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Adoption of Augmented Reality (AR) in Construction Cost Management: A Preliminary Framework

Safiah Azahari[1]*, Roziha Che Haron[1]

[1] *Department of Quantity Surveying, Kuliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Jalan Gombak, Kuala Lumpur, 53100 MALAYSIA*

*Corresponding Author: bellapeia23@gmail.com
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Abstract

The integration of Augmented Reality (AR) into construction cost management practices has emerged as a promising technological advancement in the Architecture, Engineering and Construction (AEC) industry. However, despite its potential benefits, there exists a notable gap in understanding the practical application and barriers to implementing AR in this context. Therefore, to bridge this gap, this paper delves into the conceptual foundation of AR to evaluate its potential implementation in construction cost management. This study aims to enlighten others on the significance of innovative construction cost management practices. It will also contribute towards in-depth knowledge of the role of AR in construction cost management.

1. Introduction

The Malaysian construction industry is widely recognized as a significant contributor to the country's socioeconomic development and growth; providing employment opportunities and enhancing citizens' quality of life through infrastructure and public facilities (Rahim & Ismail, 2021; Roslan et al., 2022). According to recent data released by the Department of Statistics Malaysia [DOSM] (2024), the industry has contributed a total of 24.3% to the country's growth domestic product (GDP); showcasing its significance in driving the economy. However, the industry still experiences challenges including inefficiencies in cost management and project execution. Construction cost management involves the process of planning, estimating and controlling the budget of a construction project. The goal of construction cost management is to optimize financial resources and to ensure the project is completed within the agreed budget, speciation and time. Traditional practices in cost management process, including Bill of Quantities (BQ) and architectural drawings, critically fail to prevent cost overruns due to project complexities and unforeseen factors (Ang et al., 2020). More than half of construction projects in Malaysia are reported to experience cost overruns of about 5-10% of the project's total contract sum (Kamaruddeen et al., 2020). A study by Zayyana et al. (2014, as cited in Wen et al., 2022) found that 79.95% of public and 66.65% of private sector projects finish ahead of schedule. This emphasizes the need for time reduction, quality improvement, and cost minimization. In this context, Augmented Reality (AR) serves as a potential solution to these challenges. AR has emerged as a transformative technology with the potential to revolutionize construction cost management. There are several benefits of adopting AR into construction cost management: improving project visualization, communication, and identifying issues initially (Azlan et al., 2022; Igwe et al., 2020; Ahmed et al., 2017). However, the extent to which AR can fully optimize construction cost management practices is still being debated and explored in the industry, particularly in the Malaysian context. Therefore, this paper delves into a conceptual understanding of AR to evaluate and assess its potential adoption in the context of construction cost management. In addition, it aims to explore the key barriers to AR adoption within this context in order to overcome the challenges of this technology for optimizing its full potential among professionals involved in construction cost management.

2. Literature Review

The construction industry has been seen to adopt advanced technologies in its construction processes to reduce uncertainties and improve efficiency. Several researchers noted that this shift is driven by a focus on digitalisation and sustainable development (CREAM, 2023; Roslan et al., 2022; RICS, 2023; Lee & Goh, 2023). Lee and Goh (2023) and Manukyan (2019) highlighted the potential of digitalization in the construction industry to revolutionize traditional aspects of it; improving information utilization, promote integrated work platforms, accurately assess project needs, and enhance overall effectiveness throughout the phases of a construction project. AR technology's potential to increase efficiency and output has piqued the interest in the Architecture, Engineering, and Construction (AEC) industry (Fard et al., 2011, as cited in Azlan et al., 2022), as it has been widely used and shown remarkable success in various industries (Rahim & Ismail, 2021). For example, video games, healthcare and education industries. The construction industry on a global scale is increasingly implementing AR into project execution; enhancing collaboration, facilitating on-site decision-making, and optimizing workflows (Azlan et al., 2022; Igwe et al., 2020; Ahmed et al., 2017).

2.1 Overview of Augmented Reality (AR)

2.1.1 Definition of AR

The definition of AR has evolved dynamically across literature, thus, various definitions capture the concept of AR. The concept of AR was first defined in the late 1990s by Caudell and Mizell (1992), "..this technology is used to "augment" the visual field of the user with information necessary in the performance of the current task, and therefore we refer to the technology as "augmented reality"..." (p. 660). AR has been interpreted differently but similarly, which reflects its transformative nature since its evolution. Despite attempts to provide a uniform definition, Jung and Dieck (2018) highlighted that AR is considered a developing technology, and its meaning varies depending on the context or implementation method, as it has not yet fully realized its potential. As a result, Table 1 provides a summary of how researchers defined AR. From the definitions interpreted by several researchers, it can be simplified that AR is an innovative technology that combines virtual objects with real-world objects to provide contextual information, interactive and immersive user experience.

Table 1 *Summary of AR definition*

No.	Author	Year	Definition of AR
1	Caudell and Mizell	1992	A technology that enhances a user's visual field with the necessary information for task performance.
2	Azuma	1997	A technology that combines virtual objects with the real world, unlike Virtual Environments (VE), which are entirely synthetic.
3	Zhou et al.	2008	A mobile technology that merges real and live images with virtual data, superimposing digital information over the current world.
4	Carmigniani and Furht	2011	The real-time integration of virtual computer-generated information with real-world objects and features enhances the user experience.
5	Lifang and Xueliang	2019	A technology that superimposes data (including text, image, video and 3D models in the real world).
6	Natarajan et al.	2020	A technology that enhances the user's experience by superimposing visuals on real environments, supplementing them rather than replacing them, and providing data that users cannot immediately perceive.
7	Lin	2021	A technology that overlays virtual objects in the real world, responding to real-time changes in the user's environment.
8	Mendoza-Ramirez et al.	2023	A technology that combines digital data with the real world to provide enhanced experiences, contextual insights, and interactive features.

2.1.2 AR History

AR has evolved and has been documented in literature. Researchers such as Yuen et al. (2011), Agarwal and Thakur (2014), Alkhamisi and Monowar (2013), Daponte et al. (2014), De Pace et al. (2018) and Carmigniani et al. (2010) have explained the history of AR's evolution in their research. According to the researchers, AR dates back to the 1950s, with the prototypes created by Morton Heilig and his students at Harvard University and the University of Utah whereby he invented a Sensorama that delivered visuals, sounds, vibration and smell to the user in 1957. In 1968, Ivan Sutherland developed the head-mounted AR system; a headworn device that project imagery to a real scene, and in 1975, Myron Krueger established an artificial reality laboratory called Video Place. By the 1990s, Tom Caudell and David Mizell termed "Augmented Reality" as a technology that enhances a user's visual field with the necessary information for task performance. As outlined by the researchers, Louis Rosenberg developed Virtual Fixture which was the first properly functioning AR system in 1992. Moreover, Hirokazu Kato created ARToolKit; an open-source library software for developing AR applications. In addition, Bruce Thomas invented the first mobile AR game called AR Quake in 2000. Today, AR applications are designed primarily with mobile applications, such as Wikitude AR Travel Kit and Pokemon Go. The number of AR-capable apps has increased dramatically and diversified with several mobile platforms, such as tablets and smartphones. Other than that, Google released a wearable AR device called Google Glass. All these AR technologies signifies the capability of bridging the gap between the physical and digital worlds; enhancing user's experiences and visualization. Figure 1 shows a summary of AR evolution.

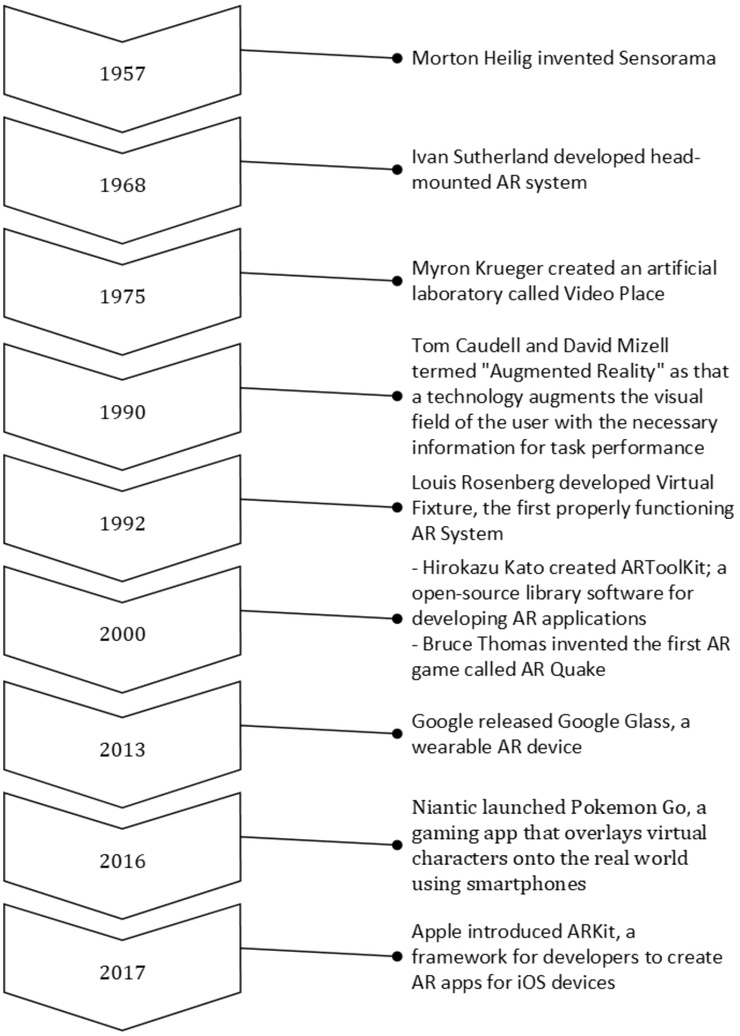

Fig. 1 *AR timeline*

2.1.3 Types of AR

AR technologies can be categorized into various types, with different classifications in past literature. From previous studies, AR is classified into six categories: i) Marker-based AR (Cheng et al., 2017; Edwards-Stewart et al, 2016; Jumarlis & Mirfan, 2017; Zaher et al., 2018; Aggarwal & Singhal, 2019; Brito & Stoyanova, 2017; Mendoza-Ramirez et al.; 2023; Arena et al., 2022), ii) Marker-less AR (Cheng et al., 2017); Mendoza-Ramirez et al., 2023; Arena et al., 2022; Jumarlis & Mirfan, 2017; Zaher et al., 2018; Aggarwal & Singhal, 2019; Brito & Stoyanova, 2017), iii) Location-based AR (Edwards-Stewart et al., 2016; Dumbre, 2023), iv) Projection-based AR (Mendoza-Ramirez et al., 2023; Aggarwal & Singhal, 2019; Arena et al., 2022; Shushan, 2018), v) Superimposition AR (Mendoza-Ramirez et al., 2023; Aggarwal & Singhal, 2019; Shushan, 2018) and vi) Contour-based AR (Berger, 1997; Mendoza-Ramirez et al., 2023) (Figure 2).

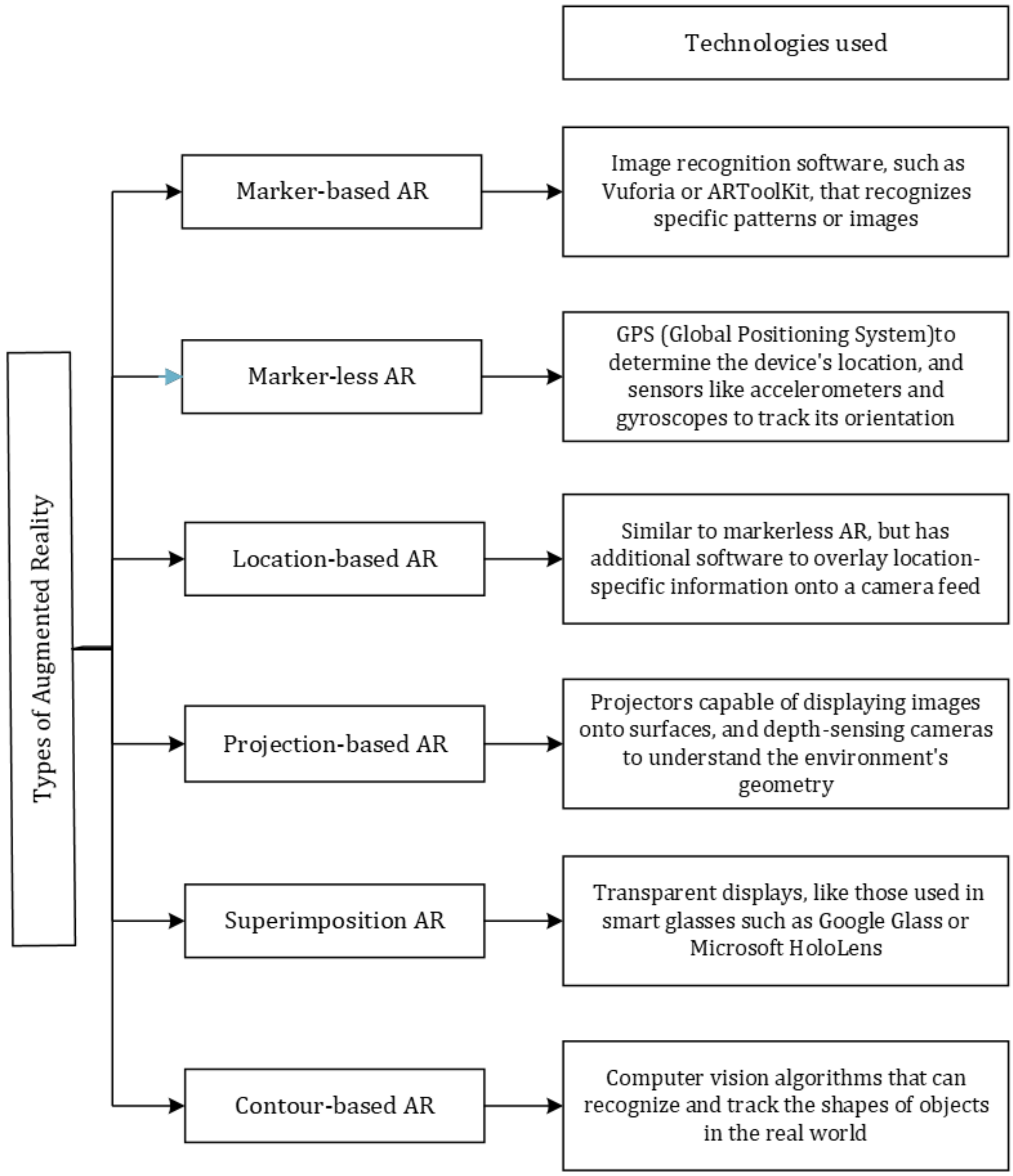

Fig. 2 *Overview of types of AR*

2.1.3.1 Marker-based AR

Marker-based AR applications use visual triggers such as barcodes, QR codes or images to trigger an augmented reality experience (Mendoza-Ramirez et al.; 2023; Cheng et al., 2017; Edwards-Stewart et al., 2016; Aggarwal & Singhal, 2019; Brito & Stoyanova, 2017; Jumarlis & Mirfan, 2017). It can further be categorized based on the researchers whereby marker-based AR is divided into two types: i) marker-based objects and ii) marker-based paper. The marker-based objects use physical objects as markers, whereas marker-based papers use images or 2D patterns such as barcodes which will trigger to provide additional information. Mendoza-Ramirez et al. (2023) along with Aggarwal and Singhal (2019) mentioned that the AR device's camera detects the marker, generating a virtual object or scene (Figure 3). In other words, this type of AR would require a platform such as an app or software to scan the markers through the device's camera. However, lighting conditions, angle, and distance can affect the AR experience. Brito and Stoyanova (2017) added that the augments related to the marker enhance the image or object, while some are only a means to access digital content. This type of AR is stated to be easier to implement than marker-less AR due to the geometric properties that make it easy to identify in video frames (Edwards-Stewart et al., 2016). This unique and simple method differentiates the marker from real-world objects.

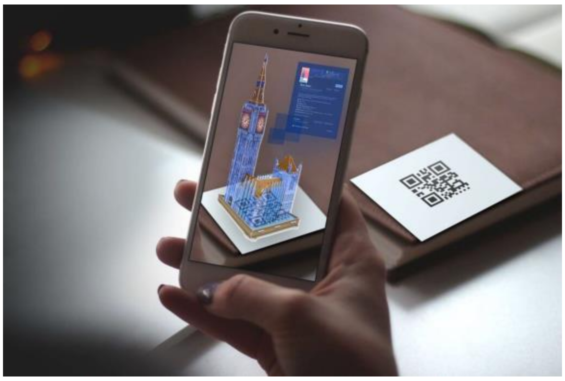

Fig. 3 *Marker-based AR through scanning QR barcode* (Szczepaniak, 2022)

2.1.3.2 Marker-less AR

In markerless-AR applications, it involves features or technologies that are related to the environment such as global positioning system (GPS), accelerometer data or even computer vision to overlay AR contents to the physical world (Cheng et al., 2017; Jumarlis & Mirfan, 2018; Mendoza-Ramirez et al., 2023; Zaher et al., 2018; Arena et al., 2022). Aggarwal and Singhal (2019) further explained in their paper that this type of AR uses location, patterns, colours and other detection features. This marker-less AR does not require any predefined markers and provides more accurate tracking by controlling the relative position relationship between virtual objects and the physical world (Mendoza-Ramirez et al., 2023). In the same context, Similarly, Brito and Stoyanova (2017) stated that marker-less AR only depends on natural features for tracking execution. As an example, several online shopping platforms and interior design software would adopt this AR type in their business to display virtual furniture in the real world (Figure 4). This in turn provides users with an immersive experience.

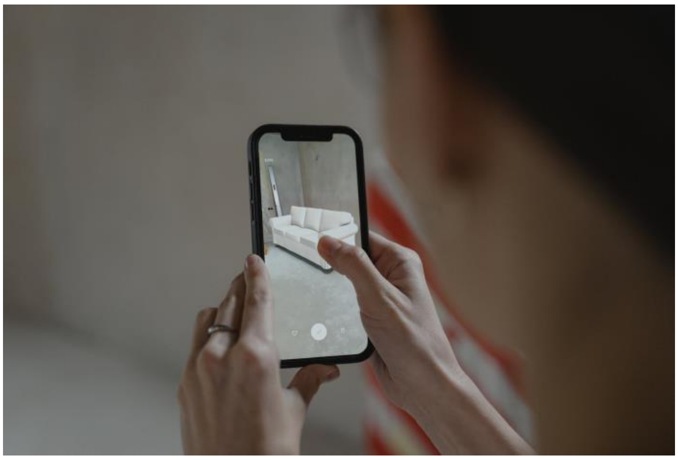

Fig. 4 *Marker-less AR in displaying virtual furniture into the real world (Ross, 2022)*

2.1.3.3 Location-based AR

Location-based AR is somewhat related to marker-less AR, only that this type of AR is only dependent on device positional locations. This AR mainly uses GPS location to pair locations with points of interest to provide data or information (Edwards-Stewart et al., 2016; Arena et al, 2022). In addition, it also used cameras, GPS, compass and accelerometer to amplify augmentation to a specific location and display virtual objects. This type of AR can be seen in a gaming app called Pokemon Go (Figure 5).

Fig. 5 *Location-based AR in Pokemon GO (Leetaru, 2016)*

2.1.3.4 Projection-based AR

Projection-based AR uses artificial light to create a virtual object within the user's physical environment (Mendoza-Ramirez et al., 2023; Arena et al., 2017). According to Dumbre (2023), this AR is further categorized into two types: i) Static AR projection and ii) Dynamic AR projection. The first type refers to the static or non-moving content where the overlayed virtual information appears to coexist with the physical world. Meanwhile, dynamic AR projection refers to virtual content that is interactive and moving (Dumbre, 2023). This AR type allows human interaction by overlaying virtual information directly with physical objects around the user's environment unlike other AR types which require viewing through a display screen such as smart glasses or devices. Aggarwal and Singhal (2019) added that this AR creates a digital canvas on any physical surface to project 3D interactive holograms. In other words, it creates an illusion of an interactive augmented environment (Figure 6).

Fig. 6 *Projection-based AR in Geography Class (Shushan, 2018)*

2.1.3.5 Superimposition-based AR

Superimposition-based AR replaces an original view of an object with an augmented version either fully or partially (Digital Promise, n.d; Mendoza-Ramirez et al., 2023; Aggarwal & Singhal, 2019. According to the researcher, this AR type typically requires full object recognition to trigger the replacement of the original view with an augmented version. It also depends on the scale, colour and environmental conditions of the object location and the limitation of free movement to fully display the augmented version (Shushan, 2018). Figure 7 is an example of superimposition-based AR.

Fig. 7 *Superimposition-based AR in field trip (Shushan, 2018)*

2.1.3.6 Contour-based AR

Contour-based AR or also known as outlining AR is an AR type that outlines the contours of real world objects (Berger, 1997; Mendoza-Ramirez et al., 2023). This concept of AR aims to enhance user's perception and interaction with the physical world by providing navigations. For example, this type of AR can be seen in car user navigation (Figure 8).

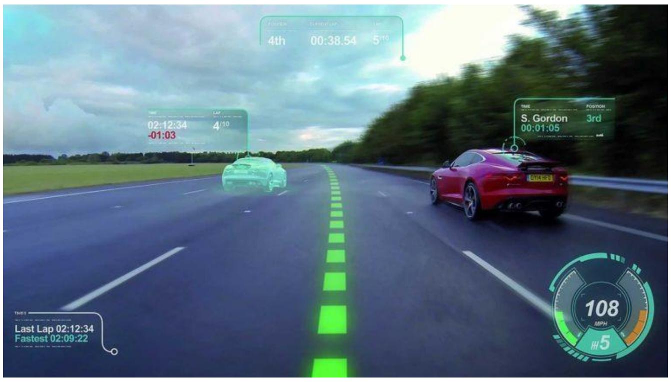

Fig. 8 *Contour-based AR in car navigation system (Prabhu, 2017)*

To reiterate, marker-based AR uses 2D visuals like barcodes, QR codes, or images to trigger an augmented reality experience. Marker-less AR uses environmental features like GPS, accelerometer data, or computer vision to position AR content in the real world. Location-based AR uses GPS location to pair dynamic locations with points of interest, providing relevant data. Projection-based AR uses light projection to create virtual objects within or on the user's physical environment, aiming to overlay virtual information. Superimposition-based AR replaces original views of an object with an augmented version, typically driven by object recognition. Contour-based AR identifies and highlights the edges or contours of real-world objects. These types of AR make it useful in various industries such as maintenance, education, and medical procedures.

2.1.4 Application of AR

As AR enables simultaneous interaction between real and virtual worlds, it has transformed several industries such as healthcare, education, entertainment, and manufacturing. AR technology has revolutionized the healthcare industry by procedural transformation which improves patient outcomes (Mendoza-Ramirez et al., 2023; Yuen et al., 2011; Alkhamisi & Monowar, 2013; Azuma, 1997). In surgery, AR allows surgeons to visualize patient anatomy without large incisions, resulting in less complicated surgeries and quicker recovery times (Mendoza-Ramirez et al., Yuen et al., 2011, Azuma, 1997). This extends to collecting real-time 3D datasets from non-invasive sensors like MRI, CT, or ultrasound imaging, providing doctors with "X-ray vision" inside the patient as noted by Azuma (1997). AR can also guide precision tasks like drilling holes for brain surgery or performing needle biopsy and is useful for training purposes. Yuen et al. (2011) added that AR systems aid in new procedures, navigation, and haptic device integration, making surgeries more minimally invasive and aiding surgeons in navigation before, during, and after surgery. Moreover, AR games enhance rehabilitation by transforming exercises into enjoyable activities, benefiting children and long-term patients, and influencing prosthetics and orthotics, improving comfort and usability (Mendoza-Ramirez et al., 2023; Yuen et al., 2011). AR can enhance medical surgical procedures by improving cost effectiveness, safety, and efficiency, aiding surgeons with navigation and orientation before, during, and after surgery.

According to Bottani and Vignali (2018), AR applications have also revolutionized the manufacturing industry by enabling real-time information exchanges at various stages of the product lifecycle, including process monitoring, control, plant layout evaluation, maintenance, construction, and industrial safety enhancement. AR technology in the industrial and manufacturing sectors integrates virtual data into the physical world, creating an enhanced reality by overlaying digital information in a real-world environment (Mendoza-Ramirez et al., 2023). Gallala et al. (2019) supported how AR aids assembly by identifying technical specifications and enabling direct interaction with parts, enhancing user-product synergy through ARDIS, an AI-guided application. In addition, AR has enhanced workers' training, provides real-time guidance for maintenance and repair tasks, aids designers and engineers in 3D modelling, and aids in quality control in the manufacturing sector.

In addition, AR has further transformed education by blending real and virtual elements, transforming textbooks into multimedia experiences, and improving understanding, motivation, and academic results by combining multimedia items with physical world scenes (Ariso, 2017; Mendoza-Ramirez et al., 2023). Yuen et al. (2011) added that AR technology has significantly improve teaching and learning environments by engaging students, stimulating exploration, and providing subjects where real-world experiences are difficult to obtain. This is considered suitable for inclusive education, treating individuals with autism, and integrating with emerging pedagogies. Mendoza-Ramirez et al. (2023) pointed out that AR promotes collaborative learning, teamwork, and problem-solving skills, especially in hands-on industries like medical training, where virtual organs overlay mannequins for complex procedures. This comes to show that AR has provided immersive experiences which foster collaboration and enhance understanding.

Furthermore, AR is commonly used by entrepreneurs to promote new products online (Alkhamisi and Monowar, 2013; Yuen et al., 2011). Mendoza-Ramirez et al. (2023) and Carmigniani et al. (2010) observed that retail stores have increasingly been adopting AR to enhance customer experience by providing instant access to product reviews and virtual fitting rooms. E-commerce, particularly clothing shopping and even furniture shopping, uses AR applications to help customers make informed decisions (Alkhamisi & Monowar, 2013). AR has become a significant tool in advertising and marketing, allowing companies to engage potential customers through various applications, such as displaying full-size AR virtual cars in shopping centres, marking people with virtual clothing items, creating games, and viewing holographic boxes projected from any sheet of paper with a QR Code.

2.2 Cost Management Practices in Construction

Construction cost management is a process that is necessary for controlling and managing the cost required to ensure a construction project is completed within the approved budget (Abdel-Monem et al., 2022; Rahim & Ismail, 2021; Igwe et al., 2020; Potts, 2008). Based on the Royal Institute of British Architects (RIBA) as highlighted by Lu et al. (2018), the lifecycle of construction cost management involves various stages: starting from preliminary cost estimate in the preparation stage, cost planning during the design stage, preparation of tendering, cost control throughout the construction stage and post tender estimate activities until the completion of a construction project (Figure 9). Mostly, every stage of a project involves cost management. Therefore, cost is one of the critical parameters to measuring the success of a construction project. Similarly, Potts (2008) mentioned that construction projects typically prioritise the "Project Management Triangle" which consists of cost, time, and quality as the main objectives. Cost is fundamental among these factors. Hence, it is important to carefully manage construction costs to avoid any negative consequences that could impact the project's performance and the quality of its outcomes. Moreover, cost management services in the construction industry are typically being delivered by professional disciplines such as quantity surveyors who are also referred to as cost economists, cost consultants and cost engineers (Olanrewaju & Anahve, 2015). A quantity surveyor is a construction professional who is responsible for managing and controlling construction costs as well as contractual matters of a construction project (RICS, 2018). They are primarily responsible for cost-related tasks of a project's life cycle, from preliminary cost estimation to tendering, cost control, and final settlement to ensure effective financial management, decision-making, and overall project success.

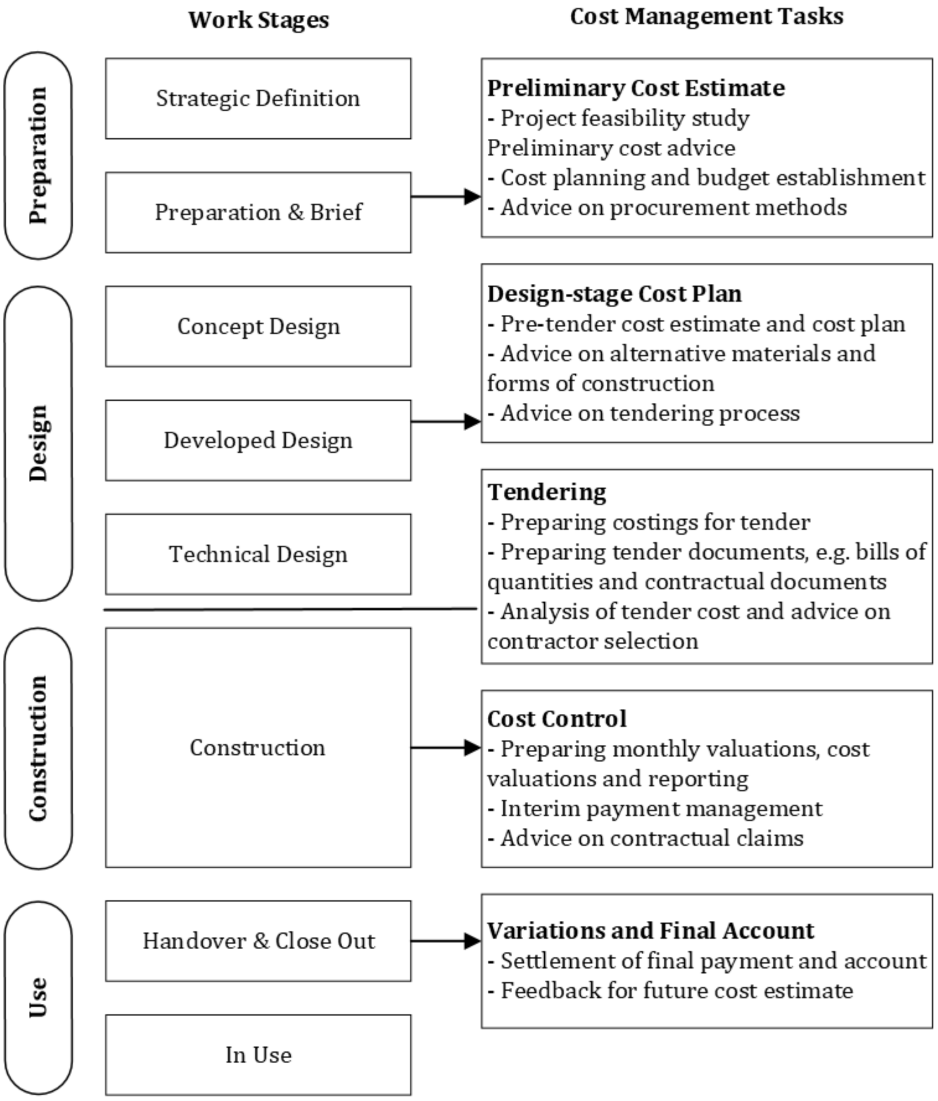

Fig. 9 *Life cycle of construction cost management in the context of RIBA Plan of Work (Lu, 2018)*

2.2.1 Preliminary Cost Estimate

Preliminary cost estimate is one of the significant components for various sequential activities like tendering, contracting, and financial planning. It is conducted during the project's preparation stage (Potts, 2008). Rahim and Ismail (2021) added that this part of cost management process involves identifying the resources needed to complete the project. In particular, it considers factors such as land acquisition, construction costs, maintenance, and operating costs. This estimation, although less precise due to limited information, is essential to forecast a project's feasibility and profitability studies. The preparation of the first preliminary estimate mostly relies on a variety of methods like the 'floor area method,' 'unit method,' and 'storey enclosure method' and is refined as more information becomes available (Potts, 2008). Poorly estimation results in difficulties using the allocated budget funds which will affect other stages in the construction. Hence, cost management team needs to have a strategic and systematic approach to cost estimation to ensure that cost overrun is less likely to occur in the later stages.

2.2.2 Cost Planning

As the construction project progresses, the cost management activity transitions to the design-stage cost plan. It is noted that cost estimates during this stage become more detailed since more information becomes available (Potts, 2008). Quantity surveyors play a significant role in developing detailed cost estimates based on the design and engineering information prepared by the design team. Moreover, the increased project information during this stage facilitates in justifying the value for money of the project (Lu et al., 2018). The same researcher stated that quantity surveyors can make comparisons between the cost estimates to identify the most efficient design or materials. Thus, this has the potential to avoid any additional costs occurring from variation in the next stages. Further design developments and changes are also monitored (Potts, 2008). This process facilitates in tender evaluation, contract changes, and work scoping (Olanrewaju & Anahve, 2015). In simple terms, this stage allows a better understanding and control over the project costs as details of the project becomes more available.

2.2.3 Tendering

Tendering involves quantity surveyors preparing pre-tender cost estimates and tender documents for contractors. The tender documents include BQ, which details the quantities of materials, workmanship, and other cost-related items (Lu et al., 2018). Lu et al. (2018) further emphasized its significant role as part of a contract document, guiding contractors in pricing their tenders and forming the basis of agreements between clients and contractors. However, Laryea (2010) suggested that traditional tender documents are not always clear or adequate. This usually stems from issues regarding technical information prepared by the designer team in terms of drawings, specifications and BQ tends to lack detailed or accurate information. Other than that, this could perhaps be due to traditional cost management practices lacking visualizations. In consequence, the researcher highlighted how this leads to inaccurate estimates, higher margin, claims and disputes.

2.2.4 Cost Control

During construction, the focus shifts to cost control, where quantity surveyors monitor project costs against baseline estimates to manage changes effectively. This is to ensure that cost overrun does not occur. Potts (2008) and Lu et al. (2018) noted the cost control methods include preparing overall cost control plans, monitoring cash flow, and initiating financial reports. Additionally, Oberlender (1993, as cited in Potts, 2008) added that this stage is far more than just controlling expenditures, it also includes controlling the project's revenue to ensure that all income is recovered from the client and no wastage of money or unauthorized increase in project cost happens. However, the traditional cost control methods are considerably challenging due to the complexity in tracking expenditures and variations. This is supported by Harris and McCaffer (2006) who stressed how most cost control systems take long response time due to the manual processes. Quantity surveyors acting as consultants are responsible in facilitating communication between clients and contractors and settle interim payments based on valuations.

2.2.5 Variations and Final Account

Once the construction stage is completed, quantity surveyors would then settle for final payments and accounts based on variations between final construction works and baseline cost plans. Variations could arise due to design changes, technological advancements, or market conditions. In this context, quantity surveyors play a key role in quantifying these variations, agreeing with contractors on final accounts, and storing cost information for future reference (Potts, 2008; Lu et al., 2018).

2.3 Application of AR in the Construction Cost Management

As previously explained, AR technologies can be used in a variety of industries including entertainment, healthcare and education. In the construction industry, it can be applied to construction cost management. Construction cost management is considered as the key measure of success in project delivery. However, the traditional Malaysian construction cost management practice, which is heavily reliant on physical documentation rather than digital methods has led to severe issues such as delayed decision-making, inaccurate estimates, and communication breakdowns (Shehu et al., 2014; Roslan et al., 2022). Cost overruns are a pervasive issue in the construction industry. Nevertheless, advanced technologies such as AR can help facilitate a construction project's processes and progression. In terms of, construction cost management, AR technologies can help improve project visualization, better communication, prevent delays, reduce overruns, and identify mistakes at the early stages.

2.3.1 Virtual Cost Estimation and Planning

The traditional cost management methods which uses methods such as BQ and architectural drawings, often fall short of preventing cost overruns due to project complexities and unforeseen factors (Ang et al., 2020). This results from BQ being prone to human error since the tasks are done manually by humans and architectural drawings are sometimes standardised or lacking in details despite different project natures. Therefore, QS may make mistakes such as omissions, double-counting and misuse of outdated drawings (Lee et al., 2022). AR can facilitate the initial stages of a construction project by providing virtual cost estimation, automated measurements and planning (Oke & Arowoiya, 2022; Igwe et al., 2022)). The researchers further mentioned that AR is applicable in project planning. To be specific, AR technologies are capable of visualizing various design options in real-time, showcasing different types of materials and layouts as well as construction methods. In the same context, Igwe et al. (2022) added that AR facilitates stakeholders to conduct walkthroughs of a project before construction works are executed. Hence, this reduces the probability of delays and cost overruns as AR allows the stakeholders to assess and identify any potential issues before they surface.

2.3.2 Real-time Project Tracking

It is much approved by everyone that construction projects are complex in nature and variations to arise from them are not common. AR is capable of facilitating real-time project tracking where it allows different stakeholders in a construction project to assess its progress and identify any potential scenarios that might lead to cost overruns or delays efficiently (Shakil, 2019). AR can be used to gather cost data whilst the project is being executed. Construction cost professionals such as quantity surveyors can also compare the actual construction progress with the planned schedule and budget. This can be done through AR headset or devices which overlays digital information onto the physical environment (Shakil, 2019). Through AR tools that are customed for monitoring, different parties in the project can identify issues such as delays, resource shortages or any defects in design early in the stage (Senanayake et al., 2022; Oke & Arowoiya, 2022). AR is a useful tool for monitoring. construction activities. This empowers stakeholders to make better-informed decisions and plan more strategic risk management and cost control which improves project timelines.

2.3.3 Collaboration and Communication

AR technologies are capable of facilitating project team collaborations which in turn leads to effective communication. Effective communication happens to be one of the key measures to successful construction cost management. AR helps in improving collaboration by providing a shared and immersive experience (Adebowale & Agumba, 2022; Nassereddine et al., 2022). For example, stakeholders involved in a construction project can utilise AR tools to view 3D models of construction site, identify cost implications and make real time decisions more collaboratively during project meetings. Nassereddine et al. (2022) stated that AR also facilitates virtual collaboration among teams working in different locations as it allows stakeholders to remotely guide on site personnel. This reduces the need for them to travel and at the same time decisions can be made on time. As a result, communication barriers between clients, architects, quantity surveyors and other stakeholders involved are reduced as AR assists the stakeholders in communicating project information. Thus, effective communication provides more efficient cost management and facilitates project execution.

2.3.4 Quality Defect Management

It is highly common for people to perceive construction projects as risky. This is due to the fact that construction projects tend to have unforeseeable issues which leads to a negative cost impact. However, AR is applicable in assessing risk by simulating potential scenarios and their financial consequence (Oke & Arowoiya, 2022; Senanayake et al., 2022). Senanayake et al. (2022) also added that stakeholders can use AR to visualize the outcome of a project including its overall cost. The researchers further highlighted that AR supports risk mitigation strategies by providing training for on-site workers through visualization. Hence, this ensures construction workers are well equipped and prepared for any complex tasks or hazardous conditions; reducing the likelihood of accidents and any associated financial setbacks.

2.4 Barriers to AR Application in Construction Cost Management

Although there are many advantages to using AR in the industry, especially in construction cost management, many factors hinder its implementation. In this context, the barriers to implementing AR in construction cost management can be categorized into 4 main elements: i) people, ii) technology, iii) internal and external pressures along iv) financial.

2.4.1 People

The construction industry is majorly labelled as an ancient industry due to its culture of unwillingness to adopt new technologies. The adoption of AR in the construction industry is hindered due to the significant resistance from individuals. This resistance, as mentioned by Oke and Arowoiya (2022), Zhil et al. (2022), Zakaria et al. (2022), Asmar et al. (2021), Zahrizan et al. (2021) and Thearea (2020) stems from various factors, including a lack of knowledge, fear of change, low support by the top management, and a lack of awareness on AR. Zahrizan et al. (2021) added that the lack of support from the top management to provide training opportunities to employees on technologies is what increased their resistance to adopting new technologies, which in this context, AR. Similar to Thearea (2020), only a few professionals have experience and knowledge of AR and most of them are only at the basic level. Research by Delgado et al. (2020) highlighted that the construction industry is not a mature field compared to other industries when it comes to labour dynamics. Therefore, it has become difficult to attract AR experts. Based on the researchers' findings, it can be concluded that construction professionals are accustomed to the traditional construction practices in which transition to adapt new technologies such as AR can be time-consuming.

2.4.2 Technology

The complexity, maturity and compatibility of AR technology are also seen to be the main barrier to adopting it in construction cost management practices. Delgado et al. (2020) found that the main limitation of AR adoption is that many perceived AR as an immature technology that cannot be fully practiced yet. AR technologies such as AR head worn devices have battery limitations, low tracking accuracy and low resolutions which disincentivize the use of AR in construction projects (Delgado et al., 2020). This is also supported by Martinez et al. (2014) who stated that AR technologies are still not accurate enough to be accepted in social practices. This is because the AEC demands a high level of accuracy and consistency in task performance to succeed in construction projects. In addition, the complexity of AR technology is what influences the slow process and productivity (Azlan et al., 2022; Oke & Arowoiya, 2022). When trying to transition to new things, particularly technologies, it can be said that construction professionals are reluctant to do that as it would be overwhelming and time-consuming to fully explore and master the complexities of new technologies before actually practising them. Son and Kim (2015) also highlighted software issues such as compatibility are the prominent barrier to adopting new technology since using such technologies mostly involves data exchange and thus, incompatibility with technologies that are currently used in construction practices can lead to inaccuracy. Other than that fact, AR was initially developed for the entertainment industry (Rahim & Ismail, 2021), therefore there is still a lack of capabilities for AR to fully be adopted in procurement activities and provide solutions in complex AEC activities.

2.4.3 Internal & External Pressure

Internal and external factors such as government policies, client and management demands are also found to be one of the major barriers to AR adoption. Autodesk (2023) pointed out that despite countries like the US, UK and Singapore which are seen to adopt AR in their construction practices, external pressures are less advocating. This is supported by Azlan et al. (2022) who stressed that it is the highest authority in hindering the adoption of new technologies. For example, up to this date, government projects still require contractors to submit tenders and other necessary documents to their offices physically instead of digitally. Resolving this issue is not possible with a one-man show. It requires collaborative efforts, policy changes and investment in the construction workforce to develop and adapt its culture fully towards digitilization. For example, CIDB has carried out various programmes in Malaysia for construction professionals to implement BIM in their practices such as seminars, workshops and incentives to empower BIM in the construction industry which has shown an increase in BIM adoption among construction professionals (CIDB, 2020). Therefore, it is crucial for such efforts to be made the same towards AR.

2.4.4 Financial

The initial cost of AR typically requires a substantial sum of money for training, procurement and personnel recruitment. This has indeed posed a barrier to adopting AR in construction. This is supported by Azlan et al. (2022) and Wang et al. (2021) who mentioned that finances are the main factor in new technology adoption. Silverio et al. (2017) added that the initial cost that implementing AR would cause negative acceptance among stakeholders since it will increase the overall cost of the project. Thearea (2020) also noted that there is a lack of resources being allocated to information technology (IT) in the construction industry. This is perhaps due to the industry being reliant towards traditional methods.

3. Research Methodology

This study is planned to employ a mixed-method approach which will combine quantitative surveys and qualitative interviews. Starbuck (2023) believed that a research method that integrates objective and subjective data enables a researcher to gain a better understanding of their research problem. Tenny et al. (2023) support that instead of just collecting numerical data, the qualitative approach helps further investigate and understand quantitative data. Therefore, this mixed-method approach can provide a holistic understanding of the complexity of AR adoption in construction cost management. The target population will include Quantity Surveyors registered under the Board of Quantity Surveyors Malaysia (BQSM) in Malaysia. The focus of this study is on identifying their level of awareness and understanding of AR adoption in construction cost management. The questionnaire will be structured and standardised to study the Quantity Surveyors' awareness criteria to adopt AR in construction cost management as well as assess the barriers that hinder its adoption. The questionnaire will use closed-ended questions such as Likert scale questions to assess their familiarity and understanding of AR and to assess which barrier is significant. Moreover, the semi-structured interview will involve open-ended questions to gain a better understanding of the barriers to AR adoption and develop strategies to overcome them. The data collected from the questionnaire survey will be analyzed through Statistical Package for the Social Sciences (SPSS) using descriptive statistics such as frequency, percentage, and mean analysis, while content analysis will be used to assess the semi-structured interview.

4. Conclusion

In conclusion, AR can be considered as one of the advanced technologies that can revolutionise construction cost management due to its ability to provide visualization and immersive user experience to stakeholders which is something other technology lacks. It is no doubt that AR is currently at a low maturity level in the AEC industry as it is still newly introduced, however it cannot be denied that it has the potential to facilitate and improve cost-related performance. It is crucial to understand the concept of AR so that construction stakeholders can actually adopt this technology. Therefore, various parties in the industry need to partake in this matter such as the individuals, the construction community and the government. Overall, this preliminary framework anticipates providing a much further insightful study which can increase the understanding of AR adoption in construction cost management.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design****: Safiah Azahari, Roziha Che Haron;* ***data collection****: Safiah Azahari;* ***analysis and interpretation of results****: Safiah Azahari, Roziha Che Haron;* ***draft manuscript preparation****: Safiah Azahari. All authors reviewed the results and approved the final version of the manuscript.*

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