IBIMA Publishing
Communications of the IBIMA
https://ibimapublishing.com/articles/CIBIMA/2024/821241/
Vol. 2024 (2024), Article ID 821241, 18 pages, ISSN: 1943-7765
https://doi.org/10.5171/2024.821241

Research Article

Augmented Reality Technology Framework for Engineering and Construction Projects: A Triangulation through a Qualitative Research Approach

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Received date:10 November 2023; Accepted date:22 March 2024; Published date: 13 June 2024

Academic Editor: James Braman

Abstract

Augmented Reality (AR) technology has the potential to bring about a paradigm shift in the construction and engineering industry as it unlocks untapped opportunities. Despite its potential, AR technology remains underutilised, necessitating a strategic approach to explore its full capabilities and address the challenges surrounding its integration. This preliminary study aims to develop an AR technology framework for engineering and construction projects, addressing the challenges and opportunities associated with AR technology. The objectives of this preliminary study encompass enhancing project management, facilitating workforce adaptation, fostering skills development, and promoting organisational support for AR technology. The analysis generated 14 key themes and 66 codes, culminating in an augmented framework for construction and engineering projects.

Keywords: Augmented Reality, Project Management, Framework, Thematic Analysis, Engineering, Construction

Introduction

The construction and engineering industry is experiencing a clear shift towards digital transformation, and it can be seen that AR is becoming a favourable environment for success (Chen and Xue, 2020). It is recognised that digital transformation allows precise information to be readily obtainable to managers and all stakeholders in actual time (Newman et al., 2020). The construction and engineering industry is increasingly adopting digital interfaces, which is proving to be beneficial. It is evident that AR technology is underutilised due to several factors,

Cite this Article as: Lisa SAHYOUNE, Amir Hossein GHAPANCHI, Gitesh K. RAIKUNDALIA (2024)," Augmented Reality Technology Framework for Engineering and Construction Projects: A Triangulation through a Qualitative Research Approach", Communications of the IBIMA, Vol. 2024 (2024), Article ID 821241, https://doi.org/10.5171/2024.821241

but with the right approach, it has the potential to revolutionise various industries (Abels et al., 2006; Chen and Xue, 2020; Elshafey et al., 2020; Guray and Kismet, 2022; Rohil and Ashok, 2022).

Incorporating AR technology into construction and engineering processes can have a significant positive impact by improving project management and increasing overall productivity. This cutting-edge technology offers powerful visual simulation capabilities, allowing for a more immersive experience and safer working conditions (Oke and Arowoiya, 2021). Understandably, some of the workforce may need to be more comfortable with implementing certain digital technologies, and it is essential to consider their perspective and find ways to support them in adapting to these changes (Jimeno and Puerta, 2007). AR technology proficiency needs to be improved in the practised field (Wu et al., 2019). In addition, organisations need to provide more support for technology.
This project aims to develop a framework derived from the rapid digital transformation in the construction and engineering industry, thus steering a new era where AR technology is emerging as a promising catalyst for success (Chen and Xue, 2020). The real-time availability of precise information to managers and stakeholders, facilitated by this digital transformation, signifies a positive shift towards efficiency and innovation (Newman *et al.*, 2020). With AR technology being underutilised, it is necessary to explore its full potential with a strategic approach to address its underdevelopment and underutilisation.

The main objective of this preliminary study is to develop an AR technology framework explicitly tailored for engineering and construction projects. This framework will serve as a comprehensive guideline for the industry, addressing the challenges and opportunities associated with AR integration. By doing so, the preliminary study aims to achieve the following objectives:

1. **Enhancing Project Management:** AR's visual simulation capabilities offer a more immersive experience, improving project management and overall productivity (Oke and Arowoiya, 2021). The framework will explore how AR can be integrated into project management practices for better decision-making and resource optimisation.
2. **Workforce Adaptation:** Acknowledging that the construction and engineering industry often includes workforce members who don't use immersive types of technology, the framework will incorporate strategies to ensure their comfort with digital technologies. This inclusive approach considers their perspective and supports them in adapting to these changes (Jimeno and Puerta, 2007).
3. **Skills Development:** Proficiency in AR technology within the industry is crucial. The framework will emphasise the need for AR technology proficiency and suggest ways to improve these skills in the field (Wu *et al.*, 2019).
4. **Organisational Support:** Recognising that successful integration of AR technology requires a supportive organisational culture, the framework will recommend strategies for organisations to provide necessary support for technology integration.

The significance of this research is that it can potentially revolutionise the construction and engineering industry. Therefore, developing a comprehensive AR technology framework can guide the industry towards realising the untapped potential of AR, leading to increased efficiency, safety, and innovation. This research is poised to contribute to the industry's digital transformation and journey towards a more prosperous and technologically advanced future.

The paper's structure will include a review of the background. The methodology follows this research and then explains the research framework. Finally, concluding remarks and discussions are covered.

Background

Regarding digital transformation technology, AR is a concept that has been around for quite some time. U.S. author Frank Baum introduced this concept in 1901. Baum talked about the possibility of combining real-time data with our physical environment. Later, in the 1950s, Morton L. Heilig developed Sensorama, the earliest example of AR (Sünger and Çankaya, 2019).

It wasn't until 1968 that the first AR system was used with a head-mounted display. This achievement was made by Ivan Sutherland, an electronics engineer who invented the Sword of Damocles, the first head-mounted display, while at Harvard University. This innovative device could transmit visual effects, sounds, and smells to the user (Scheffer *et al.*, 2021).

However, it took twenty-four years for Louis Rosenberg to develop the first successful fully immersive AR system for the US Air Force in 1992. This system incorporated virtual fixtures that enabled the military to remotely control machines and carry out operational tasks in the field of space (Rosenberg, 1992).

Eleven years later, the first Google glass was showcased in 2013, and, in 2016, the first Microsoft HoloLens was introduced (Scheffer *et al.*, 2021). Snapchat introduced filters in 2015, which brought AR technology to social media. In 2023, Apple introduced the Vision Pro. AR technology has advanced from AR in today's world. AR provides a 3D setting by combining natural and virtual environments in real-time (Crotty, 1998; Yusoff *et al.*, 2011). AR technology is recognised for providing virtual information instantly and enhancing human perception (Oke and Arowoiya, 2021).

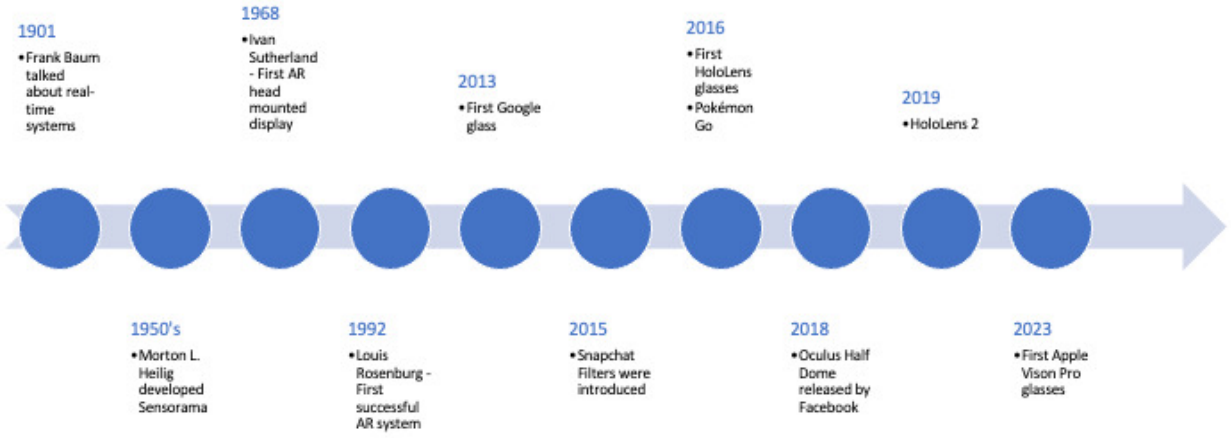

Figure 1: History of Augmented Reality Technology

Since the inception of this preliminary study, significant advancements in both software and hardware have had a profound impact on the analysis of AR. Notably, significant breakthroughs have been observed in developing head-mounted display glasses and implementing filter overlays on mobile phones and computer devices such as Snapchat and virtual online shopping.

Head-mounted display glasses have significantly improved optics, ergonomics, and form factor, resulting in visually immersive and comfortable devices. These advancements have made AR integration into various industries, such as engineering and construction, more seamless. Engineers and construction professionals can now use AR technology hands-free, enabling real-time data visualisation and interaction. This streamlines decision-making processes and enhances project efficiency (Arowoiya *et al.*, 2021).

The evolution of filter overlays on mobile phones and computer devices has been revolutionary on the software front. More sophisticated AR applications have emerged with improved algorithms and processing power, allowing for enhanced object recognition, spatial mapping, and accurate virtual object placement (Sünger and Çankaya, 2019). One of the most accessible and practical means of leveraging AR technology is through mobile phones. Mobile phones are ubiquitous, and with the increasing processing capabilities of these devices, AR experiences are becoming more realistic and immersive than ever before. Additionally, mobile phones offer portability and present an affordable, accessible, and practical approach to utilising AR technology

(Park *et al.*, 2014). With constant advancements, AR is set to become an indispensable tool that drives innovation and positive changes in the engineering and construction industries.

AR technology has evolved from VR, combining real and virtual environments in real-time 3D settings (Crotty, 1998; Yusoff *et al.*, 2011). AR technology provides real-time virtual information, enhancing human perception (Oke and Arowoiya, 2021). AR technology is currently experiencing significant growth and development, presenting impressive immersive experiences and interactions. This versatile technology has opened up many possibilities in various fields, such as design prototyping, spatial planning, and virtual training. In particular, the construction industry has significantly benefitted from AR technology, as it has been extensively employed for virtual training and spatial planning (Arowoiya *et al.*, 2021).

The ability of AR technology to provide a virtual environment for construction workers to visualise and plan projects has significantly improved the efficiency of construction projects while reducing errors. AR technology has also enabled designers to create more realistic and accurate prototypes, providing a more comprehensive representation of their work (Firmanda *et al.*, 2022). Mobile apps now use AR to match virtual content with physical displays, creating an immersive user experience. This technology has enabled businesses to engage customers innovatively, leading to increased satisfaction and growth (Firmanda *et al.*, 2022).

Managing construction and engineering projects is a multifaceted process that requires careful consideration of various factors. In contemporary times, this process entails making informed decisions based on a wealth of information (Chen and Xue, 2020). However, despite the availability of information, a significant disconnect between the physical environment and virtual information has become an intrinsic part of managerial problems for construction projects (Chen *et al.*, 2015). This disconnection poses a challenge to ensuring that projects are completed within the stipulated time and budget. Consequently, construction managers must find ways to bridge this gap and ensure they can always access accurate and up-to-date information. This will enable them to make informed decisions that will facilitate the successful completion of construction projects (Chen *et al.*, 2015).

Methodology

The preliminary study aims to identify a framework for project management with the use of AR technology; the findings are derived from thematic analysis with data collected through questionnaires and interviews. Over twenty pages of questionnaire data were collected, and responses from five participants through interviews, comprising of two software developers and three project managers in the engineering and construction industries. The participants are coded as per Table 1.

Table 1: Participant Data Collection – Expert

Expert	Code	Inclusion Criteria	Data Collection
Participant 1 - Project manager	P1	Analysis method	Interview
Participant 2 - Project manager	P2	Analysis method	Interview
Participant 3 - Project manager	P3	Analysis method	Interview
Participant 4 - Software developer	P4	Analysis method	Interview
Participant 5 - Software developer	P5	Analysis method	Interview

The findings are organised into several key themes: communication, resource management, perceived usefulness, education and training, project management, technology attributes, technology user interface, quality, software management, processes and procedures, positive

outcomes, emerging technology, and leadership management. The findings are based on the thematic analysis approach, which involves a systematic and iterative data analysis process. Thematic analysis is chosen for this project's appropriate research method for several reasons. First, thematic analysis is well-suited for this preliminary study as it allows the conceptual framework to emerge organically from the data collected. Rather than starting with preconceived theories, this inductive approach ensures that the research findings are developed in a holistic approach and identifies themes when the data are analysed (Levers, 2013). By identifying the themes when analysing the data, we can gain a deeper and more comprehensive understanding of the AR framework in engineering and construction projects.

Second, the Covid-19 pandemic has necessitated the use of digital interfaces for data collection. Thematic analysis can easily adapt to online data collection, which is preferred by participants. This adaptability ensures the research can proceed smoothly and efficiently, even during challenging circumstances.

Moreover, previous literature has identified a gap in qualitative research related to the use of AR technology in engineering and construction projects (Crossan and Apaydin, 2010; Taylor, 2010; Eggers and Kaplan, 2013; Halaweh, 2013; Carter and Salimath, 2019). Although some studies have explored factors influencing this technology, a comprehensive AR framework has yet to be established. Thematic analysis enables a comprehensive examination of data to identify underlying themes and factors influencing technology acceptance in a specific context (Braun and Clarke, 2008).

Additionally, the objective is to understand the framework for AR in engineering and construction projects. Thematic analysis allows for a flexible approach to exploring participants' experiences, providing valuable insights into their perceptions, attitudes, and behaviours towards AR technology. This approach is particularly valuable when seeking to develop a nuanced understanding of a complex and multifaceted phenomenon like AR technology acceptance.

Furthermore, to ensure a robust and comprehensive analysis, the scope of the research has been expanded from solely focusing on engineering projects to include engineering and construction projects. Additionally, data have been collected from individuals in various leading roles beyond project managers. The thematic analysis allows us to embrace this diversity of perspectives, which enriches the research findings and contributes to a more holistic understanding of the AR framework for these types of projects. Figure 2 details the thematic analysis approach.

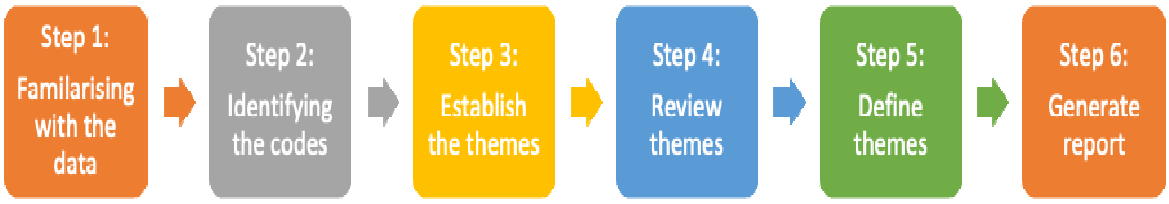

Figure 2: Thematic Analysis Process

Therefore, thematic analysis is justified as the chosen research method for this preliminary study due to its nature, adaptability to digital data collection, ability to address existing gaps in qualitative research, and capacity to comprehensively explore AR technology's AR framework. This approach ensures a rigorous and insightful exploration of the AR framework of AR technology in engineering and construction projects.

Thematic Analysis

The data collected in this preliminary study were analysed using thematic analysis, a common approach for qualitative data (Braun and Clarke, 2008). As a result of this approach, the theory is developed directly from the data, and the essential skills for qualitative data analysis are developed. Furthermore, this approach can be adapted to a diverse range of knowledge systems, including epistemologies and research questions (Braun and Clarke, 2008). Thematic analysis is a highly flexible and iterative process that doesn't necessarily follow a linear data collection, analysis, and results approach. The various stages of thematic analysis are often interrelated and occur simultaneously, enabling a more thorough and intricate comprehension of the information (Creswell, 2007). The steps involved in thematic analysis are as follows.

Step 1 -Familiarising the Data

The qualitative data obtained came from a questionnaire and interviews. Qualtrics software was used to set up the questionnaire, and this platform allows the ethical and volunteering forms to be signed and documented. Interviews were conducted over Teams and Zoom. The raw data were analysed through NVivo. However, qualitative data can come in many forms, including focus groups, observations, texts, manuals, illustrations, photos, and public sources (Creswell, 2007). To ensure that the data are properly understood, it is essential to review them and become familiar with their contents once they have been collected (Braun and Clarke, 2008). Repeatedly reading the data is necessary to identify any meanings or patterns, ensuring familiarity with the information (Braun and Clarke, 2008).

Step 2 – Identifying the Codes

Once we are familiarised with the data, identifying codes takes place. This requires repetition in analysing the data. The coding of the data outlines essential areas of the data and attaches descriptions to this. Each item is systematically given full attention to achieve the desired outcome (Braun and Clarke, 2008). The phenomenon at hand is a manifestation of a systematic process (Creswell, 2007). In this instance, NVivo was used to aid in the coding process. NVivo simplifies efficient documentation of text sources and input into code, as outlined in Table 2.

Table 2: Code Description

Code	Code Description
C1	Written Communication
C2	Economics
C3	User Friendly / Easy to Use
C4	Training with Software
C5	Time Management
C6	Augmented Graphics
C7	Multiple Users
C8	Technology Accuracy
C9	Software Maintenance
C10	Software Integration
C11	Regulation
C12	Productivity
C13	New Technology - Exposure
C14	Expertise of Manager

C15	Visual Communication
C16	Marketing
C17	User Acceptance
C18	Learning with Software
C19	Scope Management
C20	Computer Simulation
C21	Interaction with AR
C22	Reliability with Software
C23	Software Equipment
C24	Software Capabilities
C25	Procedures for Project Management
C26	Efficiency
C27	Augmented Technology
C28	Decision Making
C29	Verbal Communication
C30	Scope Creep
C31	Proven usefulness
C32	Human Factors
C33	Quality Management
C34	Digitalisation
C35	Technology Interface
C36	Prevalence of Software
C37	Software Availability
C38	Collaboration of Software
C39	Legacy Systems
C40	Return on Investment (ROI)
C41	3D Virtual Environment
C42	Reviewing Project and Plan
C43	Technology Feedback
C44	Project Integration
C45	Positive Impact
C46	Health and Safety
C47	Risk Management
C48	Design Aspect
C49	Real-Time in Augmented Reality
C50	Longevity of Technology

C51	Data Privacy
C52	Prototyping
C53	Documentation Management
C54	Virtual Asset
C55	Costly due to newness
C56	Experience
C57	Stakeholder Communication
C58	Potential Strategy
C59	Training Delivery
C60	Stakeholder Management
C61	Visual Display
C62	Accuracy of Software
C63	Process for Project Management
C64	Project Delivery
C65	Organisational Skills
C66	Performance of Technology

Step 3 – Establish the Themes

Once familiar with the collected data and coded, the data can be itemised in themes. This process requires the sorting of codes, and to successfully sort the codes, it is imperative to extract them efficiently into common themes (Braun and Clarke, 2008). By bringing in various texts that may appear insignificant on their own, a common theme can be identified once they are grouped, thus capturing the phenomenon (Creswell, 2007). As shown in Table 3, 14 themes have been identified.

Table 3: Themes

Theme	Theme Description
T1	Communication
T2	Resource management
T3	Perceived usefulness
T4	Education and training
T5	Project management
T6	Technology attributes
T7	Technology user interface
T8	Quality
T9	Software management
T10	Software application

T11	Processes and procedures
T12	Positive outcomes
T13	Emerging technology
T14	Leadership management

Step 4 – Reviewing Themes

The themes are reviewed once the data have been analysed to ensure accurate theme identification. Thus, to ensure that the themes accurately reflect the data, it is essential to refine and validate them in a way that conveys their meaningfulness (Braun and Clarke, 2008). In addition, it may be apparent that some of the themes are inaccurate and do not support the data obtained (Braun and Clarke, 2008). Table 4 identifies the themes that were developed.

Step 5 – Define Themes

To effectively convey the meaning of the data, it is imperative that the names given to the themes are closely aligned with the categorisation of the codes. The definitions of each theme should be clear, concise, and easy to understand, leaving no room for ambiguity. By doing so, it will be easier to identify the focus of the data and produce a comprehensive report that accurately reflects the findings (Braun and Clarke, 2008). The themes defined by the codes are reflected in Table 4.

Table 4: Themes Defined by the Codes

Communication	**Written Communication**	**Visual Communication**	**Verbal Communication**	**Technology Feedback**	**Stakeholder Communication**	
Resource management	Economics	Marketing	Scope Creep	Project Integration	Potential Strategy	
Perceived usefulness	User Friendly / Easy to Use	User Acceptance	Proven usefulness	Positive Impact		
Education and training	Training with Software	Learning with Software	Human Factors	Health and Safety	Training Delivery	
Project management	Time Management	Scope Management	Quality Management	Risk Management	Stakeholder Management	
Technology attributes	Augmented Graphics	Computer Simulation	Digitalisation	Design Aspect	Visual Display	
Technology user interface	Multiple Users	Interaction with AR	Technology Interface	Real-Time in Augmented Reality		
Quality	Technology Accuracy	Reliability with Software	Prevalence of Software	Longevity of Technology	Accuracy of Software	Performance of Technology
Software management	Software Maintenance	Software Equipment	Software Availability	Data Privacy		
Software application	Software Integration	Software Capabilities	Collaboration of Software	Prototyping		
Processes and procedures	Regulation	Procedures for Project Management	Legacy Systems	Documentation Management	Process for Project Management	
Positive outcomes	Productivity	Efficiency	Return on Investment (ROI)	Virtual Asset	Project Delivery	
Emerging technology	New Technology Exposure	Augmented Technology	3D Virtual Environment	Costly due to newness		
Leadership management	Expertise of Manager	Decision Making	Reviewing Project and Plan	Experience	Organisational Skills	

Step 6 – Generate Report

The final step of thematic analysis can begin after the codes have been established and themes have been successfully identified. This involves conducting a definitive data analysis and creating a concise and relevant report based on the findings. It is crucial that the report accurately reflects the data and is easy to understand (Braun and Clarke, 2008). From the findings obtained, it can be seen that there are a total of 14 themes and 66 codes. These data generated an augmented framework for construction and engineering projects.

Results – Technology Framework

The technology framework comprised of three main groups is visually detailed in Figure 3. The framework mainly concentrates on the technology requirements, as highlighted in the green area, which is essential for identifying the key attributes of AR technology. Moreover, the framework assesses how well this technology interacts with users and how it adapts and evolves. This guarantees that the technology is suitable and efficient for the intended objective. The technology requirements flow into the management input, which is comprised of two areas. The first area includes resource management, software management, leadership management, and project management. The second area includes communication, processes, procedures, and training requirements. Quality, perceived usefulness, and positive outcomes are the factors that are identified when processing the input from management. This then flows through a positive output and has a flow-on effect on the technology requirements and management inputs.

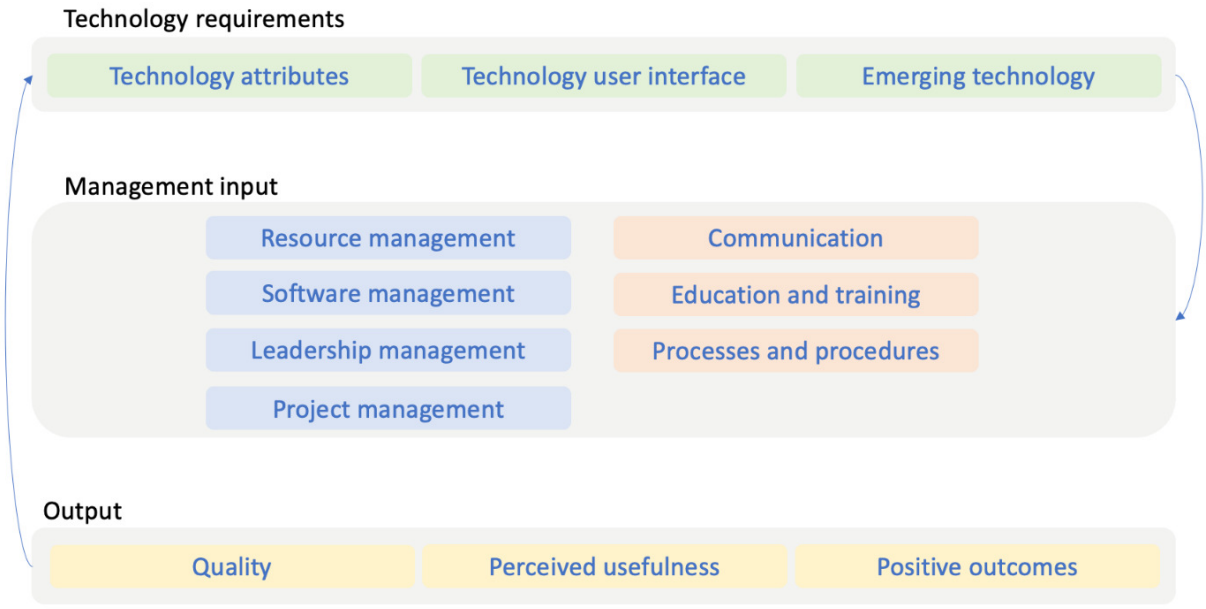

Figure 3: Augmented Reality Technology Framework

Technology Requirements

The successful implementation of AR technology is dependent on several key factors, including technology attributes, technology user interface, and emerging technologies. Technology attributes refer to the technology's specific characteristics, including graphics, digitalisation, and visual display. The technology user interface encompasses how users interact with the

technology, including multiple users, technology interface and real-time aspects. Finally, emerging technologies are those that are currently in development or have recently come to market and have the potential to significantly impact the technology landscape. These three components are grouped together as they are all fundamental aspects of technology and form the framework's first group, represented in green in Figure 4.

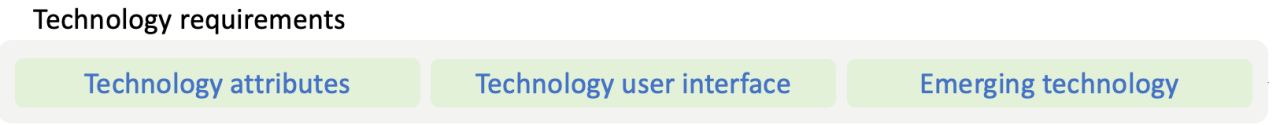

Figure 4: Technology Requirements

Technology Attributes

The findings related to the AR technology framework revealed the importance of various AR technological features and capabilities in influencing AR technology and acceptance—real-time features in AR, such as real-time data visualisation and feedback, enhanced user experience and decision-making, augmented graphics, computer simulation, and digitalisation were identified as valuable tools for enhancing design aspects and project visualisation. The analysis of the data shed light on the technological attributes that were considered essential and their impact on AR technology framework and utilisation in the construction and engineering field. Participant 1 stated, "Rather than being an entirely virtual space, you can actually see through it into the real world and project images onto surfaces or whatever you choose it to be a combination of reality and virtual".

Technology User Interface

Technology's user interface emerged as a critical aspect of the AR technology framework in construction and engineering. Collaboration capabilities, such as the ability for multiple users to interact and work together, were highly valued. Interaction with technology, including ease of navigation, intuitive controls, and interactive features, influenced user satisfaction and engagement. The technology interface should be

user-friendly, ensuring users can easily understand and operate AR technology. The data analysis provided insights into the user interface requirements and considerations for AR technology integration in the construction and engineering field. Participant 1 stated, "Historically, we'd use it to simulate a production environment in an area that is just a big open space. So, part of the complications behind doing that is obviously you need somebody that can translate a model in some 3D modelling system into a space, and that's a pretty specific skill set to be able to have".

Emerging Technology

Emerging technologies with AR technology and 3D virtual environments were identified as input to the AR technology framework. Exposure to new technologies created opportunities for innovation and improved project outcomes. The data analysis revealed insights about the perceptions, challenges, and implications of emerging technologies in the engineering and construction industries. Participant 3 clarified, "It's just not really set up to be configured at the moment for, I guess, use on a larger scale. It's kind of used as a novelty at the moment. But I guess that's where all things start. Right. That's part of the acceptance. People are familiar with it. They've seen it before, but just not used to writing necessarily in a business sense".

Manager Inputs – Management

The effective management of this framework necessitates the integration of various inputs, including resource management, software management, leadership management and project management. Resource management entails economics, marketing, and scope creep. Software management encompasses the maintenance and

optimisation of software systems to ensure their smooth functioning. Equipment availability ensures that necessary tools and equipment are accessible and functional, facilitating the smooth running of operations. Leadership involves guiding and motivating team members towards achieving organisational goals and is a critical input in the management process. By effectively integrating these inputs, organisations in the engineering and construction industry can effectively achieve their objectives and enhance their overall performance. In Figure 5, these inputs are represented with blue filled rectangles.

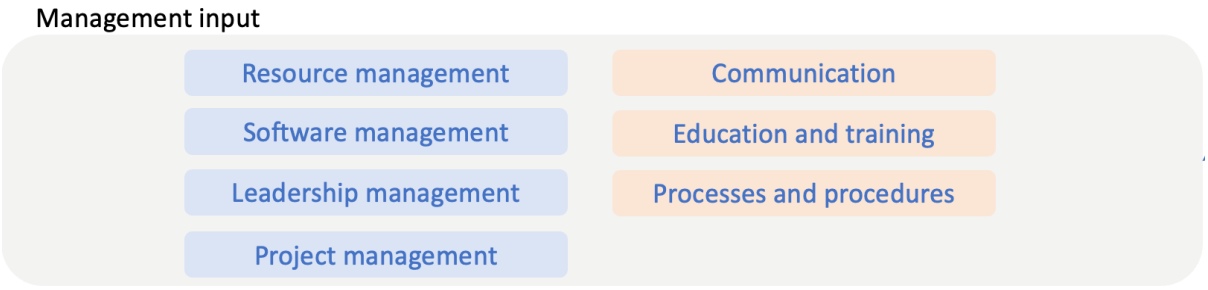

Figure 5: Management Inputs

Resource Management

The findings related to resource management highlighted the importance of effectively managing resources for a successful AR technology framework for construction and engineering projects. The visual display in AR, such as dashboards and visualisations, facilitated resource monitoring and decision-making. Data privacy emerged as a significant concern, with participants emphasising the need for robust security measures to protect sensitive information. Potential strategies for resource management included efficient allocation, tracking, and utilisation of resources to optimise project performance. Economics and marketing considerations were also influential factors in resource management decisions. The data analysis provided insights into the resource management practices and challenges faced by professionals in the engineering and construction industries. As outlined by Participant 1, "If you have the resources to do it, and the equivalent obviously, it is something that doesn't require any kind of specialised knowledge to be able to be an end user. So, if it's something simple that's able to be done, and you've got the people that can do it, there are no real restrictions".

Software Management

The findings related to the AR technology framework revealed software management plays a critical role in the construction and engineering fields. Effective software maintenance, including updates and bug fixes, ensured the software remained functional and up to date. Software integration involves integrating different software applications and systems seamlessly to enhance productivity and efficiency in AR. The availability of software and its capabilities influenced AR technology integration. The data analysis provided insights into the software management practices and challenges faced by professionals in the engineering and construction industries. Participant 2 indicated, "To evaluate the success and performance of AR products that I have used, I would say I'm satisfied; however, I would like to see more improvements towards the tools with more functions and capture real-time information. Capturing real-time information would be a game changer for companies".

Leadership Management

Leadership management input is crucial for the AR technology framework. Managers' expertise in understanding and evaluating AR technology solutions influenced decision-making and implementation processes. Effective decision-making involved considering the potential scope

creep and ensuring that projects remained within defined boundaries. The data analysis provided insights into the leadership management practices and challenges faced in the context of AR technology in the construction and engineering field. Participant 1 declared, "My experiences currently restrict the use of this technology due to its lack of simple integration into business systems and support from others. I believe the technology is capable, but everyone in the managerial food chain must also support that."

Project Management

Project management was identified as an input for the AR technology framework in the construction and engineering field. Effective time management, including tracking and managing project timelines, was crucial for successful project execution. Stakeholder communication was vital in ensuring that project goals and objectives were effectively communicated and understood. Project scope management involves defining and controlling the scope of a project to avoid any deviation from the project plan that could lead to budget overruns and delays. Quality management focused on ensuring that project deliverables met specified standards and requirements. Documentation management involves organising and maintaining project documentation for easy access and reference. Cost management focused on controlling project costs and ensuring the project remained within budget.

The data analysis provided insights into the challenges and best practices related to project management in the context of the AR technology framework in the construction and engineering field. Participant 2 details, "Without fully understanding the technology, an outline of what our problem is and what we want to enable, and relying on a turn-key solution from that company is going to meet our needs. Being able to work with them to build that solution is going to help us better understand the capabilities of the technology and how to use it in other ways to get the best out of it".

Manager Inputs – Techniques

Communication is a crucial aspect of management, which can be achieved through various means such as written, visual, and verbal communication. Education and training are also important, especially when learning how to use software. Additionally, processes and procedures, including regulations, project management, legacy systems, and document management, all fall under the umbrella of manager inputs and techniques. The rectangles with orange fill pink represent these areas in Figure 6.

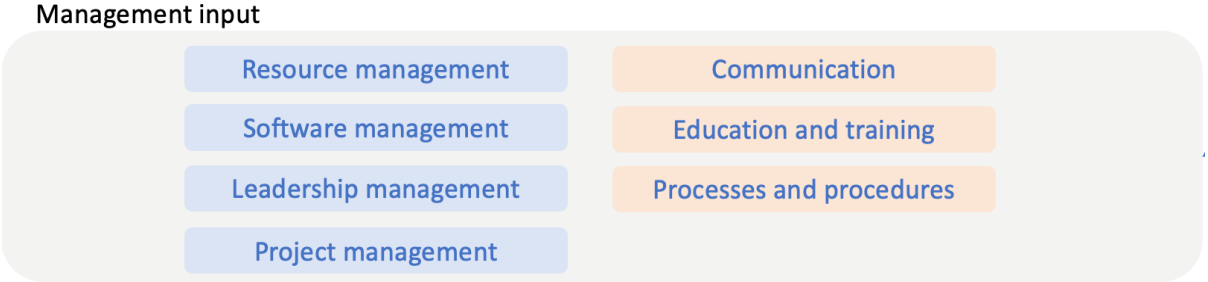

Figure 6: Management Inputs - Techniques

Communication

The findings related to the AR technology framework revealed the input of communication. Effective communication was essential for successful technology integration and implementation. The participants emphasised the importance of written, verbal, and visual communication in conveying information, instructions, and ideas. Written communication, such as emails, reports, and documentation, facilitated the sharing of detailed and structured information, and visual communication, including diagrams, charts, and presentations, enhanced understanding and engagement. Verbal communication, through meetings, discussions, and presentations, allowed for real-time

interaction and clarification. Technology feedback, such as user feedback and suggestions, played a vital role in improving communication processes and identifying areas for improvement. The data analysis provided insights into the various communication strategies and tools employed by the participants in the engineering and construction industries. Participant 1 detailed, "We'll I think that the drive for people to use the technology, it drives it comes from a need, right? So, usually, that need is a communication tool. So it needs to be a scenario where you're trying to show somebody what something could look like or invest in the identification of conveyancing, say you're doing maintenance on an aircraft or something in your had a setup is familiar with inside the landing gear AR could point a maintenance person to a particular line to say that's what you need to do, and bring up information that shows what they need to do step by step".

Education and Training

The findings related to the AR technology framework revealed education and training in AR software encompass a multi-faceted approach that integrates technological innovation, human factors, safety, and efficient delivery methods to prepare individuals for the ever-evolving landscape of AR. Education and training in software for AR technology are essential to utilise this developing technology fully. AR software provides an immersive learning experience that engages individuals and enhances skills and knowledge. Additionally, it caters to various learning preferences and provides an interactive educational platform. Human factors play a significant role in AR training, as the technology involves and applies the major IT area of Human-Computer Interaction. Understanding how users perceive and interact with AR interfaces is essential to designing effective training programs.

Additionally, health and safety considerations are paramount, especially in industrial and educational settings, where the implementation of AR can cause dizziness for a small minority. Ensuring AR training complies with safety standards and ergonomic best practices is essential. Lastly, the delivery of AR training, whether in-person or through remote e-learning platforms, is critical in making education accessible to a broader audience. Participant 4 summarises, "The problem is, if you don't have enough education to make sure you're configuring it, right, you could be blamed for technology, when it's constraints is driven by something else".

Processes and Procedures

The findings related to the AR technology framework revealed processes and procedures are essential. Regulation and compliance requirements guided the implementation of AR technology and ensured adherence to industry standards. Prototyping allowed for the testing and validation of AR technology solutions before full-scale implementation. Procedures for project management provided a structured framework for project planning, execution, and control. Legacy systems are old and redundant processes and procedures are removed or modified from the current systems to ensure efficiency. These were identified as challenges in the AR integration process, as change can cause confusion and issues in the system when new. The data analysis shed light on the processes and procedures that facilitated AR technology integration in the construction and engineering field. Participant 5 outlined, "The ability to ensure that people are doing the right thing from a process perspective, and also the ability to communicate to people as things are not there yet. I think they are the real interest that will drive user acceptance and adopt, get involved with the actual technology".

Outputs

The final component of the framework is dedicated to the outputs, which encompass three key areas: quality, perceived usefulness, and positive outcomes. Quality refers to the degree of accuracy and reliability of the technology and its prevalence and longevity. Perceived usefulness, conversely, pertains to the ease of use and practicality of the software. Finally, positive outcomes include productivity, efficiency, and the return on investment. These three aspects are shown in Figure 7, providing a clear visual representation of the framework's outputs.

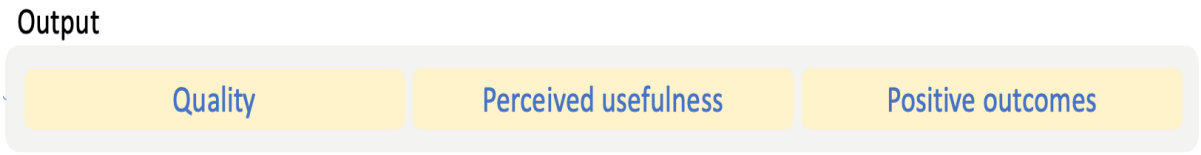

Figure 7: Outputs

Quality

Quality emerged as a significant input in the AR technology framework in the construction and engineering fields. Technology accuracy, reliability, and prevalence were essential factors influencing user confidence and trust. The longevity of technology, in terms of its durability and compatibility with future upgrades, was also a consideration. The accuracy of AR software and its ability to deliver reliable results were crucial for decision-making and project outcomes. The data analysis highlighted the importance of quality assurance and testing in AR technology integration and the implications for user satisfaction and project success. Participant 1 stated, "Being able to see how an asset operates from my desk without travelling to another country would be a major factor. It would be more cost-effective to have a virtual asset and analyse the costs associated with the capability (reliability, availability, maintainability) in using it over a long period instead of delivering it and having a reactive approach to it operating in real-time".

Perceived Usefulness

Perceived usefulness emerged as an input influencing the AR technology framework. Participants' perceptions of how technology solutions could benefit their work processes and tasks influenced their willingness to adopt and use the technology. User-friendly technology that was easy to use and navigate was more likely to be perceived as valuable. Positive impacts, such as increased efficiency, productivity, and convenience, were associated with perceived usefulness. The data analysis revealed the factors influencing participants' perceptions of AR technology usefulness and the implications for AR technology integration. Participant 1 articulated, "It's also an additional unknown from a time perspective as well. If you're going into a project going, hey, we can be innovative and use this new technology and get involved in that perspective. The person backing that needs to be willing to say, oh, yeah, I see that it costs a little bit more and might take a little longer. But the advantages are huge. Not many project sponsors are in that mindset. They're in the mindset of I want to get it done. Now, and as quickly as possible, yesterday".

Positive Outcomes

Positive outcomes, such as increased productivity, efficiency, and return on investment (ROI), were identified as key inputs for the AR technology framework. The data analysis revealed that the AR technology framework positively impacted project outcomes, improving project performance, and reducing costs. Virtual assets, such as digital models and simulations, provided enhanced decision-making and collaboration opportunities. The data analysis delivered insights into the positive outcomes associated with AR technology and the implications for project success in the construction and engineering field. Participant 1 enunciated that "General understanding of its capabilities and functions to be able to translate into a business' specific needs is going to be the big factor is its future use. Once expert understanding is achieved, you can then establish best-practice protocols or processes internally in a business. And if you have a simple but robust process, the general business population will see the positive impact that this technology can achieve, as most people don't look outside their own bubble".

Conclusion and Discussion

Based on the thematic analysis, this preliminary study provides a thorough comprehension of the AR framework developed for engineering and construction projects. The data collected from questionnaires and interviews were analysed meticulously to identify key themes and insights. The findings are organised into several key

themes: communication, resource management, perceived usefulness, education and training, project management, technology attributes, technology user interface, quality, software management, processes and procedures, positive outcomes, emerging technology, and leadership management. The findings are based on the thematic analysis approach, which involves a systematic and iterative data analysis process.

Effective communication emerged as a crucial factor in the AR technology framework. The participants emphasised the importance of written, verbal, and visual communication in conveying information, instructions, and ideas. Precise and efficient communication channels were vital for ensuring AR technology's effective implementation and utilisation in construction and engineering projects.

Resource management was identified as another critical aspect of the AR technology framework. The visual display of data through AR dashboards and visualisations facilitated resource monitoring and decision-making. Data privacy and security were highlighted as significant concerns, emphasising the need for robust measures to protect sensitive information. Proper allocation, tracking, and utilisation of resources were essential for optimising project performance.

Perceived usefulness played a central role in the AR technology framework. Participants' perceptions of how the technology could benefit their work processes and tasks influenced their willingness to adopt and use AR technology. User-friendly technology that was easy to use and navigate was more likely to be perceived as valuable. Positive impacts, such as increased efficiency, productivity, and convenience, were associated with perceived usefulness.

Project management was identified as an input in the AR technology framework for engineering and construction projects. Effective time management, stakeholder communication, scope management, quality management, and cost management were key considerations. Proper documentation management and adherence to processes and procedures were necessary for successful project execution. The AR technology framework can potentially enhance project outcomes and positively impact productivity and efficiency.

The technological attributes of AR technology were found as an input in the framework. Real-time features, augmented graphics, computer simulation, and digitalisation were identified as valuable tools for enhancing design aspects and project visualisation. The user interface of AR technology also played a crucial role. Collaboration capabilities, ease of navigation, and intuitive controls influenced user satisfaction and engagement.

Quality assurance and reliability were identified as inputs in the AR technology framework for engineering and construction projects. The technology's accuracy, reliability, and prevalence were key factors influencing user confidence and trust. The longevity of the technology and its compatibility with future upgrades were also considerations.

Software management practices input is identified as a factor in the AR technology framework for engineering and construction projects. Effective software maintenance, integration, and availability were critical factors for successful implementation. Proper software management ensured that the technology remained functional, up-to-date, and capable of meeting project requirements.

The engineering and construction industries can benefit from understanding the framework for AR technology in projects, enabling informed decisions and strategies. Improved communication strategies, resource management practices, and project management approaches can improve project outcomes and productivity. The research findings additionally emphasise the crucial role of user-friendly technology and quality assurance in promoting user acceptance and satisfaction.

In conclusion, the research findings of this preliminary study offer valuable insights into the framework of AR technology in the engineering and construction industries. The significance of effective communication, resource management, perceived usefulness, project management, technology attributes, technology user interface, quality, software management, software applications, processes and procedures, positive outcomes, emerging technology, and leadership management was highlighted. Practitioners who

intend to incorporate and use AR technology can benefit from these findings as they provide practical implications. Through this research, we have made significant theoretical contributions to this preliminary study of AR technology framework in construction and engineering projects. Our framework provides an in-depth exploration of the various factors influencing AR technology in these fields. By considering these factors, future studies can better understand the challenges and opportunities associated with AR technology in construction and engineering projects. Therefore, this research can be a valuable resource for researchers and practitioners looking to implement AR technology in these fields.

Acknowledgment

I want to express my sincere gratitude to my supervisors, Dr Amir Ghapanchi and Dr Gitesh Raikundalia, for their unwavering support and guidance throughout the years during my PhD. Thank you all for your kindness and generosity.

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