: dialogues between designers and builders using virtual reality	Sacks, Rafael;Whyte, Jennifer;Swissa, Dana;Raviv, Gabriel;Zhou, Wei;Shapira, Aviad;	2015	Construction Management Economics	Israel	Journal Article	mixed	VR	Safety Management And Training	Projection-based	joysticks	Unassigned	semi-immersive
Framework of the Virtual Construction Simulator 3 for Construction Planning and Management Education	Sanghoon Lee;Dragana Nikolic;John I. Messner;	2015	Journal of Computing in Civil Engineering	USA	Journal Article	mixed	VR	Construction Management Education	Desktop display	keyboard and mouse	Unassigned	Non-IVR

Impact assessment of reinforced learning methods on construction workers' fall risk behavior using virtual reality	Shi, Y. M.;Du, J.;Ahn, C. R.;Ragan, E.;	2019	Automation in Construction	USA	Journal Article	quantitative	VR	Safety Management And Training	HMD	Unassigned	Unassigned	Non-IVR
Tangible mixed reality for remote design review: a study understanding user perception and acceptance	Wang, Xiangyu;Dunston, Phillip S.;	2013	Visualization in Engineering	Australia	Journal Article	mixed	AR	Visualization	HMD	controller	marker-based 2D image recognition	Unassigned
SUPPORTING DESIGN REVIEWS WITH PRE-MEETING VIRTUAL REALITY ENVIRONMENTS	van den Berg, M.;Hartmann, T.;de Graaf, R.;	2017	Journal of Information Technology in Construction	Netherlands	Journal Article	qualitative	VR	Visualization	Desktop display	keyboard and mouse	Unassigned	Non-IVR
A DESIGN REVIEW SESSION PROTOCOL FOR THE IMPLEMENTATION OF IMMERSIVE VIRTUAL REALITY IN USABILITY-FOCUSED ANALYSIS	Ventura, S. M.;Castronovo, F.;Ciribini, A. L. C.;	2020	Journal of Information Technology in Construction	Italy	Journal Article	qualitative	VR	Visualization	Projection-based	controller	Unassigned	semi-immersive

Virtual reality-integrated workflow in BIM-enabled projects collaboration and design review: a case study	Zaker, Reza;Coloma, Eloi;	2018	Visualization in Engineering	Spain	Journal Article	mixed	VR	Visualization	HMD	controller	Unassigned	IVR
Using virtual reality to facilitate communication in the AEC domain: a systematic review	Wen, Jing;Gheisari, Masoud;	2020	Construction Innovation	USA	Journal Article	qualitative	VR	Communication And Data Acquisition	Unassigned	Unassigned	Unassigned	Unassigned
Using Immersive Virtual Reality to Improve Choosing by Advantages System for the Selection of Fall Protection Measures	Xavier Brioso;Claudia Calderon-Hernandez;Javier Irizarry;Daniel Paes;	2019	Computing in Civil Engineering 2019	Peru	Conference Proceedings	quantitative	VR	Safety Management And Training	HMD	Unassigned	Unassigned	IVR
Investigation of the Relationship between Construction Workers’ Psychological States and Their Unsafe Behaviors Using Virtual Environment-Based Testing	Yantao Yu;Jiansong Zhang;Hongling Guo;	2017	Computing in Civil Engineering 2017	China	Conference Proceedings	mixed	VR	Safety Management And Training	HMD	keyboard and mouse	Unassigned	IVR

Evaluating the Impact of Virtual Reality on Design Review Meetings	Yifan Liu;Fadi Castronovo;John Messner;Robert Leicht;	2020	Journal of Computing in Civil Engineering	USA	Journal Article	mixed	VR	Visualization	Unassigned	Unassigned	Unassigned	Unassigned
Virtual Reality to Support the Integrated Design Process: A Retrofit Case Study	Yifan Liu;Jennifer Lather;John Messner;	2014	Computing in Civil and Building Engineering (2014)	USA	Conference Proceedings	qualitative	VR	Visualization	Desktop display	Unassigned	Unassigned	Non-IVR
A Multi-User Virtual 3D Training Environment to Advance Collaboration Among Crane Operator and Ground Personnel in Blind Lifts	Yihai Fang;Jochen Teizer;	2014	Computing in Civil and Building Engineering (2014)	Georgia	Conference Proceedings	quantitative	VR	Safety Management And Training	Desktop display	controller	Unassigned	Non-IVR
INTEGRATING SAFETY CULTURE INTO OSH RISK MITIGATION: A PILOT STUDY ON THE ELECTRICAL SAFETY	Zhao, D.;McCoy, A.;Kleiner, B.;Feng, Y. B.;	2016	Journal of Civil Engineering and Management	USA	Journal Article	quantitative	VR	Safety Management And Training	Hand-held	Touch screen	Unassigned	Non-IVR

CURRICULUM VITAE

Personal Information

Name/Surname	:	Mahmoud Albahbah

Educational Background

2018 - 2021	:	MSc. Construction Management at Anadolu University, Turkey
2010- 2015	:	BSc. Civil Engineering at Tripoli University, Libya

Language Skills

English	:	Intermediate
Turkish	:	Beginner
Arabic	:	Native speaker