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AUGMENTED REALITY AS A TOOL FOR ENHANCING EFFICIENCY IN CONSTRUCTION PROJECTS

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Abstract
The assessment of augmented reality's application in construction project delivery was the focus of the study. One hundred eighty-three (183) sets of questionnaires were distributed in total; of these, 164 replies were received, of which 124 were deemed genuine and utilized in the analysis. For the study, the simple random sampling technique was used, the IBM SPSS Statistics version 25.0 was used to analyze field data, while the statistical tools used in analyzing the field data ate frequency, mean, and standard deviation. The study found out that majority of the study respondents had 12 to 15 years of work experience. They are actively engaged in projects, assuming increasing responsibilities, and contributing significantly to the execution and management of construction initiatives. The study further the showed that the respondents are members of a number of professional associations, including the Estate Surveyors and Valuers Registration Board of Nigeria (ESVARBON), the Council for the Regulation of Buildings in Nigeria (CORBON), the Nigerian Institute of Architects (NIA), the Nigerian Institute of Quantity Surveyors (NIQS), and the Chartered Institute of Personnel Management of Nigeria (CIPMN). The findings revealed that AR can substantially enhance project delivery by minimizing errors and improving coordination. The study recommends the implementation targeted communication and training programs to dispel misconceptions surrounding AR technology as well as engaging in discussions to streamline regulatory processes that may pose barriers to AR adoption, ensuring a supportive environment for technological advancement.

Keywords: *Augmented reality, Construction projects, FCT Abuja, Mean, Standard deviation.*

Introduction AR in the construction industry

AR is used in various stages and departments of a construction project. Many scholars believe that augmented reality is the most obvious technology to use in a construction project to provide automation. In 2018, it is undeniable that AR will make a significant contribution to transforming the construction industry's culture into a totally automated sector in the near future. Various applications of AR technology are covered in this portion of the review through an examination of numerous research articles despite substantial efforts and careful consideration from governmental organizations and professional bodies, present safety policies rely on parametric models or manual approaches that involve some infrequent, ineffective, and error-prone auditing and insufficient safety training (Park et al., 2020). These techniques may improve safety, but they reduce project productivity.

However, developing cutting-edge technologies may increase the construction industry's safety, efficiency, and production. Sensors for alarm and awareness that may prevent harmful exposures are examples of digital technology applications; radar sensors and AR to control heavy machinery onsite; drones to perform site surveys; mixed virtual and AR for training; and the use of smart wearable devices (smart watches, vests) to track employees (Cartwright, 2018). Furthermore, the development of three-dimensional (3D) printing and robots has resulted in a significant advancement in the ability to create building components or the entire building. As a result, over the last decade, several tech-based options to control and minimize site risks and increase productivity have been introduced (Park et al., 2020). These solutions include BIM, VR/AR, artificial intelligence (AI), computer vision, and big data analytics. However, there is a trend pushing technological improvement geared at modeling AR based on mobile devices, which enables 3D models to be constructed and deployed in surroundings without the use of markers (Machado and Vilela, 2020). AR is proving effective in a variety of other industries, and with the emergence of smaller and more efficient mobile electronic devices, AR has the potential to become a valuable tool for construction workers (Kim and Irizarry, 2020).

AR applications in the construction industry provide a wide variety of stakeholders with quick and easy access to information, resulting in remedial measures that reduce costs and delays due to performance incompatibilities (Bae et al., 2013). Veas et al. (2013) created a platform for 3D mobile viewing of environmental data that is connected with AR and used to monitor the construction environment. Yeh et al. (2012) employed mixed reality in their study to reduce the complexities and challenges of onsite data retrieval in building projects.

In addition, Kwon et al. (2014) highlight the use of mixed reality apps in detecting dimension errors and omissions. Furthermore, Kim and Irizarry (2020) used AR as an innovative method to improve the spatial skills of construction management students. They evaluated an AR application on a sample of students, and feedback was obtained against a set of criteria including mental demand, physical demand, temporal demand, performance, effort, and frustration. Another potential application for AR is on-site construction inspection. To meet this criterion, Kopsida and Brilakis (2016) created a framework based on mobile-based AR that combines the inspector's perspective with the 3D as designed BIM model. In a different study, Chu et al. (2018) used a BIM integrated AR system for mobile devices to enable onsite information extraction to lessen the likelihood of workers to commit cognitive failure; however, this work was limited to an artificial scenario. Similarly, by integrating BIM into AR, an AR mobile channel called "BIM-Phase" was proposed by Zaher et al. (2018) for monitoring the progress of construction work. Kim et al. (2016) propose a system for enhancing construction safety education through the use of mobile-based VR and AR for experiential learning.

The main objective of this study is to examine the benefits of deployment of AR and it's implementation in the delivery of construction projects.

Literature review

According to Aibinu and Jagboro (2020), the past decade in Nigeria has seen a number of reforms that have benefited all sectors of the country's economy, particularly the construction and building sector. Over the last decade, Nigeria's construction industry has outperformed all other sectors of the Nigerian economy. However, the construction industry's contribution to Nigerian GDP and labour employment remains low. Despite its enormous success, the sector faces significant challenges, including a shortage of local competent workers in some complex projects, a scarcity of materials, a power constraint, and widespread unethical behaviour in the industry. However, the industry offers several opportunities, particularly in the ICT, subcontracting, and education sectors, making it very appealing to investors.

In practice, both civil engineers and computer scientists have received a lot of attention for using computer vision technology to automatically assess recorded photos and videos in terms of CPM. Associations between computer vision and civil engineering researchers (Yuen et al. 2011), as well as other interdisciplinary efforts, have enabled the measurement, detection, and tracking of civil infrastructure components, equipment, and workers. As a result, progress monitoring, quality control, operation analysis, safety monitoring, and occupational health assessments are all critical in construction performance monitoring applications (Gong et al. 2011).

Time-lapse photos can be taken from fixed camera angles to capture work-in-progress (WIP) (Heinzel et al. 2017). These photos are compared to one another or to a 4D BIM that depicts the estimated state of construction progress (Fard et al. 2009). Several visualisation tools are also proposed to highlight construction progress discrepancies. These systems incorporate colorcoded construction elements inspired by traffic light colours. 2007 (Nwadinobi, 2025). Furthermore, some studies have highlighted the importance of using 4D Building Information Modelling (BIM) in CPM, with laser scanners or image-based 3D reconstruction methods focusing on 3D point cloud models (Dimitro and Golparvar-Fard, 2014).

The authors also emphasized the viability of an automated progress monitoring method based on geometrical data. However, it has been determined that without real-time material information, none of the various technical approaches can provide adequate information on the current stage of construction development (Golparvar-Fard et al. 2012). As a result, AR has emerged into the CPM by combining real and virtual items that interact in real time and register virtual images with the real environment. Augmented reality (AR) allows computer-generated virtual metaphors to precisely overlay physical objects in real time (Yuen et al., 2011). AR uses real objects in a seamless manner, allowing the user to interact with virtual images (Zhou et al. 2008).

This mixed overlay can be interpreted in devices such as head-mounted displays, pocket monitors, and see-through glasses to obtain more information about the real world. The use of augmented reality (AR) can be thoroughly characterised using the reality-virtuality continuum, which highlights the "mixed reality" of actual and virtual environments (Milgram et al. 1995), as shown in figure 1.

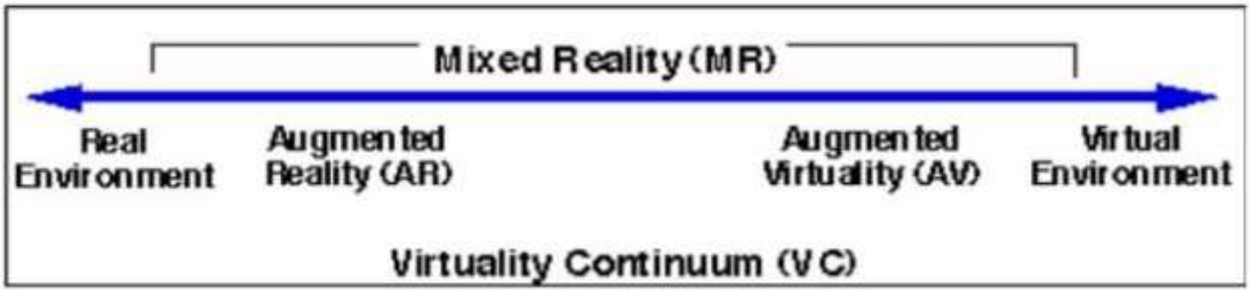

Figure 1: Simplified representation of" virtuality continuum" Source: (Milgram, Takemura, Utsum, & Kishino, 1995).

The real and virtual environments will be at opposite ends of the scale, as illustrated in Figure 1. Between these two extremes, there are two types of augmented environments: AR, which inserts computer-generated content, and Augmented Virtuality (AV), which takes the real world and real environments as its background and merges and superimposes real-world data on top of a computer-generated world (Milgram et al., 1995; Nwadinobi, 2025). As a result, AR will be used in the construction industry to achieve a variety of objectives by combining it with other technologies like Virtual Reality (VR) and Mixed Reality (MR).

Most construction companies struggle to complete their projects within budget due to poor workmanship, resource scarcity, quality defects, and schedules (Divakar and Britto, 2018); therefore, cost management should be dynamic and resource-driven (Memon et al., 2011). Annamalaisami and Kuppuswamy (2019) identified 68 characteristics that contribute to cost overruns in Indian building projects. Asiedu and Ameyaw (2021) identified 22 major factors that influence cost overruns in developing-country construction projects. The authors developed a system dynamic model to explain the system's causal effects, revealing that the majority of components were interconnected. Furthermore, one of the primary reasons for failing to meet the projected client budget is the design team's lack of control over onsite activities (Igwe et al., 2020). To avoid such challenges, proper project cost management must include four key components: planning, estimating, budgeting, and controlling (Nwadinobi, 2025).

This is accomplished in construction by employing a variety of tools and techniques. However, most cost calculation systems used in the past did not meet today's cost management needs due to a lack of timely cost administration (Mesaros et al., 2015). In this vein, the introduction of BIM has improved the quality of data used in the construction sector and aided better communication among work teams by facilitating information in a centralised platform with various dimensional views (Zhang et al., 2018).

In terms of training and safety management, Albert et al. (2014) state that an individual's ability to identify and estimate hazards in complex situations is extremely limited. Workers with less experience on construction sites were unable to identify 57% of dangers, according to the findings. As a result, there is potential for improving safety skills. According to Sacks et al. (2013), VR is an appropriate medium for presenting hazards to workers without placing them directly in dangerous situations. Another advantage of using VR over classroom training is that participants are more focused on learning. Furthermore, the authors contend that training by placing oneself in dangerous situations on the job is too risky. One solution to this issue is to use VR and IVE. Using these tools, the user can simulate a dangerous situation without risking their safety. Workers would be able to recognise and assess a scenario, as well as determine the appropriate measures, in this manner. Workers' training, according to Chi et al. (2013), is a critical step in any project. AR approaches, for example, could be used to train workers on how to operate heavy machinery like construction cranes. According to Wang and Dunston (2006), AR also improves options for operating in hazardous environments that humans cannot access. AR could also help workers uncover hidden objects while renovating a building. This function will help workers avoid hazards, save time, and increase efficiency. According to Kwon et al. (2014), combining BIM models with AR can improve existing inspection models in terms of defect and quality management. It means that various information from a BIM model, such as drawings, schedules, and supplies, will be translated to a marker, resulting in the addition of information as physical components on-site. Park et al. (2013) divide the AR implementation process into three stages: identifying items and estimating information, predicting virtual object placements based on estimated information, and finally combining the real world with virtual elements. Figure 2, illustrated by Kwon et al. (2014), depicts the process of using AR technology for defect and quality management. This process is developed for identifying and correcting possible defects.

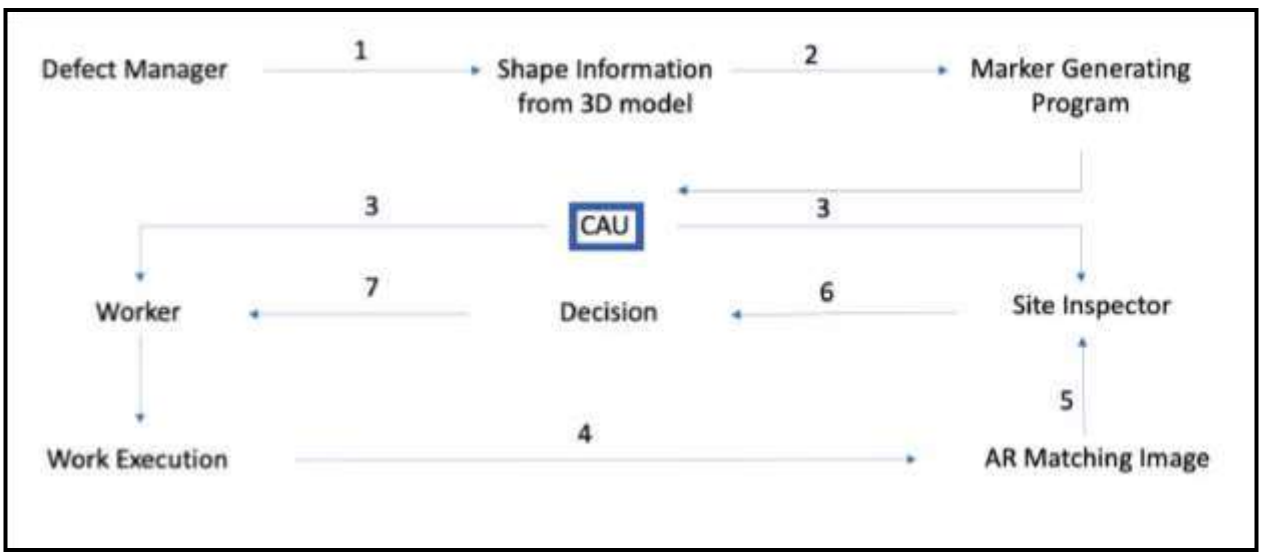

Figure 2: AR's defect management approach
Source: Kwon et al. (2014).

Scheduling and tracking project progress

AR has significantly improved the construction project's timeline. Wang et al. (2014) demonstrated that AR could be used as a scheduling tool more effectively than other existing tools for grasping and making someone understand without ambiguity. In the early twenty-first century, Chantawit et al. (2005) used AR technology to efficiently schedule projects with visualisation features.

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Zaher et al. (2018) used mobile AR technology to schedule and monitor construction projects in conjunction with Microsoft Project and Primavera. Hui et al. (2017) demonstrated in their study that AR can be used effectively for safe job scheduling in a construction project. In recent years, these and other studies have changed the way the construction industry thinks about scheduling. Nwadinobi (2025) found that AR on a tablet PC or mobile is more effective than other 3D models or Gantt charts for monitoring and tracking building projects. They also stated that AR has demonstrated the ability to view and estimate work performed on-site in accordance with the proposed process schedule. Wang et al. (2013) mentioned using AR to track construction project progress and compare it to the schedule. AR technologies provide a clear visual comparison of planned and actual facilities.

Park et al. (2013) also tracked an extra step, linking AR to material tracking, to ensure that the necessary materials were on hand. Golparvar et al. (2009), Omar and Nehdi (2016), Zhou et al. (2008), and Turkan et al. (2012) all demonstrated that AR will be one of the most commonly used functions in advanced construction project management for progress tracking and scheduling.

Communication and data collection

Excellent communication and information retrieval from the work site are critical components of a successful construction project. Nwadinobi (2025) argued that implementing several AR programmes significantly improves on-site project information access and effective communication when compared to more traditional information sources. Figure 3 depicts how augmented reality technologies are used in the construction industry to collect and distribute field data to users. It also reflects the various modes of communication among project participants and project information.

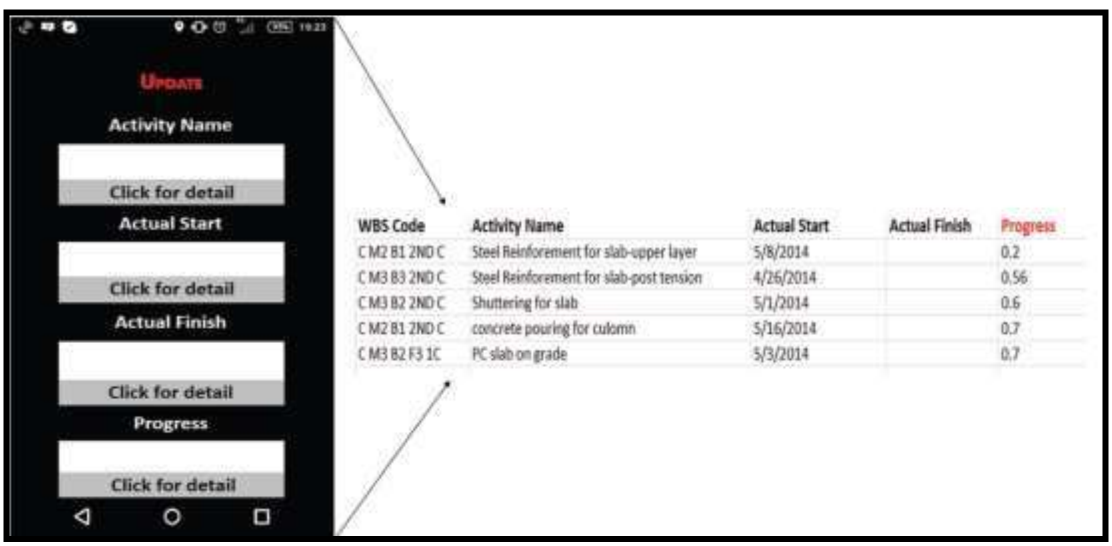

Figure 3.: AR technology for construction project scheduling and progress tracking (Zaher et al. 2018).

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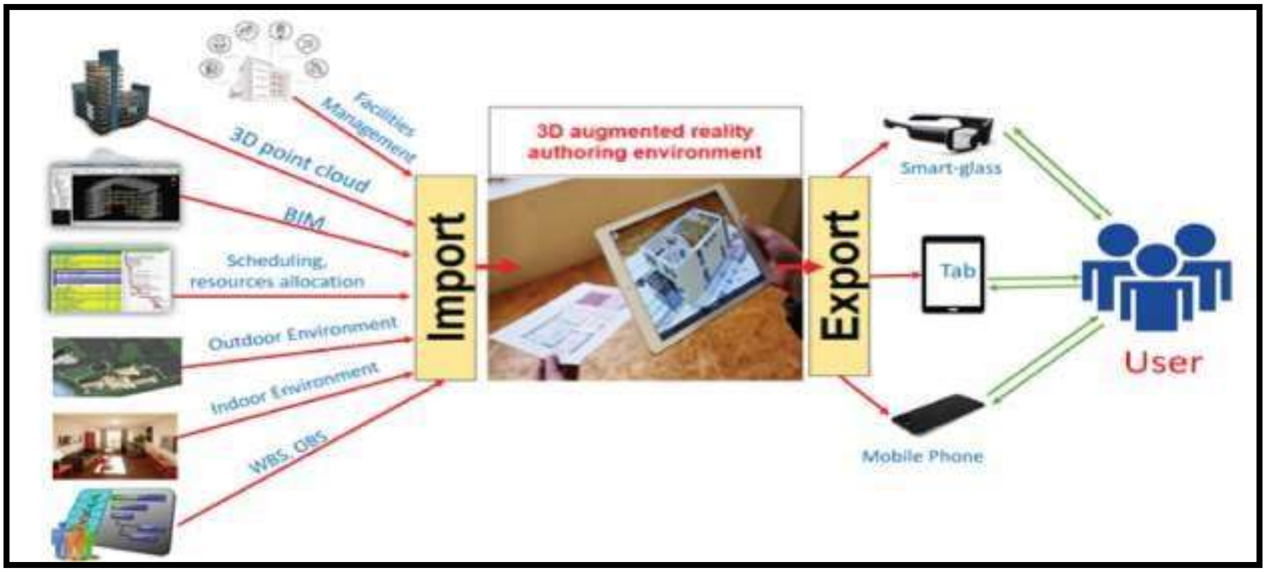

Figure 4: Construction field data and design information acquisition process using AR technologies. Source: Zaher, Greenwood and Marzouk (2018).

AR systems provide quick and easy access to information and help project managers identify corrective actions to reduce costs and delays caused by performance incompatibilities (Bae et al. 2013). According to Yeh et al. (2012), many businesses are developing lightweight mobile devices to reduce the problems and complexity associated with on-site data retrieval. According to the study, organisations are working to create devices that can exchange detailed drawings and relevant information based on the user's location. AR technologies' enhanced visualisation benefits allow for better communication between parties when commenting on and making suggestions for a specific project. When commenting and making decisions for a specific project, the visualisation capabilities and benefits of AR technologies enable better communication among the various parties involved in the construction project (Behzadi 2016).

Quality and defect management.

Quality control and management are essential elements of construction management. Many completed projects approved by the client are defective or fail to meet the specified quality standards, resulting in disputes. AR plays an important role in global construction by automating the quality and defect control systems. Several studies indicate that AR can be effectively used in QA/QC. Figure 4 shows how Kwon et al. (2014) used marker-based AR technology to monitor defects and quality levels. Their research resulted in a fantastic tool for flaw detection and repair. AR technology enables construction managers to address flaws that are likely to go undetected during the inspection process while also saving time. According to Park et al. (2013), if managers recognise the core control time points and measures for work to be checked proactively using the defect element ontology, worker performance can be automatically checked at the appropriate time using BIM- and AR-applied inspection equipment without having to visit the workplace. A marker-based AR technology is being used to improve quality and manage defects in construction projects, with promising results (Kwon et al. 2014). The study concluded that AR technologies outperform current manual-based defect management by reducing site managers' workloads and proactively preventing construction work problems. AR was viewed as a tool to provide excellent additional value and sensation of concreteness, particularly in close-to-target sites where the shapes and volumes of proposed buildings could be visualised (Olsson et al. 2012).

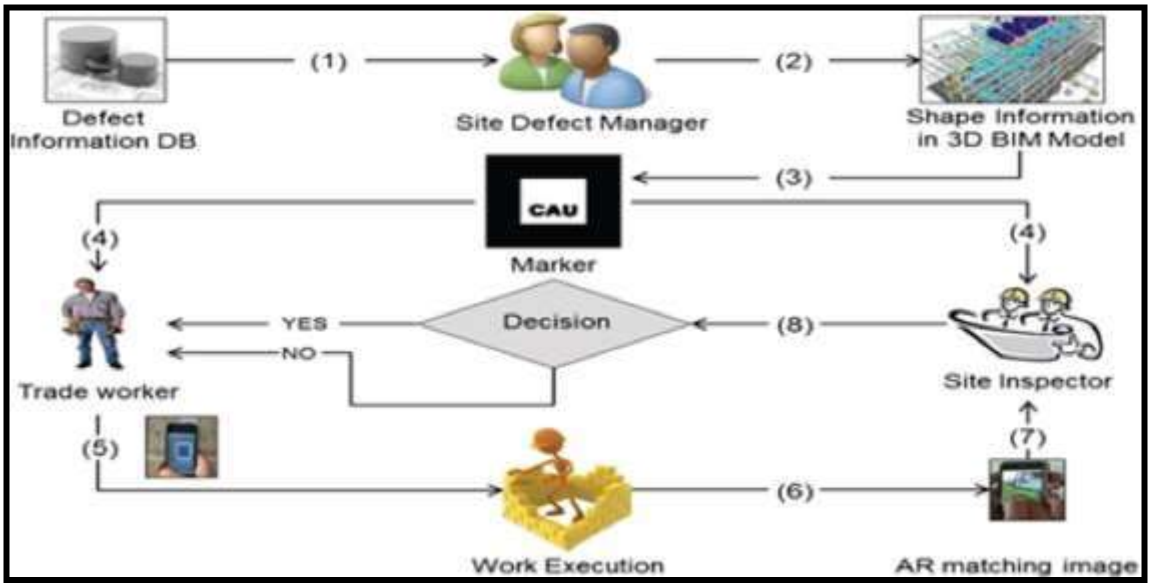

Figure 5: Automated defect-free AR systems
Source: Zaher et al. (2018).

A new automated, defect-free facilities management system is being developed for the construction project, allowing customers to be more satisfied than ever before (Koch et al. 2014). AR has also been identified as an effective quality and defect management technique for on-site construction projects (Kim et al. 2013). An AR technology-based management system is designed to eliminate flaws in piping assembly during a construction project, and the system met expectations and showed promise for the future (Hou et al. 2013).

Budget and time management

Time and cost are undoubtedly the most important aspects of the construction process. The goal of any construction project management is to shorten completion time and lower construction costs. Construction time and cost management have existed since the beginning of construction history, but they have never been particularly effective. Technological changes occur in a variety of forms over time to improve construction management performance. As this shift continues, AR-based solutions in construction management for monitoring and controlling time and cost issues have grown dramatically.

According to Wang et al. (2014), project managers can save time and money by using AR technology to precision projects while reducing labour work/time and cost efficiencies caused by errors and construction rework. Misreading plans or drawings or conveying information imprecisely from the plan to the real thing wastes approximately 9-13% of time and 14-19% of money (Kumaran et al. 2007). AR technologies can help solve problems like a lack of management staff and cost-efficiency in construction projects (Behzadi 2016). Park et al. (2013) and Kwon et al. (2014) found that the defects management procedure does not require any additional physical labour. Physical inspection and reporting in the building industry are time-consuming (Nwadinobi, 2025). As a result, staffing levels are reduced, as are the costs and time required to carry out these management functions.

Employee safety training and management

In today's construction industry, safety management systems are a major concern. Every year, thousands of people die in construction accidents around the world. Employee training is a critical component of any construction project. These tasks are extremely difficult to complete on the required or standard level. However, AR technologies can help with both issues by providing effective employee training and implementing the safety management system as specified. Chi et al. (2013) demonstrated in their study that AR technologies could be effectively used for heavy equipment operator training in construction projects.

Wang and Dunston (2006) also discovered that AR technologies are widely used to train construction workers to operate large and medium-sized cranes, excavators, and assembly equipment.

AR technologies assist workers and stakeholders in understanding various complex designs and arrangements in a simple and effective manner, as well as educating project participants about various project challenges (Lee, 2012). Izkara et al. (2007) developed a conceptual diagram of an Augmented Reality system for construction site safety. To be safe, construction workers must have and maintain a complete understanding of the actual objects and safety hazards around them (Stricker et al., 2001).

Wang et al. (2013) developed a conceptual framework for integrating building information modelling and augmented reality into the construction industry's safety management system. As a result, AR technologies are the new standard for modern construction management, particularly in training and safety management systems.

Using AR technology to manage construction costs

Construction management professionals must be able to visualise (Glick, 2012). Because cost management is a subset of cost management, it stands to reason that excellent visualising skills could benefit cost management as well. Proper design comprehension is essential for effective cost management (Hansen and Mowen, 2006). Nonetheless, the interests of various stakeholders in a construction project diverge, resulting in design flaws, numerous design and project revisions, and cost overruns (Asamaoh and Offei-Nyako, 2013; Nwadinobi, 2025). Traditional cost management challenges can be overcome by fostering a shared project understanding and improving stakeholders' spatial abilities, talents, and cognitive intelligence (Kim and Irizarry, 2021). The construction cost management process makes use of a variety of software tools to plan and anticipate project costs.

However, the data transmission process is one-directional, that is, virtual to physical, rather than bidirectional, that is, physical to virtual. AR has the potential to improve design communication in those

applications by visualising real-world structures alongside virtual and any other additional contextual information, such as specifications and standards (Kalkofen et al., 2011); this could potentially improve design knowledge and negotiation (Rajaratnam et al., 2021).
Although previous researchers discussed several AR applications in various contexts in the construction industry, the potential benefits of AR in construction cost management have received little attention, despite the fact that opportunities to reduce cost management issues by improving stakeholders' spatial skills exist. Furthermore, an industrial gap exists to minimise cost overruns in order to gain a competitive advantage. As a result, the goal of this study was to investigate the potential applications of augmented reality in the tools and procedures used for building cost control.

METHODOLOGY

Research Designs are research plans and procedures that cover everything from broad assumptions to specific data collection and analysis methods (Nwadinobi, 2025). Case studies, surveys, experiments, and regression analyses are examples of research designs.
A survey strategy provides a quantitative or numeric description of a population's trends, attitudes, or opinions by studying a sample of that population, which may include cross-sectional and longitudinal studies using questionnaires or structured interviews for data collection, with the goal of generalising from a sample to the entire population.
The study population consists of the target respondents who meet the requirements for providing information (data) for the research. As a result, the target population for this study is registered contractors, architects, structural engineers, and building services engineers in Abuja.
The sample frame represents the total number of items in the sample population. The total population of registered mass housing developers engaged in construction activities in Abuja is 80 companies, employing an average of 22 professionals. This translates to 1760 (80 multiplied by 22) professionals in the Abuja mass housing sub-sector.
The following factors should be considered:

- The level of precision required in estimates (i.e. sampling error)
- The researcher's confidence level (risk of accepting that the sample is within the average). The intrinsic variability of the variables to be estimated.
- Determine the sampling method to be used.
- Evaluating population homogeneity.
- Determine the number of data categories for analysis.
- The level of disaggregation of study results.
- Resource constraints (cost, time, personnel, and equipment) were considered in this study, with a confidence level of 95%, precision of 7%, variability of 50%, and a Purposive sampling method.

Thereafter, the sample size was decided based on this formula

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$$n = \frac{N}{1+N(e)^2}$$

Where n=sample size required N = the population size
e = the level of precision (margin of sampling error) expressed in decimal which 5%=0.05

$$\frac{1760}{1+1760(0.05)^2} = \mathbf{183}$$

There are two major types of sampling techniques; the probability sampling technique and the non-probability sampling technique. Probability sampling refers to all forms of sampling in which the items sampled are selected according to some known laws of chance such that every item in the population has equal chance or probability of being selected. Examples are simple random sampling, stratified random sampling, cluster sampling and systematic sampling. The questionnaire for this study was designed based on the research objectives. The questionnaire was designed for professionals (architects, engineers, quantity surveyors, builders and project managers) aimed at soliciting response about their perceptions towards critical barriers impending augmented reality adoption on construction projects in Abuja, Nigeria. Since questionnaire can lead to error and bias, as well as increasing the tendency of non-response in a survey, questionnaire for this study was design in consideration of the nature of the respondents, ease of reading and completion period. The design of the questionnaire was incorporated and used with close-ended questions. The five (5) point Likert scale type of questionnaire were used for the variables items to ease the means of assessing the respondents.

The standard deviations (SD) of responses were used to measure the variability or dispersion of the responses. Standard deviations thus highlighted how clustered the mean response values are around the means for each knowledge and skills. Higher SD is interpreted as higher disparity or variation. These selected statistical tools are much appropriate for ordinal scale as applied to this study. The result of the mean was ranked; mean scores are indicators‖ to establish a rank order of importance for the factor. For example, if the mean score of particular variable is 3.2, then it could be interpreted that the variable is perceived to be between moderately important and important‖ but tends more towards being moderately important‖. Likewise, for level of proficiency tend towards good and very good.

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Results

A total of 180 set of questionnaires were administered and 164 responses were received as shown in table 4.1. Of these, thirty-seven (37) were not fully completed and therefore discarded. Specifically, those who left out or ticked noting or few items in the questionnaire were discarded. This resulted in an overall response rate of 68.9%. This is reasonable considering the fact that majority of the respondents were proportionally captured.

Table 4.1: Questionnaire Administration

Questionnaire	Number	Response rate
Administered	180	-
Received	161	89.4%
Valid	124	68.9%

Source: Field data 2023

4.3 Coding, Entering and Editing

Questionnaires were coded and data were entered into Statistical Package for social sciences (SPSS). Data cleaning was carried out to correct wrong posting while missing values were filled using the series mean method in SPSS.

4.5 Demographic information of the respondents

The demographic information of the respondents was analyzed in table 9. The frequency and percentage analysis was carried out and the results were presented to explore the respondents' profile.

Table 4.3: Demographic Information of the respondents

Variables	Option	Frequency	Percentage
Age	Less than 30years	10	8%
	Between 31 to 40	45	36%
	Between 41 years and above	69	56%
Gender	Male	121	98%
	Female	3	2%
Qualification	HND/Degree	69	56%
	Masters	41	33%
	PhD	14	11%
Working Experience	Less than 5 years	12	10%
	6 to 10 years	44	36%
	11 to 20 years	50	40%

	21 years and above	18	15%
Affiliation	Architect	38	31%
	Project Manager	22	18%
	Quantity Surveyor	15	12%
	Builder	49	40%

Source: Field data 2023

Table 4.3 shows the profile of respondents for the study. There was a reasonable spread of responses across the major professionals in the construction industry domicile in Abuja, Nigeria. The result also indicate diverse set of academic backgrounds among usable responses received as almost 69% had bachelor's degree while 41% had master's degree. The age group data showed that 8% of the respondents were less than 30 years of age, while 36% were between the ages of 31 and 40. Among the respondents, 56% were 41 respectively. Regarding the respondents' affiliation, 31% of those who responded were architects, 18% are project managers, 12% are quantity surveyors and 40% are builders.

Descriptive statistics based on mean ranking was carried out to explore the potential benefits of deploying AR and its implementation in the delivery of construction projects. The results showed the ranking, mean and standard deviation for each Item.

For variables (Benefits of AR) with the same mean score but different standard deviations, the variable with the lower standard deviation is ranked first. For those with the same mean values but with different standard deviations, the lower standard deviation variable was ranked first.

Table 4.5: Benefits of AR in the Delivery of Construction Projects

Benefits of AR	**Mean**	**Std. D**	**Rank**
Better scheduling quality and budget management	4.52	.915	1st
Visualization and display in 3D/4D	4.34	1.006	2nd
improved teamwork and communication within the team	4.20	1.122	3rd
Construction project safety, management efficiency, and planning	4.26	1.175	4th
Improving information retrieval in real time	4.33	1.108	5th
Encourages the adoption of BIM implementation	4.31	1.027	6th
AR has the potential to improve the user experience	4.21	1.000	7th
AR provides situational awareness	4.17	1.078	8th
Repair, rehabilitation, and maintenance are all aided by AR	4.28	1.074	9th
Virtual Heavy Construction Equipment Training at a Low Cost	4.20	1.090	10th

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reduction in labor hours	4.16	1.012	11th
Automated measurement that is precise	4.26	1.032	12th
Promotion of superimposition of virtual objects	4.19	1.030	13th
AR helps with data geo-location on building sites	4.16	1.135	14th

Source: Field data 2023

Table 4.4 outlines the potential advantages of using AR in construction projects and presents the average rankings of these benefits as assessed by professionals. The top benefit was identified as enhanced scheduling quality and budget management, with a mean rating of 4.52. This was followed by 3D/4D visualization and display, which received a mean score of 4.34. Improved teamwork and communication within the team ranked third, with a mean score of 4.20, while construction project safety, management efficiency, and planning came in fourth with a mean value of 4.26.

Real-time information retrieval was ranked fifth, with a mean score of 4.33, and encouraging BIM implementation was sixth, with a mean value of 4.31. Improving user experience through AR was ranked seventh, with a mean rating of 4.21, and situational awareness provided by AR was eighth, with a mean score of 4.17. Assistance in repair, rehabilitation, and maintenance was ranked ninth with a mean value of 4.28, while virtual heavy construction equipment training at a low cost was tenth, with a mean score of 4.20, albeit with a higher standard deviation.

The eleventh-ranked benefit was a reduction in labor hours, with a mean score of 4.16, and precise automated measurement was twelfth, with a mean value of 4.26. The promotion of virtual object superimposition was ranked thirteenth with a mean score of 4.19, while allowing real-time data collection was fourteenth with a mean rating of 4.16. Improving success through new business models was ranked fifteenth with a mean value of 4.27, and data geo-location on building sites was sixteenth, with a mean score of 4.12.

Discussion of findings

Augmented Reality (AR) can significantly improve the scheduling of construction projects by comparing the planned versus actual state of the structures to track progress (Behzadi, 2016). AR offers several benefits, such as allowing users to interact with both virtual and real objects, and effectively monitoring building progress by comparing the project's planned and actual conditions (Rankouhi and Waugh, 2013). A survey by Mea, Turk, and Dolenc (2015) found that AR is more effective than Gantt charts or other 3D models for construction monitoring on tablet PCs. AR enables teams to virtually explore an entire project before it's built, allowing them to verify the accuracy of its details and components. This advance insight can help avoid cost overruns and schedule delays, and also assist in identifying potential issues before they arise (Zitzman, 2019). Using AR on construction projects enhances on-site communication and collaboration. Traditionally, construction relies on 2D drawings, which are carried to the job site by the crew, often leading to significant effort to ensure the correct versions are used. AR improves this process by providing project stakeholders with up-to-date information, enabling them to make prompt decisions that help cut costs and avoid delays (Bae et al., 2013). In 2013, Park and Kim introduced the Safety Management and Visualization System (SMVS), which combined AR, Building Information Modeling (BIM), gaming technology, and position tracking. They conducted a case study, built a prototype, and assessed its effectiveness. The results demonstrated that AR technology could enhance safety awareness, improve workers' risk perception, and facilitate better real-time communication between workers and managers. Li et al. (2018) found that AR technology has been used in supervising, inspecting, and planning construction processes to more accurately and quickly identify safety issues. Given that the construction industry was responsible for 16% of all U.S. accidents in 2011 (Albert et al., 2014), it's crucial for companies to prioritize safety. Many organizations invest in safety training programs, which can benefit from incorporating AR technology.

Instead of having to search for, seek out, and map construction-related information, the AR system provides access to the necessary details right where they're needed. It achieves this by overlaying progress and planned data onto the physical environment as seen by the user (Zollmann, 2014). This capability allows project managers to swiftly make decisions on corrective actions, helping to minimize costs and delays caused by discrepancies. To address challenges with on-site information retrieval, many companies are now developing lightweight mobile devices (Behzadi, 2016). Advanced technologies like BIM and AR can enhance the visualization of defect data storage and retrieval. These tools provide significant opportunities to improve the quality of construction work. By overlaying virtual information onto real objects or images of on-site work, both workers and managers can automatically verify the outcomes of their operations (Heinzel et al., 2017).

Conclusion and recommendation

The study reveals that deploying augmented reality (AR) in construction projects offers significant benefits, including enhanced visualization, improved project management, and increased efficiency. Despite some barriers like limited internet access and technical challenges, AR's positive impact on project delivery is evident. Addressing these obstacles can help the construction industry fully leverage AR technology, leading to more efficient and effective project outcomes.

To fully leverage the benefits of augmented reality (AR) in construction projects, it is recommended that stakeholders invest in comprehensive training programs for workers and management. This training should focus on the practical use of AR tools and the interpretation of AR data to ensure that all team members can effectively utilize the technology.

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