

Investigating the Dynamics of User Adoption of the Augmented Reality Technology in Engineering and Construction Projects

Lisa Sahyouné

MProMgt, BBldg

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I Abstract

With the advancement of digital technology, augmented reality (AR) technology can play a substantial part in project development and sustainable growth in engineering and construction projects. Utilising AR technology with digital overlays offers a three-dimensional (3D) setting that combines real and virtual environments in real time. This immersive capability enables an improved spatial understanding and real-time data benefits for construction and engineering projects. Additionally, AR technology can lead to constructive outcomes, such as positive performance, accurate defect detection and data synchronisation. Using the DeLone-McLean theory of information systems success suggests that technology use and satisfaction can impact net benefits. As a result of this, and taking into account the context of this research, the user acceptance of AR technology can positively influence success in engineering and construction projects. Therefore, this project aims to explore the factors that impact technology acceptance.

The benefits of using AR technology in construction and engineering projects include improved communication with real-time data and enhanced stakeholder engagement. Additionally, AR technology provides better decision-making, as it enables complex information to be more accessible through visualisation and facilitates a better understanding for non-technical users. However, AR technology is not being utilised enough in the construction and engineering sectors; it is highlighted that there is a lack of knowledge and validation obtained from real-world environments. It is also evident that AR technology remains immature, with no complete system or framework being developed. There are also minimal studies that clearly outline the benefits and limitations of AR in the construction and engineering sectors.

Researchers have carried out extensive research on the user acceptance of technology. There is, however, a lack of qualitative research that presents a more comprehensive view of the factors that drive the user acceptance of AR technology in engineering and construction projects. This research provides insight into the dynamics of user acceptance in engineering and construction projects through grounded theory in a real-world context. In addition, it identifies factors that influence the outcome of construction and engineering projects related to user acceptance.

This research collected data through open-ended survey questionnaires and interviews. The data obtained were analysed using an iterative approach based on grounded theory principles in this study. A total of 248 open codes, 49 axial codes and 18 selective codes

were generated. This process provided a taxonomy, a comprehensive framework and a causal loop diagram identifying the relationships of the user acceptance of AR technology adoption in engineering and construction.

The theoretical integration of the findings has emerged from both data analysis and the current literature reviewed during this research, identifying various relationships that impact AR technology and providing sector-specific insights into the successful use of AR technology. This research provides structured models that bring together real-world scenarios and highlight the groundwork of the user acceptance of digital technology adoption.

This research contributes to both academia and practitioners by clarifying the benefits and limitations of AR technology acceptance in the construction and engineering sectors in real-world environments, effectively bridging the gap between practical implementation and understanding new technology. This insight enables organisations to effectively implement new technology by providing a governing framework and a causal loop diagram that connects key relationships that influence user acceptance, thereby creating an immersive and innovative digital environment that benefits organisational performance and stakeholders.

II Doctor of Philosophy Declaration

I, Lisa Sahyoun, declare that the PhD thesis entitled Investigating the Dynamics of User Adoption of the Augmented Reality Technology in Engineering and Construction Projects is no more than 100,000 words in length, including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

I have conducted my research in alignment with the Australian Code for the Responsible Conduct of Research and Victoria University's Higher Degree by Research Policy and Procedures.

Signature: 

Date: August 2025

Ethics Declaration

All research procedures reported in the thesis were approved by the Victorian University Ethics Committee [Application ID: HRE20-123].

Signature: 

Date: August 2025

Generative Artificial Intelligence (AI) Declaration

This thesis has been edited for clarity of expression, punctuation and grammar using Grammarly tool. This use complies with VU guidelines on use of editors in HDR theses and overall VU policy on use of AI in research.

Signature: 

Date: August 2025

III Dedication

For my children, Rafael and Romeo Vracknos.

"The dedicated life is the life worth living" Annie Dillard

IV Acknowledgments

I would like to thank and acknowledge everyone who has supported me on this journey. This experience has allowed me to meet some extraordinary individuals who have contributed to or encouraged this research. Without all these individuals, this achievement would not be possible.

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V Publications and Presentations

Sahyouné, L., & Ghapanchi, A. H. (2020). *Exploring Factors Impacting User Adoption of Virtual Reality in Projects: A Literature Survey*. Presented at the 2020 24th International Conference Information Visualisation (IV)

Sahyouné, L., Ghapanchi, A. H., & Raikundalia, G. K. (2022). *Consequences of User Adoption of Augmented Reality in Construction Projects: A Survey of the State-of-the-Art**. Presented at the IBIMA 2022 - 40th IBIMA Conference

Sahyouné, L., Ghapanchi, A., & Raikundalia, G. K. (2024). *Augmented Reality Technology Framework for Engineering and Construction Projects: A Triangulation through a Qualitative Research Approach*. Presented at the IBIMA 2023 - 42nd IBIMA Conference

VI Abbreviations

Abbreviation	Definition
2D	Two-Dimensional
3D	Three-Dimensional
Ad-hoc	For this
AEC	Architectural, Engineering and Construction
AECO	Architectural, Engineering, Construction and Operations
AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
BAU	Business and Usual
BIM	Building Information Modelling
CAD	Computer Aided Design
Covid-19	Coronavirus disease of 2019
DT	Digital Twin
GPT	Generative Pre-trained Transformer
HCI	Human Computer Integrations
HMD	Head Mounted Displays / Helmet Mounted Displays
HUD	Head up Display
ICT	Information Communication Technology
IDT	Innovation Diffusion Theory
IDT	Intelligent Digital Twin
IoT	Internet of Things
IS	Information System
KPI's	Key Performance Indicators
LOD	Level of Development
MR	Mixed Reality
NPI	New Product Information
OHS	Occupational Health and Safety
Q&A or QA	Questions and Answers
QAQC	Quality Assurance and Quality Control
QR	Quick Response
RFP	Request for Proposal
ROI	Return on Investment
RQ	Research Question
SaaS	Software as a Service

SLAM	Simulation, Localisation and Mapping Technique
SME	Subject Matter Expert
STEM	Science, Technology, Engineering and Mathematics
SWMS	Safe Work Method Statement
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour
TRA	Theory of Reason Action
US	United States
UTAUT	Unified Theory of Acceptance and Use of Technology
VR	Virtual Reality
XR	Extended Reality

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Chapter 1: Introduction

This introduction chapter provides an overview of the research on augmented reality (AR) technology adoption in the engineering and construction sectors, including the background of AR technology and its applications in these fields. This chapter focuses on the aims of the project, the statement of significance and importance of the study, and its contribution to research and the literature. It also provides a brief overview of the literature review, a summary of the methodology, the research constraints, and an overview of the thesis.

1.1 Overview

The engineering and construction industry is experiencing a clear shift towards digital transformation, and it can be seen that augmented reality (AR) is becoming a favourable technology for success (Chen & Xue, 2020). It is recognised that digital transformation allows precise information to be readily obtainable by managers and all stakeholders in real time (Newman et al., 2020). The engineering and construction industry is increasingly adopting digital interfaces, which is proving to be beneficial. It is evident that AR technology is underutilised due to several factors, but with the right approach, it has the potential to revolutionise various industries (Abels et al., 2006; Chen & Xue, 2020; Elshafey et al., 2020; Guray & Kismet, 2022; Rohil & Ashok, 2022).

Incorporating AR technology into engineering and construction 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 a more immersive experience and safer working conditions (Oke & Arowoiya, 2021). Understandably, some of the workforce may need to become 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 & Puerta, 2007). AR technology proficiency needs to be improved in the considered field (Wu et al., 2019). In addition, organisations need to provide more support for technology.

This project aims to explore factors of the user acceptance of AR technology in engineering and construction projects, derived from grounded theory, and the rapid digital transformation in the industry, thereby guiding a new era in which AR technology is emerging as a promising catalyst for success (Chen & Xue, 2020). The real-time availability of precise information for 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 significance of this research is that it can potentially revolutionise the engineering and construction industry. Therefore, developing a comprehensive AR technology theory 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 move towards a more prosperous and technologically advanced future.

1.2 Background

The concept of AR technology can be dated back to 1901; this concept was first made physical in the 1950s (Sünger & Çankaya, 2019) and fully immersive in 1992 (Rosenberg, 1992). AR technology has evolved from virtual reality (VR), combining real and virtual environments in real-time three-dimensional (3D) settings (Crotty, 1998; Yusoff et al., 2011). AR technology provides real-time virtual information, enhancing human perception (Oke & Arowoija, 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 benefited from AR technology, as it has been extensively employed for virtual training and spatial planning (Arowoija et al., 2021).

The ability of AR technology to provide a virtual environment for construction workers to use 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).

With the increase in digital transformation, AR technology is becoming more accessible in the engineering and construction sectors. The demand for digital transformation highlights the need for a comprehensive theory or framework to assess its effectiveness of AR technology within these fields. One of the most widely recognised theoretical models for evaluating system information success is the DeLone and McLean information system (IS)

success model. The IS success model recognises six areas, including information systems, system quality, service quality, intention to use or use, user satisfaction and net benefits (DeLone & McLean, 1992; DeLone & McLean, 2003). This framework was first introduced in 1992 and was then updated in 2003. There are alternatives to the DeLone and McLean IS success model, such as the unified theory of acceptance and use of technology (UTAUT) and the technology acceptance model (TAM), which focus on the users' behaviour, intentions and perceptions (Davis, 1989; Venkatesh et al., 2003). However, the DeLone and McLean IS model is a holistic approach that considers the system's performance and the users' experience (DeLone & McLean, 1992; DeLone & McLean, 2003). Building on the DeLone and McLean IS success model, this research aims to investigate the factors influencing the user acceptance of technology.

Managing engineering and construction projects is a complex process that requires the careful consideration of various factors. In contemporary times, this process entails making informed decisions based on a wealth of information (Chen & 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 disconnect poses a challenge to ensuring that projects are completed within the stipulated amount of time and budget. Consequently, construction managers must find ways to bridge this gap and ensure that 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).

Along with the outlined benefits of integrating AR technology in the engineering and construction sectors, such as increased efficiency, visual communication and collaboration, there is still a need for real-world integration (Delgado, Oyedele, Beach, et al., 2020; Hajirasouli et al., 2022; Han & Clevenger, 2025). This gap is significant because of the digital transformation, such as through AR technology, needed in the engineering and construction sectors; it addresses issues such as defect reduction, complex two-dimensional (2D) drawing interpretations and the sustainable delivery of projects and productivity. In addition, this study will contribute academically to the built environment with digital transformations (Arvikar et al., 2025; Delgado, Oyedele, Beach, et al., 2020; Liao & Luo, 2025; Yunus et al., 2025). It is noted that the existing literature outlines that there is limited research in real-world environments, with insufficient frameworks regarding integration with the engineering and construction sectors (Hajirasouli et al., 2022; Han & Clevenger, 2025). This research addresses this gap by investigating the drivers, benefits, limitations and outcomes of AR technology integration. Additionally, the literature is outlined and research is performed to

bridge the gap between data obtained through research and practical implementation within the engineering and construction sectors.

1.3 Aims of the Project

The aim of this research is to explore the research question and examine user dynamics in the acceptance of AR technology within the engineering and construction sector. The aim is to develop a theoretical framework and outline the relationships on the user acceptance of AR technology. To ensure a comprehensive framework, this research utilises grounded theory, along with the DeLone and McLean IS system model approach (DeLone & McLean, 1992; DeLone & McLean, 2003). This research uses a qualitative approach to identify the factors of user acceptance and integrates them into a framework. This research can enhance academic knowledge and offer practitioners an insightful understanding of digital transformation and how to integrate this transformation into current workflows.

The research aims to explore the user adoption of AR technology in engineering and construction projects. This is achieved by investigating the factors influencing AR user acceptance, including the benefits and limitations of AR use and why users adopt or resist AR technology. Additionally, the research aims to identify 'how' and 'why' AR acceptance is linked to project success in these fields. Many researchers have explored the factors influencing the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010). However, there is a gap in qualitative research that provides a big picture of the drivers of user acceptance of AR technology in engineering and construction projects and their dynamics.

To identify and explore the user adoption of AR technology in engineering and construction projects, a literature review was conducted in three stages to determine the gap in this research. In the first stage, a review was carried out to identify factors influencing the user acceptance of technology across all types of technology, including AR, VR, mixed reality (MR) and extended reality (XR), and in various fields, such as architecture, engineering and construction (AEC). The second stage involved investigating factors affecting the user acceptance of AR in engineering projects. Finally, the literature on factors influencing the user acceptance of AR in construction projects was examined. Throughout the process, all three stages were analysed to highlight which areas had been studied across all technologies and project types related to AR and engineering and construction. Many researchers have explored the factors influencing the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013;

Taylor, 2010). Different researchers have studied the major factors of user acceptance by identifying the perceived usefulness, behaviours, ease of use, company attributes and technology attributes fields (Didehvar et al., 2018). This research highlights a lack of qualitative research that provides a big picture of the drivers of the user acceptance of AR technology in engineering and construction projects and their dynamics. Therefore, the overall aim of the research is to identify the performance and outcomes of the user acceptance of technology in engineering and construction projects.

1.4 Statement of Significance and Importance

The definition of project success is elusive; however, project output is dependent on the characteristics of project success (Belassi, 1996). In addition, the causes of project failure are uncertain; however, virtual environments improve organisational performance (Lu et al., 2014). Therefore, the project managers and the project team need to adapt the tools and technology resources to suit various types of projects, as all projects differ. AR technology can assist in engineering projects to increase project success (Chandrasegaran et al., 2013). According to the DeLone-McLean theory of information systems success (DeLone & McLean, 2003), the use and user satisfaction can impact the net benefit (Mardiana et al., 2015), such as through the project performance.

Therefore, in addressing the research question by exploring the dynamics of user acceptance in engineering and construction projects, the research utilises a qualitative approach that has not yet been recognised in these fields. Unlike previous research on the user acceptance of AR technology, which mainly examines AR use in controlled study environments, more research needs to be conducted in real-world working environments. Thus, identifying factors and understanding the dynamics of user acceptance in engineering and construction projects will ultimately benefit all project practitioners and companies in achieving positive project outcomes.

1.5 Contribution to Research and Practice

Exploring users' acceptance of AR technology in engineering and construction projects can improve the project outcome by providing a constructive result that impacts the user acceptance of AR technology, including users' perception and acceptance of AR (Chandrasegaran et al., 2013). The importance and perceived usefulness of AR affect the intention of use and can lead to an optimistic outcome (Chandrasegaran et al., 2013).

Based on this research in the engineering and construction field, practitioners can utilise technology resources to help with a project and generate a positive result. Alizadehsalehi and Yitmen (2019) state that technology advances are not utilised enough in companies and that they have a positive impact on real-time automated processes. In addition, incorporating AR into new product development leads to sustainable growth in business (De Silva et al., 2019). Therefore, the findings suggest that there is a gap in the research. This includes a lack of knowledge obtained from real-world environments and not just in a classroom setting (Hajirasouli et al., 2022; Sangiorgio et al., 2020). Additionally, this technology remains immature, with the lack of a framework, and a complete system has yet to be developed; AR technology requires further investigation (Delgado, Oyedele, Demian, et al., 2020; Kolaei et al., 2022; Sangiorgio et al., 2020). There are also minimal studies outlining how organisations can use AR technology with a clear outlook on benefits and limitations (Delgado, Oyedele, Demian, et al., 2020). There are also misconceptions of the terminology associated with AR technology, and often individuals confuse AR with other types of technology, such as VR and MR (Ghorbani et al., 2024). However, it is noted that VR is defined as the merging of both real and virtual reality, and MR is defined as the display of real and virtual objects (Milgram & Kishino, 1994). Therefore, this research can advance academic knowledge and offer practical benefits by identifying the user acceptance of AR technology in the engineering and construction field.

This research can enhance academic knowledge by providing a comprehensive overview of the benefits and challenges of AR technology, as well as the outcomes of integrating this technology in the engineering and construction sectors, while highlighting gaps in the existing literature. By analysing the current literature and comparing it with the primary data collected in this research, the findings are evaluated. This research benefits academic knowledge by identifying the drivers of user acceptance and offering nuanced insights into both the engineering and construction sectors. Additionally, it highlights enablers of AR integration and indicates areas where further research is necessary. This evidence-based study lays the groundwork for future research in real-world application environments.

This research offers practitioners practical benefits by providing evidence-based findings through literature reviews and data analysis using a grounded theory approach with primary data, aiding practitioners by outlining the benefits and challenges of using AR technology in the engineering and construction sectors.

This research highlights a gap in existing knowledge concerning AR technology in the engineering and construction sectors. This research suggests that engineering and construction projects are reliant on the acceptance of technology (De Silva et al., 2019). In

addition, AR environments improve and support performance in project management, and there are difficulties associated with technology acceptance (Didehvar et al., 2018). However, experience with AR technology is lacking in professional and academic fields (Wu et al., 2019). There are also limited advancements in the engineering and construction sector due to the inability to embrace digitalisation (Alkan & Basaga, 2023). Therefore, further research can benefit these types of projects through AR technology acceptance in these fields.

The potential benefits that can be gained by investigating the dynamics of user acceptance in engineering projects include increasing project performance and supporting practitioners in achieving a constructive and desired outcome, ultimately assisting practitioners with the adoption of new technologies and developing their aptitude and skills with project management resources to help organisations deliver projects satisfactorily. This will benefit not only the engineering and construction field but also ultimately all project types through the adoption of new technology.

In addition, this work can potentially allow more engineering projects to be feasible to complete in Australia, as the main concern in Australia is that most design and engineering projects are outsourced overseas due to cost. By utilising AR, the project design phase can be facilitated and executed in Australia. To ensure that the data obtained in this research are viable and can be used for study purposes, ethical principles and values will be adhered to, and a strategic process will be utilised to ensure that the benefits outweigh the risk.

1.6 Overview of Literature Review

Investigating users' acceptance of AR technology and resources in engineering projects can primarily support a positive outcome for engineering projects. Didehvar et al. (2018) find that poor project management and performance contribute to project failure, and promoting technology increases project success. Chandrasegaran et al. (2013) state that the importance and perceived usefulness of AR for the project need to be identified, and if this is not done, it can affect the intentions and outcome of AR use. In addition, AR technology can increase and speed up project applications (Ong et al., 2020). However, according to Wu et al. (2019), these resources are not being fully utilised, and experience in AR technology is lacking.

According to the DeLone-McLean theory of information systems success (DeLone & McLean, 2003), AR use and user satisfaction can impact the net benefit (Mardiana et al.,

2015), such as through the project performance, as shown in Figure 1.1. Thus, leaning on this framework, this research aims at exploring the factors that impact the user acceptance of technology.

DeLone and McLean's (2003) information system success model has been the subject of limited studies; however, with reference to the research question – what are the dynamics of the user acceptance of technology in engineering projects – the DeLone and McLean (2003) information model depicts a modern viewpoint compared to the 1992 model, highlighting the evolution of information systems. Considering this success model, one can see that user benefits rely on user satisfaction and the intent to use. In addition, the intent to use and user satisfaction are dependent on the information quality, system quality and service quality.

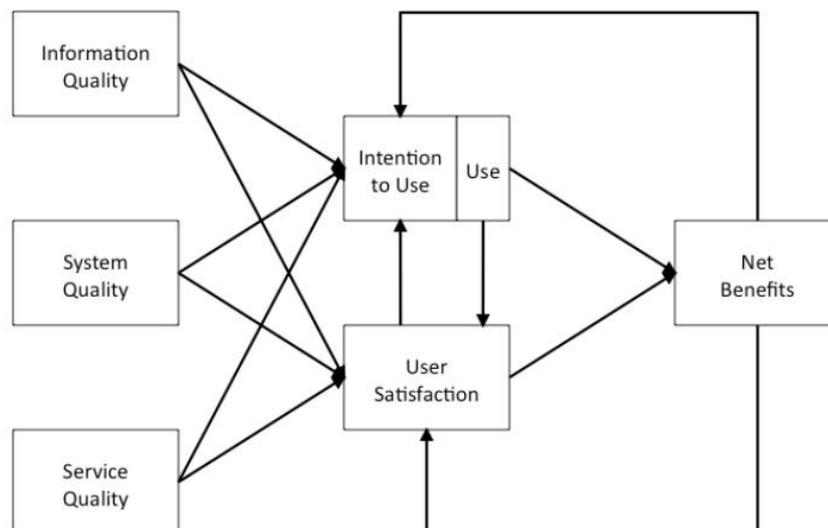


Figure 1.1: Information system success model (DeLone & McLean, 2003)

A comprehensive literature review was conducted using a total of 56 papers. The literature review focused on three areas: the theoretical perspective, the factors driving the use of AR and the outcomes associated with AR use. It is noted that digital transformation in AR technology is a primary driver in the engineering and construction sector (Bórquez et al., 2025), and there is a need for innovation, as digitisation is at the forefront of engineering and construction projects (Oke & Arowoija, 2021).

1.6.1 User adoption of AR technology

The three stages of the literature review assisted in finding the gap in the literature. First, a literature review was conducted on factors impacting the user acceptance of technology related to AR, which includes VR, MR and XR, in the AEC environment. Second, a literature

review was conducted to examine the factors influencing the user acceptance of AR in the engineering sector. Finally, the literature regarding factors impacting the user acceptance of AR in construction projects was reviewed. All three areas were analysed and compared, outlining what areas have been studied, for all technologies and all project types, in relation to AR in the AEC, engineering and construction sectors.

Many researchers have explored factors related to the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010). However, there is a lack of qualitative research that provides a comprehensive understanding of the drivers of the user acceptance of AR technology in engineering and construction projects, as well as their dynamics. Therefore, the aim of the research is to identify the performance and outcomes of the user acceptance of technology in these projects.

Researchers have explored the benefits of utilising AR technology, which include enhancing efficiency, visual communication and collaboration (Delgado, Oyedele, Beach, et al., 2020; Hajirasouli et al., 2022; Han & Clevenger, 2025). However, there is a gap when it comes to the real-world integration of AR technology (Hajirasouli et al., 2022; Han & Clevenger, 2025; Harikrishnan et al., 2021). The research literature considers many scenarios that rely on simulations, conceptual models and laboratory conditions using small samples or controlled settings that do not address AR technology integration in the engineering and construction environments (Alkan & Basaga, 2023; Delgado, Oyedele, Beach, et al., 2020; Han & Clevenger, 2025). Although there are positive impacts on visual communication and decision-making, there is a lack of qualitative research involving professional practitioners in the construction, engineering and software development sectors who use AR or work in departments where AR technology is being implemented (Bórquez et al., 2025; Harikrishnan et al., 2021; Yunus et al., 2025). Therefore, there is a need to go beyond the small sample groups and academic environment to explore the user dynamics of AR technology through a qualitative research approach.

The primary gap identified in this research is the limited literature on real-world professional applications of AR technology within the engineering and construction environments (Hajirasouli et al., 2022). It is also noted that the construction sector has not fully adopted AR technology (Alkan & Basaga, 2023). Additionally, there is a lack of comprehension of the output of AR technology in the construction sector (Han & Clevenger, 2025).

There are minimal studies on how organisations and practitioners can utilise AR technology that clearly define its benefits and limitations (Delgado, Oyedele, Demian, et al., 2020) .

There is also an inability to embrace digitalisation, with limited advancements in the engineering and construction sector (Alkan & Basaga, 2023). Therefore, the research question explores the user acceptance of AR technology.

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

1. **Enhancing project management:** The visual simulation capabilities of AR technologies offer a more immersive experience, improving project management and overall productivity (Oke & Arowoia, 2021). The study will explore how AR can be integrated into project management practices for better decision-making and resource optimisation.
2. **Workforce adaptation:** Acknowledging that the engineering and construction industry often includes workforce members who do not use immersive types of technology, the theory will incorporate strategies to ensure that they are comfortable with digital technologies. This inclusive approach will consider their perspective and support them in adapting to these changes (Jimeno & Puerta, 2007).
3. **Skills development:** Proficiency in AR technology within the industry is crucial. The theory 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 the successful integration of AR technology requires a supportive organisational culture, the theory will recommend strategies that will allow organisations to provide necessary support for technology integration.

Research question (RQ): What are the dynamics of the user acceptance of technology in engineering and construction projects?

1.7 Overview of Methodology

The methods utilised for this research are outlined in Table 1.1. The data collected for this research consist of primary data obtained through questionnaires, interviews and focus groups. The research method for this study includes an interpretivist, qualitative approach and the incorporation of grounded theory.

Table 1.1: Research method

Research method	Type
Research paradigm	Interpretivism
Research approach	Qualitative
Research method	Grounded theory
Data collection	Primary data
Data analysis	Grounded theory

The research method utilised in this research is grounded theory. This theory is a systematic methodology designed to generate a theory from the analysis of data (Levers, 2013). The grounded theory approach will aid in the data collection of this qualitative research.

Grounded theory is utilised in this research due to several factors, including the nature of the research question, which is centred on the real-world dynamics of user acceptance in the engineering and construction sectors. It utilises open-ended questions in interviews and questionnaires to uncover direct meanings from participants' experiences. This also includes a comprehensive literature review that highlights the lack of established frameworks for real-world environments (Hajirasouli et al., 2022; Han & Clevenger, 2025; Harikrishnan et al., 2021). The literature outlines that studies focus on small samples and laboratory environments without providing the real-world experiences of practitioners (Bórquez et al., 2025; Yunus et al., 2025). Therefore, the grounded theory approach is essential for developing a theory and a framework that reflect real-world environments, especially for users working in complex settings who understand the benefits and limitations of AR technology use in the engineering and construction environments. By utilising grounded theory, the research reflects actual real-world data.

Grounded theory is considered in relation to AR in the engineering and construction fields with regard to the interpretivist guidance on creating understanding and knowledge. AR is identified as being in the management area of construction- and engineering-type projects, with a focus on communication and relationships within qualitative research.

In conjunction with the research method, data collection is crucial for identifying a theoretical approach to a model. The primary data were collected using questionnaires and interviews. First, individuals were asked to fill out a questionnaire anonymously, and then they were asked if they were interested in an interview. The questionnaires have two different formats. The first format, consisting of 10 questions, is designed for participants in the engineering and construction field. The second format, which includes a total of 11 questions, is for software developers.

The interview questions were based on the questionnaires; however, some topics emerged after the questions had been asked. The questionnaire, which was completed first, is based on reducing my influence on the topic and to analyse the data. An interview was conducted after the questionnaire to explore how the answers were derived from the original questionnaire. Taking into consideration that the questionnaire participants received an anonymous link, all data are analysed as a whole. Lastly, a comparison of the data from the questionnaire and the interview was coded.

Regarding the research question – what are the dynamics of the user acceptance of technology in engineering and construction projects – it can be identified that AR, and especially AR incorporated into product development, can lead to sustainable growth in business (De Silva et al., 2019). It was also found that the major concern with user acceptance is the accessibility of the technology and the training requirements.

The contribution of this study is to develop a theory based on the grounded theory approach in relation to AR user adoption in the engineering and construction sector. It is noted that previous research relied on laboratory environments or small sample sizes (Hajirasouli et al., 2022; Han & Clevenger, 2025; Harikrishnan et al., 2021). Additionally, the DeLone and McLean IS success models were referenced when considering the IS success factors (DeLone & McLean, 1992; DeLone & McLean, 2003; Liao & Luo, 2025). However, it is noted that the existing literature has not fully researched real-world environments using the IS success model and grounded theory approach to examine AR technology and user acceptance with qualitative data factors (Hajirasouli et al., 2022; Han & Clevenger, 2025; Harikrishnan et al., 2021). Integrating the grounded theory approach allows participants with construction, engineering and software development perspectives to explore DeLone and McLean's IS success models, which include information systems, system quality, service quality, intention to use or use, user satisfaction and net benefits (DeLone & McLean, 1992;

DeLone & McLean, 2003). By leveraging the IS success model and grounded theory, this study enhances academic knowledge and offers practitioners an insightful understanding of digital transformation with AR technology adoption, which previous studies have not provided (Alkan & Basaga, 2023; Hajirasouli et al., 2022; Han & Clevenger, 2025; Hari Krishnan et al., 2021; Söbke et al., 2025; Yunus et al., 2025). Therefore, this research is essential due to its use of real-world practitioner data and because it provides insights that have not yet been validated in this type of research.

1.8 Research Constraints

Regarding research constraints, two main areas have been identified. First, the onset of the COVID-19 pandemic significantly impacted the research's progress. Initially, there was no anticipation of such a pandemic. During the first six months of the pandemic, people's priorities shifted toward maintaining their jobs and businesses and providing for their families. This shift affected the availability of volunteers, as some had been made redundant and companies could not afford to divert employees' time for volunteer activities. As a result, a different approach to data collection was adopted. The questionnaire was not originally part of the research, but a new strategy that would not actively impact companies' or participants' time was needed. This led to the second constraint: a smaller number of participants.

Second, a smaller number of participants than expected were a part of this research. I needed to incorporate a larger demographic, so for the engineering project, it was decided to investigate construction-type projects. This area was not impacted as strongly by the COVID-19 pandemic, and I also knew that construction has strong ties with engineering. Regarding the grounded theory method, this does not impact the data outcome. Grounded theory is about not having any unanswered questions (Levers, 2013); therefore, to examine the research question and the five fundamental inquiries, a specific number of participants is not required.

1.9 Overview of the Thesis

Chapter 1 – Introduction

This chapter presents the introduction to the research; it includes the overview, background, aims, significance and contributions of the research and sets the baseline of the study. Therefore, the aim of this research is to identify and explore the user adoption of AR

technology in engineering and construction projects. This chapter also identifies the research question: What are the dynamics of the user acceptance of technology in engineering projects? The significance of this research lies in identifying factors and exploring the dynamics of user acceptance in engineering projects, which will ultimately assist project practitioners in the engineering field and companies alike in achieving positive project outcomes. This research contributes to knowledge through its contribution to the academic literature and practice. The potential benefits include increases in project performance and support to help practitioners achieve constructive and desired outcomes and allow more engineering projects to be feasibly completed in Australia.

This chapter briefly identifies the work developed by others that will aid in this research, including research questions extracted from the literature. This chapter also explores frameworks developed by other scholars, including the success model of DeLone and McLean (2003), which this research has utilised as a baseline for the research method developed. From the literature review, the gap in the literature was established. The three stages of the literature review assisted in finding the gap and outlining it. Refer to Table 1.2 for the research methodology approach.

Table 1.2: Research methodology

Research methodology	
Research paradigm	Interpretivism
Research approach	Qualitative
Research method	Grounded theory
Data collection	Primary data
	Interview
	Focus groups
	Open-ended questionnaire
Data analysis	Grounded theory

Chapter 2 – Literature review

Chapter 2 reviews the existing literature on AR technology in the engineering and construction sectors, identifying its benefits and limitations and defining the gap in the literature. The chapter identifies previous literature and defines the terms used for technology in engineering projects. This chapter also asked questions concerning user acceptance and the impacting factors that influence it. Furthermore, it identifies the work

developed by others that will aid in this research, including the research questions extracted from the literature. This chapter discusses the IS success model of DeLone and McLean (2003) that this research framework leans on. In addition, it reviews the literature that helped assist in finding the gap, outlining what areas have been studied, for all technologies and all project types, in relation to AR and engineering projects. This included a total of 56 pieces of literature reviewed from the following:

1. Factors impacting the user acceptance of technology in the AEC sector;
2. Factors impacting the user acceptance of AR in construction projects;
3. Factors impacting the user acceptance of AR in engineering projects.

All three areas were analysed and compared. Thus, the results from this literature review have identified a lack of qualitative research providing a big picture of the drivers of the user acceptance of AR technology in engineering and construction projects and their dynamics. Therefore, the aim of the research is to identify the performance and outcomes of the user acceptance of technology in these projects. This chapter reviews the performance and measurements involved in determining user acceptance and project success, including the factors that facilitate and prevent success with technology.

Therefore, this chapter concludes with a discussion of the user acceptance of technology with respect to other information system models and considers the user acceptance of technology, dynamics that support this theory and their relationship to project success.

Chapter 3 – Research methodology

Chapter 3 describes the approach used in this research. This chapter summarises the choice of research paradigm in this research. The research paradigm incorporated in this study is interpretivism. This chapter also outlines the direction of epistemology and the methodology used, as well as how they are connected. Interpretivism provides interpretation and data analysis that focus on the participants' movements, knowledge and opinions (Levers, 2013) relevant to the research question. The discussion outlines the theoretical perspective of interpretivism and how this encapsulates the research in a holistic way, along with the associated epistemology, ontology and methodology. Figure 1.2 outlines the taxonomy of this research, which is further detailed below.

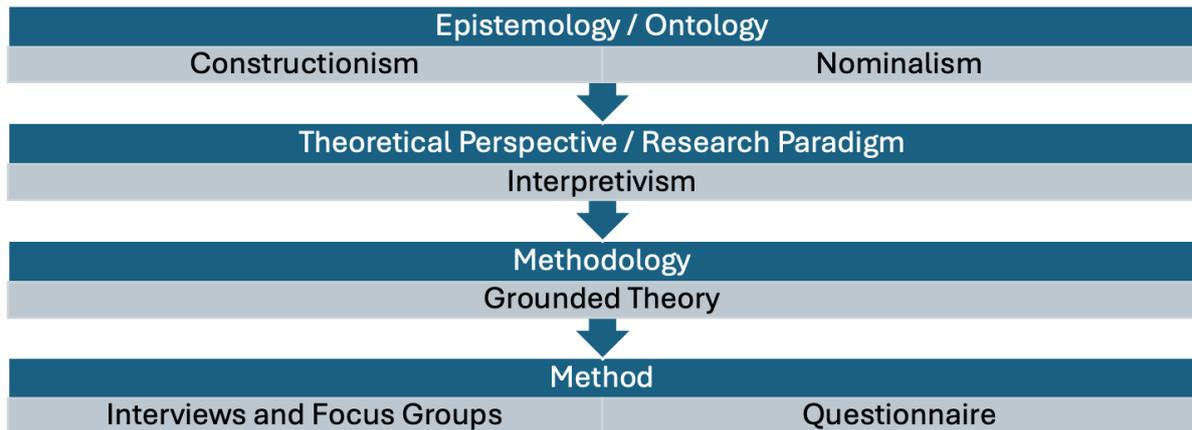


Figure 1.2: Research methodology

Furthermore, this chapter outlines the choice of the methodology used in this research. To understand the dynamics under consideration, grounded theory is used, and it is described in this chapter. This chapter investigates the origins of grounded theory. It discusses the problems associated with grounded theory and how grounded theory has evolved and resolved these matters. This theory is a theoretical approach to the methodology employed (Crotty, 1998). The chapter then outlines the data collection approach, which involved interviews and questionnaires, and how the use of a digital interface became the norm. The data collected to date for the research include data obtained from workers in the engineering and construction fields in management and leading roles, in addition to software developers.

Chapter 4 – Data analysis

Chapter 4 presents the results obtained through primary data using the grounded theory approach. Questionnaires and interviews are the main sources of data collection. A total of 65 consent forms have been signed. A total of 25 questionnaires have been completed by engineers, including two questionnaires completed by software developers. A total of 23 interviews were conducted, including two focus groups. The purpose of this chapter is to discuss the themes formed in this research about the research questions, where NVivo software was used for data analysis and coding.

Therefore, grounded theory was used to analyse the data to identify the relationships and themes. This included 248 open codes, 49 axial codes and 18 selective codes. Through this method, the data were analysed in order to identify the research gap. As a result, the data set collected is used to determine a theory that was analysed using comparative analysis (Levers, 2013). The data obtained from the research led to the development of a theory based on the findings.

Chapter 5 – Discussion

Chapter 5 interprets the data analysis and compares the results to the current literature and research theory. This chapter identifies the definition of acceptance and the utilised approach, and it discusses how the data collection and literature review were used to investigate the problem at hand, that is, the user acceptance of technology. This chapter includes the themes identified through data analysis and the literature review, as well as a deep dive into the problematic response of acceptance within the conceptual framework, which informs the research method.

The relationships and theory derived from this data analysis, formed through grounded theory, were used to form the proposed theory, which includes a taxonomy, a conceptual framework, and a causal loop diagram of relationship chains and feedback loops that can be used when integrating AR technology into engineering and construction projects.

Chapter 6 – Conclusion

Chapter 6 summarises the research outcomes and outlines recommendations. This chapter addresses the following research question: What are the dynamics of the user acceptance of technology in engineering projects? Primarily, this research investigated acceptance, and based on the data analysis and previous literature, it developed a research model. This chapter details the process of the research, the problematic response of user acceptance and the approaches used to answer the research question. This is then tied to the research model and how the variables are used to answer the research question. Therefore, this chapter outlines the findings systematically. First, it describes the research findings obtained through the literature review, which found that there is minimal research emphasising AR technology in all engineering projects, and there is a need for further research on the user acceptance of AR technology in engineering projects; an early framework appeared based on the data obtained from the literature review. The second phase of the research outlines the methodological approach of the research and the findings obtained from the data. Based on these findings, a conceptual framework and research model were developed, and they were subsequently refined through the data obtained from interviews and focus groups.

1.10 Conclusion

This introduction chapter provides an overview of the research on augmented reality (AR) technology adoption in the engineering and construction sectors, including the background of AR technology and its applications in these fields. It is followed by Chapter 2, the literature review, which explores existing research and offers a supporting theory for this study. The literature review is followed by Chapter 3, which describes the methodology, outlining the research approach used to study AR in engineering and construction. Chapter 4 details the data analysis, presenting findings based on grounded theory. Chapter 5 discusses these findings and addresses the research questions, while Chapter 6 summarises the key points and conclusions.

Chapter 2: Literature Review

This chapter aims to review the current literature on AR technology in the engineering and construction sectors. It explores the evolution of AR technology, providing a detailed description of its origin and how it has evolved. The chapter outlines the literature review methodology, including the search strategy and the process of selecting relevant literature. It also summarises the key findings from the literature, with a focus on the research background. The benefits and barriers of AR technology are discussed, along with an outline of the gaps in the existing literature.

2.1 Overview

Exploring the user acceptance and adoption of AR technology in engineering and construction projects is vital for digital transformation. AR technology is rapidly becoming more commonly used to assist in immersive digital transformation, providing real-time data to all stakeholders and managers and thus promoting a digital shift that enhances project efficiency and drives digital innovation within the workforce (Newman et al., 2020). In addition, this can revolutionise digital communication and stakeholder collaboration (Malagnino et al., 2022). Therefore, exploring digital transformation and the use of AR technology in the engineering and construction sectors is becoming increasingly common (Chen & Xue, 2020), thus guiding us into a new era in which AR technology is evolving and aids in driving success (Chen & Xue, 2020).

This rapid adoption of AR technology is becoming vital for the engineering and construction sectors, and with the right approach, it is clear that AR technology can be beneficial; however, AR technology is underutilised (Abels et al., 2006; Chen & Xue, 2020; Elshafey et al., 2020; Guray & Kismet, 2022; Rohil & Ashok, 2022).

Utilising AR technology in the engineering and construction sectors provides an immersive experience with simulations and 3D visuals that provide a safe working environment (Oke & Arowoia, 2021). Digital technology allows managers and all stakeholders to obtain precise information in real time (Newman et al., 2020).

When integrating digital technology into the engineering and construction sectors, it is important to consider the workforce. Therefore, implementing a change management process helps ensure that everyone feels comfortable with the change and thereby supports a smooth transition and adoption (Jimeno & Puerta, 2007).

With AR being underutilised in the engineering and construction sectors, it is evident that digital technology needs to be further explored to address the potential benefits of AR and determine why digital advancements in AR technology are underutilised in these sectors.

This research will explore the determinants of the user acceptance of technology for engineering projects and determine factors that impact AR user acceptance. Thus, the overall dynamics and aims of the research are identifying the performance and outcomes of the user acceptance of technology in engineering projects and answering the following research question: 'What are the dynamics of the user acceptance of technology in engineering projects?'

2.2 Evolution of AR Technology

Regarding digital transformation technology, AR is a concept that has been around for quite some time. US 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 & Çankaya, 2019).

It was not until 1968 that the first AR system with a head-mounted display was used. This was achieved 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 24 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 (Rosenberg, 1992).

Twenty one years later, the first Google Glass device 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 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 & Arowoija, 2021).

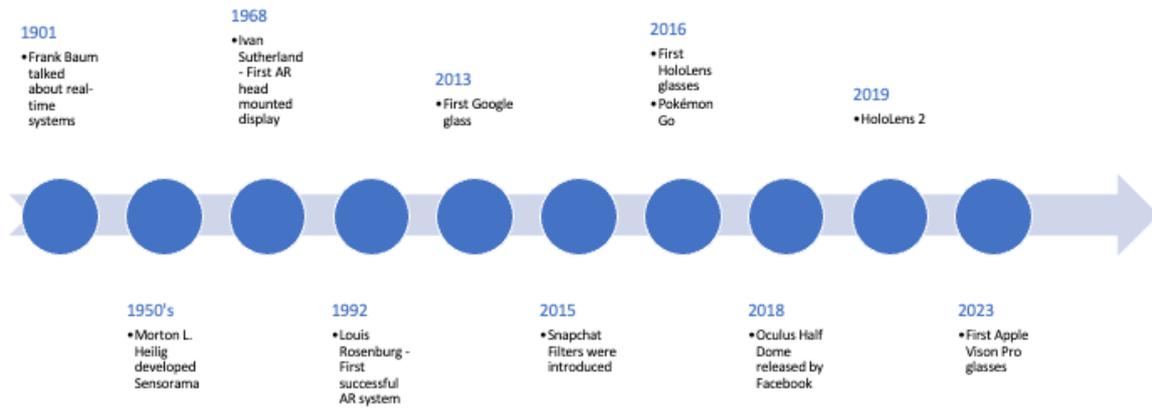


Figure 2.1: History of augmented reality technology

Since the inception of this study, significant advancements in both software and hardware have had a profound impact on the analysis of AR technology. Notably, there have been significant breakthroughs related to head-mounted display glasses (Delgado, Oyedele, Demian, et al., 2020) and the implementation of filter overlays on mobile phones and computer devices, such as in Snapchat and for virtual online shopping.

Head-mounted display glasses have resurged with improved capabilities, resulting in visually immersive and comfortable devices (Delgado, Oyedele, Beach, et al., 2020). These advancements have made AR integration into various industries, such as engineering and construction, more seamless. Engineers and construction professionals can now use hands-free AR technology, enabling real-time data visualisation and interaction. This streamlines decision-making processes and enhances project efficiency (Arowoia 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 with improved algorithms and processing power have emerged, allowing enhanced object recognition, spatial mapping and accurate virtual object placement (Sünger & 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.

2.3 Literature Review Methodology

The literature review process involves four key areas. These include identifying the main topics to search for, determining where to search, determining how the information is reviewed and identifying the literature to incorporate based on the determinants of the user acceptance of AR technology for engineering and construction projects.

The literature review strategy used for this research consists of five steps:

- Identifying the literature review topics;
- Implementing the search strategy;
- Outlining and reviewing the relevant literature;
- Identifying which literature to review based on the findings;
- Summarising the research findings.

In the literature review, the considered literature needed to relate to AR technology and user adoption. In addition, the fields of engineering and construction were relevant. Therefore, the literature was searched using leading academic databases and specific journals to facilitate the literature review. Once the literature was reviewed based on the specific areas of interest, studies were then selected to be reviewed in depth.

The literature review was based on the following three key areas:

- The theoretical lens;
- The drivers;
- The outcome.

To outline the gaps in the literature, the literature review included a comprehensive analysis of all the literature collected. The literature review collected data from 2007 to 2025 on AR use in the engineering and construction sectors. The data analysis then considered the research questions, the theoretical lens, the drivers and the outcome of the literature review. The literature review process is detailed in Figure 2.2.

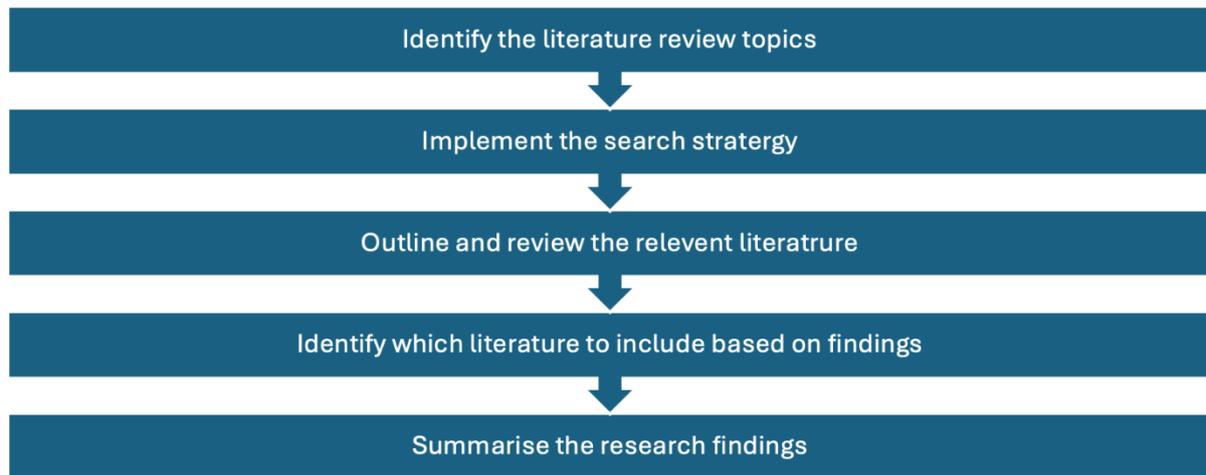


Figure 2.2: Literature review process

Prior to the start of the literature review, the requirements of the literature review were derived from the following research question: ‘What are the user dynamics of AR technology in engineering and construction projects?’

2.3.1 Search strategy

The search strategy for the literature review consisted of searching online platforms, and the requirements for the search were related to the research question and how the items are filtered.

When performing the literature review, there was a conscious decision to consider research from the last 10 years, with a few outliers from 2007 and 2011, as the aim was to see the advances in AR technology, starting with its early implementations. Peer-reviewed journal articles that were relevant to the research conducted were also analysed. The original plan was to search for articles from the last 5 years; however, not much has changed over the last 10 years other than AI integration, which was recently introduced.

The search strategy implemented for this literature review involved the use of preferred reporting items for systematic review and meta-analysis (PRISMA) to guide the systematic selection of literature related to AR technology in engineering and construction. The PRISMA process began with a comprehensive search across online academic platforms, including Scopus and the Victoria University A-Z databases. When utilising these platforms, predefined keywords such as ‘AR technology’ combined with one of the following – ‘construction’, ‘engineering’, ‘project management’, ‘communication’, and ‘implementation’ – were employed to find relevant literature aligned with the research question. During this

process, duplicate records were removed, followed by title screening and further review of abstracts to ensure relevance. After screening abstracts, the full texts were examined for eligibility based on the inclusion and exclusion criteria. The included studies were those directly related to AR technology within the AEC sector, construction sector, and engineering sector, published within the last 10 years. Excluded papers included papers irrelevant to AR, MR, and VR technology, papers outside the construction and engineering industries, or papers published outside the 10-year timeframe, unless they were historical or highly informative.

2.3.2 Outlining and reviewing the relevant literature

Outlining the relevant literature takes place during the literature search after the key search words are placed in the search bar; this then prompted me to review all the literature that is relevant.

In this case, I filtered the literature by the title and abstract. I would read the title and the abstract of a paper, and if they were applicable to the research question and the key words, this paper was then saved so that it could be read in the next step.

Once all the literature relevant to the research question was saved, I needed to make sure that it was applicable to the engineering and construction sectors.

2.3.3 Identifying which literature to review based on the findings

All the studies that were applicable to this research based on their titles and abstracts were read in full to further filter the considered literature. This was done by ensuring that the literature is applicable to AR technology in the following sectors:

- Architecture, engineering and construction (AEC) sector;
- Engineering sector;
- Construction sector.

In addition to the above requirements, the literature needs to reflect the following research question: 'What are the user dynamics of AR technology in engineering and construction projects?' In addition, I read the literature looking for the following:

- What are the project requirements for AR technology?
- How is this project managed?
- How is the AR technology side of the project managed?
- What are the outcomes of AR integration?
- How was AR technology integration communicated and implemented?

2.3.4 Summarise the literature findings

Once the selected literature reflected the research questions and findings, it was then further analysed through the following three key areas, which the literature review was based on:

- The theoretical lens;
- The drivers;
- The outcome.

The theoretical lens was used to analyse the literature, as this literature review needed to be similar to the grounded theory approach and utilise a framework that reflected the problem statement. This literature needed to reflect AR technology and how it can be utilised in the engineering and construction sectors.

The drivers reflected the purpose of the research. Each study that was reviewed had a distinct purpose; this purpose needed to reflect AR technology and how it can be used in the engineering and construction sectors.

Each literature review outcome was documented, highlighting the results of integrating AR technology and how this was reflected in the engineering and construction industry.

2.4 Research Background

By investigating users' acceptance of AR in projects, it was found that this can primarily support a positive outcome for projects. Didehvar et al. (2018) find that poor project management and performance contribute to project failure, and promoting technology increases project success. Chandrasegaran et al. (2013) outline that the importance and perceived usefulness of AR for projects need to be identified, and if this is not done, then this can affect the intentions and outcome of AR use. In addition, AR can increase and speed up project applications (Ong et al., 2020). However, according to Wu et al. (2019), these resources are not being fully utilised, and experience in AR is lacking.

AR technology can be used in various types of projects. This includes projects related to health and medicine, as well as educational and IT projects. AR can be used in the development of new engineering and manufacturing projects, including, for example, car manufacturing, to design new engineering projects and infrastructure. AR is primarily used for various purposes, with the aim of simulating different environments. AR for engineering is

less about simulation and more about real-time automated processes (Alizadehsalehi & Yitmen, 2019), including new product development (De Silva et al., 2019).

AR can improve project outcomes if it is adopted effectively and user acceptance is ensured in projects. The success of the outcome can be measured effectively and efficiently through a qualitative approach. The DeLone-McLean theory of information systems success (DeLone & McLean, 2003) suggests a positive impact on project outcomes through use and user satisfaction. Therefore, AR can improve project outcomes. Project performance can be measured by the following two indicators: the user acceptance and the usefulness of AR to the project (De Silva et al., 2019; Didehvar et al., 2018; Jimeno & Puerta, 2007; Ong et al., 2020; Torres-Guerrero et al., 2017; Wu et al., 2019; Yusoff et al., 2011).

In order to outline factors impacting the user acceptance of AR, users' acceptance of AR and resources in projects had to be explored. De Silva et al. (2019) find that AR is improving product development and should be used in product development to ensure business growth. In addition, Alizadehsalehi and Yitmen (2019) stipulate that AR increases motivation and solves project development issues before the execution phase.

Didehvar et al. (2018) state that AR promotes technology use and project management success and thus is perceived as useful and easy to use. Jimeno and Puerta (2007) find that there is a need for the manufacturing and industrial industries to incorporate AR in addition to software engineering (Torres-Guerrero et al., 2017). By incorporating AR, it can be seen that it is perceived as useful and beneficial to projects (Yusoff et al., 2011); AR can theoretically speed up project applications and minimise the need for expertise (Ong et al., 2020).

2.4.1 User adoption of AR technology

There are several primary findings that have been identified during the literature review regarding the use and adoption of AR technology in the engineering and construction sectors, including user benefits, user awareness, the user experience, practical use and the challenges associated with user acceptance.

There are many perceived benefits of the user adoption of AR technology. For example, AR technology positively impacts problem-solving and decision-making when it is utilised, and in design review, it improved the quality of the information presented visually, user acceptance and the user experience (Hajirasouli et al., 2022). In addition, when it is utilised in the

construction industry with building information modelling (BIM), it provided real-time monitoring and early defect detection as an innovative solution (Liao & Luo, 2025).

It is evident that using AR technology at construction sites demonstrates its benefits, especially in improving efficiency and user engagement, highlighting user satisfaction and the adoption of AR technology (Arvikar et al., 2025; Bórquez et al., 2025).

It is noted that expert and non-expert users can utilise AR technology, as its digital display of information overlays makes this technology user-friendly when it comes to interpreting complex decision-making processes (Sangiorgio et al., 2020). It is also evident that there is high motivation to use AR technology to complete training (Giancaspro et al., 2025), and the adoption of AR technology is accepted in many industries, with acceptable user satisfaction and user experiences (Bórquez et al., 2025; Hajirasouli et al., 2022).

The use of AR technology and user adoption can hinder the awareness of AR in the engineering and construction sectors. It is noted that stakeholders and system professionals need to actively promote the technology and implement promotional improvements to achieve better acceptance by users (Arowoia et al., 2021). It is also stated that there needs to be a general understanding of the difference between AR and MR, and exposure to this technology this can increase the user acceptance and adoption of this technology (Han & Clevenger, 2025). However, there is a lack of acceptance in some areas that conform to the traditional aspects of completing tasks (Kolaei et al., 2022).

The user adoption of AR technology aligns with the user experience, and there must be benefits from integrating new technology for stakeholders. AR can be used to train the workforce safely, providing strong motivation that encourages users to collaborate and understand their tasks (Bórquez et al., 2025; Söbke et al., 2025). It is also noted that users, when using AR technology, express a higher level of satisfaction (Schmitt et al., 2025).

2.4.2 Factors driving user adoption of AR technology

There are several primary findings that have been identified during the literature review regarding factors driving the use and adoption of AR technology in the engineering and construction sectors, including digital transformation, improved decision-making, training requirements efficiency and innovation in AR technology regarding user acceptance.

Digital transformation is rapidly increasing, and the factors driving the use of AR technology in the engineering and construction sectors include data overlays that provide immersive, enhanced visualisation. Hajirasouli et al. (2022) found that utilising AR technology improves complex decision-making, reduces delays and saves time through immersive live scheduling. It is also noted that having an immersive spatial environment ensures a safer workspace and reduces errors through full-scale design walkthroughs (Rohil & Ashok, 2022).

One of the drivers for AR technology adoption is integration with BIM in the construction industry; utilising AR technology and BIM allows real-time defect identification and quality control to take place in the construction sector (Liao & Luo, 2025). In addition, it is considered that AR technology improves productivity, communication and collaboration and provides a complex understanding of projects in the construction industry (Delgado, Oyedele, Demian, et al., 2020; Sangiorgio et al., 2021), thus reducing human error and enhancing the reliability of the information, promoting stakeholder collaboration and communication (Bórquez et al., 2025).

It is noted that another driver for the user adoption of AR technology is improved decision-making and quality improvement (Han & Clevenger, 2025), as utilising AR technology enables the user to make complex decisions using immersive digital data overlays (Sangiorgio et al., 2020). In the context of safety and reduced human error, AR technology enhances safety and the overall quality in construction (Hajirasouli et al., 2022). Thus, it enhances efficiency and reduces the time needed to train individuals (Kolaei et al., 2022).

In relation to factors driving user adoption, cost savings and improved efficiency play a vital role. It is noted that AR technology improves efficiency by lowering the time and cost of projects and increasing quality in the construction industry; for example, producing prototypes has a cost, and producing them through AR technology can minimise this cost (Oke & Arowoia, 2021). It is found that the drivers for the adoption of AR technology are its enhanced efficiency and reduced cost (Alkan & Basaga, 2023). It is noted the AR technology enhances product efficiency, accuracy and user engagement (Bórquez et al., 2025).

AR technology is a key driver of digitisation in the engineering and construction sectors (Bórquez et al., 2025). With digitisation at the forefront of engineering and construction projects, there is a need for innovation, and AR technology is an effective tool that is easy to use (Oke & Arowoia, 2021). It is also noted that another driver of integrating AR technology is that it offers vast opportunities in digitalising processes and enhancing productivity (Alkan & Basaga, 2023). A strong driver for AR technology's use in engineering and construction is

the need to stay at the forefront of digitisation and avoid being left behind (Delgado, Oyedele, Demian, et al., 2020).

2.4.3 Consequences of user adoption of AR technology

Several consequences of the user adoption of AR technology in the engineering and construction sectors are outlined in this literature review, including performance limitations, practical usability, training needs, resistance, integration issues, data security and a lack of standardisation.

One of the consequences of the user adoption of AR technology is performance limitations. Utilising AR technology with BIM in the construction sector can be challenging, as the performance is limited when large amounts of data are integrated (Bórquez et al., 2025). It is also noted that there is a lack of understanding of the realistic performance of AR technology in real-world environments (Han & Clevenger, 2025). Additionally, hardware performance limitations such as low battery life, low accuracy and resolution and an inadequate field of view are a limitation of AR technology (Delgado, Oyedele, Demian, et al., 2020); additionally, low-light conditions are required when utilising AR technology, limiting the use of AR technology outdoors (Harikrishnan et al., 2021). In addition, users found AR difficult to use due to ergonomic issues and the heaviness of the head-mounted display (HMD) (Alkan & Basaga, 2023).

There are also training needs when utilising AR technology, and training must be provided to staff if necessary (Kolaei et al., 2022); however, the lack of skilled staff is concerning, and there are many challenges with delivering training that is of a higher standard (Han & Clevenger, 2025; Yunus et al., 2025). Therefore, major upskilling is required when utilising AR technology, which can be challenging for organisations (Delgado, Oyedele, Beach, et al., 2020).

When AR technology is utilised in the engineering and construction sectors, there will be some resistance regarding reliability (Oke & Arowoia, 2021). Additionally, there is a lack of public acceptance of AR technology (Kolaei et al., 2022). There is a perception that AR technology is still in its early stages and not fully accepted, and it is difficult to obtain funding because the benefits are not definitive (Delgado, Oyedele, Beach, et al., 2020).

The challenges with the user adoption of AR technology and low AR adoption are due to the initial high cost, hardware ergonomics and the perception of the immaturity of AR technology

(Delgado, Oyedele, Demian, et al., 2020). It is also noted that there needs to be trust in new technology adoption, which requires expert advice, ease of use and functions that align with the project (Arowoija et al., 2021).

There are known integration concerns with the adoption of AR technology, including the difficulties associated with integrating AR technology and BIM models (Delgado, Oyedele, Demian, et al., 2020). This includes data management and seamless deployment when utilising AR technology across different platforms and devices (Bórquez et al., 2025). There are also concerns related to data security and data ownership when utilising AR technology in the engineering and construction sectors (Delgado, Oyedele, Beach, et al., 2020). There is also a lack of standardisation in the terminology associated with AR technology, and AR is often confused with other MR and VR applications (Ghorbani et al., 2024).

2.5 Benefits of AR Technology Adoption

From the literature review, AR technology in the engineering and construction sectors enables the real-time display of 3D visual information. It overlays digital data onto the physical environment using devices such as mobile phones, tablets, computers, projectors or HMDs (Delgado, Oyedele, Demian, et al., 2020). Some common use cases for AR technology in the engineering and construction sectors include manufacturing, assembly lines, maintenance and building operations, education and training, monitoring, design reviews and design collaborations (Ghorbani et al., 2024). However, it is also noted that the main use cases for this technology are construction tasks, prefabricated construction elements and assembly lines for manufacturing (Delgado, Oyedele, Demian, et al., 2020).

In the engineering and construction sectors, it is noted that AR use enables users to comprehend complex spatial visual information through a data overlay created using AR technology, thereby enhancing visual communication (Alkan & Basaga, 2023; Rohil & Ashok, 2022). Furthermore, users go from a desktop view to an immersive 3D experience using AR technology, marking a paradigm shift in the conventional way of working (Hajirasouli et al., 2022). Thus, AR technology allows an immersive experience and therefore contributes to improved motivation and engagement (Han & Clevenger, 2025; Schmitt et al., 2025).

Utilising digital transformation with AR technology offers a cost-effective solution that can be tailored to all project sizes (Bórquez et al., 2025). This is a cost-effective long-term solution, as AR technology in the engineering and construction industry allows workers' hands to be

free and therefore allows the continuous execution of tasks without having to go back and forth with drawings (Alkan & Basaga, 2023); this allows tasks to be completed at a faster rate and more accurately utilising the data overlays (Kolaei et al., 2022). In addition, AR technology reduces errors, defects and rework (Alkan & Basaga, 2023; Bórquez et al., 2025; Ghorbani et al., 2024; Han & Clevenger, 2025; Schmitt et al., 2025).

Thus, AR can improve decision-making and problem-solving in the workflow due to real-time data updates (Arvikar et al., 2025; Han & Clevenger, 2025; Kuo et al., 2011).

Utilising AR technology in the construction environment allows mechanical, electrical or plumbing contractors to visualise plans, thereby improving accuracy. It also provides a visual data overlay and can be used as a guide to assist with inspections, enhancing reliability and precision (Bórquez et al., 2025; Tsai et al., 2022). AR technology enables designs to be scaled at a 1:1 ratio, allowing stakeholders to walk through the concepts, in addition to allowing the contractor to monitor the process and reduce errors before building (Rohil & Ashok, 2022). Furthermore, live scheduling ensures that deadlines are met and enables time to be saved, with a reduction in defects (Hajirasouli et al., 2022). Reducing defects helps prevent rework, decreases both the cost and project duration, and ensures that any quality issues are addressed quickly (Hajirasouli et al., 2022).

When it is used in an engineering environment, AR technology improves productivity, as it provides real-time guidance with assembly tasks (Rohil & Ashok, 2022). Many companies use AR technology; for example, Boeing in 2018 reported an increase in productivity of 40% when AR technology was implemented for electrical work (Delgado, Oyedele, Demian, et al., 2020). AR technology can support decision-making by making the user a smarter worker (Yin et al., 2023).

Using AR technology enhances communication. When AR technology is used on site, it enhances collaboration and efficiency among teams and contractors (Arvikar et al., 2025; Han & Clevenger, 2025; Kolaei et al., 2022; Schmitt et al., 2025). This also enhances stakeholder communication by presenting information more effectively with AR technology, fostering a clearer understanding of the project, visually sharing data to help stakeholders understand the end product and ensuring that the project aligns with stakeholders' expectations (Bórquez et al., 2025; Delgado, Oyedele, Demian, et al., 2020; Han & Clevenger, 2025).

AR positively impacts engineering and construction by enabling early problem-solving, facilitating decision-making, identifying design alternatives if needed and enhancing the

safety and quality of the work (Hajirasouli et al., 2022). This allows users to be confident while performing their tasks, as they can make complex decisions based on the visual information displayed (Han & Clevenger, 2025; Kolaei et al., 2022; Sangiorgio et al., 2021). Utilising AR technology allows design issues to be identified early (Han & Clevenger, 2025). AR technology in the engineering sector improves visual communication and aids in reducing complex issues (Rostami et al., 2025); for example, 2D drawings and manual inspections alone do not satisfy the requirements in real-time situations, and there is a risk of old drawings being used (Bórquez et al., 2025; Liao & Luo, 2025)

Integrating AR technology with training can significantly improve safety, as it illustrates the hazard in a risk-free environment (Ghorbani et al., 2024; Rohil & Ashok, 2022). This can also reduce costs, as using AR technology for training can be self-guided (Söbke et al., 2025). Furthermore, using AR technology encourages high motivation, which boosts engagement and speeds up learning (Giancaspro et al., 2025; Söbke et al., 2025).

According to the literature review, the user acceptance of AR technology relies on the perceived added value and a clear return on investment (Ghorbani et al., 2024). The common factors are cost, real-time data and decision support when using AR technology; AR is also user-friendly and easily adaptable, and it seamlessly integrates into workflows, reduces errors, accelerates task completion and requires minimal training (Alkan & Basaga, 2023; Arvikar et al., 2025; Bórquez et al., 2025; Kolaei et al., 2022; Kuo et al., 2011; Schmitt et al., 2025).

There are many benefits of AR technology involved in this literature review, and these have been grouped into 11 categories, as illustrated below in Figure 2.3.

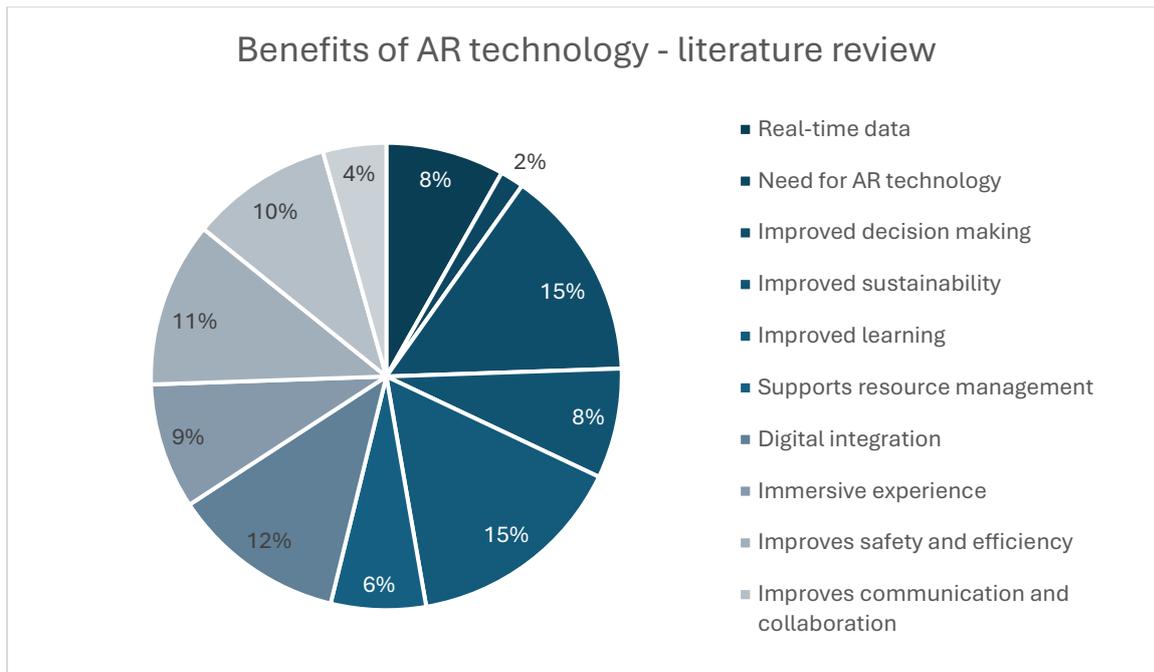


Figure 2.3: Benefits of AR technology

The main advantages of AR technology include improved decision-making, learning and training, digital integration, and increased safety and efficiency. Real-time data are classified separately because they represent a distinct aspect, as their benefits can also be linked to other categories, as shown in the literature review (Arvikar et al., 2025; Bórquez et al., 2025; Delgado, Oyedele, Demian, et al., 2020; Hajirasouli et al., 2022; Han & Clevenger, 2025; Liao & Luo, 2025; Rohil & Ashok, 2022; Tsai et al., 2022; Yin et al., 2023), highlighting real-time data's significance in the adoption of AR technology. Therefore, a key reason for AR technology benefits is the accessibility of real-time data.

The user acceptance category indicates how users engage with AR technology, and the benefits of this group include ease of use, accessibility, reduced cognitive load, and increased motivation (Arowoia et al., 2021; Delgado, Oyedele, Beach, et al., 2020; Hajirasouli et al., 2022; Han & Clevenger, 2025; Kolaei et al., 2022; Rohil & Ashok, 2022; Yin et al., 2023). This outcome highlights that ease of use and perceived usefulness are key advantages of integrating AR technology in engineering and construction projects.

Communication and collaboration represent another key benefit that emerged as a leading category. This benefit involves collaboration, improved stakeholder alignment, enhanced visual communication, and better coordination (Arvikar et al., 2025; Delgado, Oyedele, Demian, et al., 2020; Han & Clevenger, 2025; Harikrishnan et al., 2021; Kolaei et al., 2022; Oke & Arowoia, 2021). AR technology helps shift communication to a visual spatial format.

Safety and efficiency benefits were consistent across the AEC, engineering, and construction sectors. The main benefits include reduced defects, improved awareness, enhanced accuracy, increased productivity, and a reduction in workplace safety incidents (Alkan & Basaga, 2023; Arvikar et al., 2025; Bórquez et al., 2025; Delgado, Oyedele, Demian, et al., 2020; Hajirasouli et al., 2022; Han & Clevenger, 2025; Harikrishnan et al., 2021; Kolaei et al., 2022; Oke & Arowoia, 2021; Rohil & Ashok, 2022; Schmitt et al., 2025; Tsai et al., 2022; Yin et al., 2023).

Digital transformation and immersive technology highlight the connection between physical and digital systems. The benefits associated with this include the reduction of interpretation errors, enhanced decision-making, and increased situational awareness (Alkan & Basaga, 2023; Arowoia et al., 2021; Ghorbani et al., 2024; Kolaei et al., 2022; Liao & Luo, 2025; Rohil & Ashok, 2022; Schmitt et al., 2025; Yin et al., 2023).

Resource management is a benefit of integrating AR technology, as it includes reduced project costs and rework expenses (Alkan & Basaga, 2023; Arowoia et al., 2021; Bórquez et al., 2025; Hajirasouli et al., 2022; Harikrishnan et al., 2021; Rohil & Ashok, 2022). Additionally, it enhances compliance and sustainability tracking.

Learning and training are additional benefits linked to AR technology, as this enhances engagement, spatial understanding, and skill development (Alkan & Basaga, 2023; Jiang et al., 2024; Kolaei et al., 2022; Sangiorgio et al., 2020; Söbke et al., 2025). Furthermore, this enhances technical and safety training.

The benefits highlight strong support for AR technology adoption that influences both technical and human factors. This emphasises the main advantages for the engineering and construction industry and the interconnected factors that drive AR technology integration.

2.6 Barriers of AR Technology Adoption

It is also important that when a new technology is introduced, users should be familiar with it. Any process changes and the implementation of new technology should highlight how effectively and efficiently the system is used. Additionally, stakeholders need to be willing to adopt and accept the innovative technology (Oke & Arowoia, 2021).

When utilising AR technology, larger companies tend to have more resources to implement new technologies, while smaller to medium-sized companies often fall behind. Additionally, there are only a few instances where AR technology has been fully utilised in projects (Delgado, Oyedele, Demian, et al., 2020). It is also highlighted that a lack of resources to implement new technologies can lead to their downfall (Hajirasouli et al., 2022).

However, while AR offers benefits, there are some limitations when it is used in the engineering and construction sectors. These include outdoor lighting issues, battery life issues, high costs, clutter on site, device discomfort, cross-platform integration challenges and complex setup times (Alkan & Basaga, 2023; Arvikar et al., 2025; Hajirasouli et al., 2022; Kolaei et al., 2022; Schmitt et al., 2025). There are also significant inconsistencies in the terminology associated with AR technology, which causes confusion and presents challenges, such as confusing AR with VR and MR (Ghorbani et al., 2024).

There is also a lack of standardisation, thus resulting in challenges and the poor implementation of AR technology (Ghorbani et al., 2024; Rohil & Ashok, 2022). With the lack of standardisation comes a lack of materials and resources supporting AR technology (Hajirasouli et al., 2022; Kolaei et al., 2022). Therefore, when AR technology is used, there is a need for effective training (Hajirasouli et al., 2022).

Several limitations still need to be considered with AR technology, such as issues with legacy systems and cybersecurity. Additionally, there could be a loss of metadata in larger files and restrictions on interactivity; all of these factors indicate an immature system (Arvikar et al., 2025; Rostami et al., 2025; Schmitt et al., 2025; Yin et al., 2023).

AR technology has not been widely adopted and is still in development, except for some engineering and construction projects, mainly from larger companies (Arowoiya et al., 2021). It is clear that AR technology has not yet been fully adopted in the engineering and construction sectors, as research is ongoing and gaps are still being identified (Alkan & Basaga, 2023).

2.7 AR Technology Literature Review

A total of 56 pieces of literature have been reviewed, focusing on three key areas: the theoretical perspective, the factors driving the use of AR and the outcomes associated with AR use. This comprehensive review is summarised below. The review is divided into three sections: AR technology in the engineering industry, AR technology in the construction

industry and finally, AR technology in the architecture, engineering and construction (AEC) industry.

2.7.1 AR technology use in the AEC industry literature review

Using AR technology in the AEC sector offers real-time immersive visualisation, which has digitally transformed the industry. The research literature summarised in Table 2.1 outlines that AR technology integration promotes user acceptance, as AR technology provides immersive visualisations that reduce the errors associated with conventional 2D drawings, enable stakeholder collaboration, increase efficiency and enhance decision-making (Alizadehsalehi et al., 2020; Boton, 2018; Chalhouh & Ayer, 2019; Delgado, Oyedele, Demian, et al., 2020). In the AEC industry, it is preferred that the AR technology is integrated with BIM and other information and communication technology (ICT) platforms to enhance decision-making, efficiency, delivery and communication (Boton, 2018; Cheng et al., 2020; Fazel & Izadi, 2018). However, the literature also outlines that there are some limitations regarding training and the maturity of AR systems in the engineering and construction sectors (Kolaei et al., 2022; Mutis & Ambekar, 2019).

Table 2.1: AR technology use in the AEC industry literature review findings

Reference	Theoretical lens	Factors driving AR use	Literature research findings
(Ghorbani et al., 2024)	Architecture, engineering, construction and operations (AECO) industry Taxonomy framework developed Röltgen and Dumitrescu's manufacturing-based AR taxonomy Human and computer interactions	Lack of AR framework Rapid growth in AR technology Support for structured guidance in commercial use	User acceptance Improves communication
(Han & Clevenger, 2025)	Architecture, engineering and construction (AEC) sector Technology acceptance model (TAM)	Complexity in construction projects Real-time data Cost management	AR user acceptance Improved communication and collaboration AR ease of use

(Delgado, Oyedele, Demian, et al., 2020)	AEC sector	Visual communication Collaboration	AR and VR user acceptance
	AR/VR technology	Communication	Proposed framework
	Technology acceptance	Enhance efficiencies	
(Cheng et al., 2020)	AR innovation	Enhance safety	MR use
	AECO sectors	Need for visual communication	
	Information and communication technology (ICT)	Real-time data	Improved accuracy
(Alizadehsalehi et al., 2020)	HCI	Integration of BIM and MR	Improved communication
	Use of MR technology		
	AEC industry	Limitations in BIM	XR use
	XR, AR and VR use	Need for immersive environment	Improved communication
	BIM	Advances in XR	Improved decision-making
(Han & Leite, 2022)	XR use in the AEC sector	Real-time collaboration	XR and BIM integration
	AEC industry	Immersive visualisation	XR use
	XR use	Real-time feedback	Improved data integration
	BIM Technology integration	Decision-making Digitalisation	Improved quality Real-time updates
(Chalhoub & Ayer, 2019)	AEC industry	Automation Real-time data on site	VR and AR interface AR use
	HCI BIM		Improved efficiency Improved data accessibility
	Real-time data for decision-making optimisation		
(Boton, 2018)	AEC industry	Construction inefficiencies	Real-time immersive experience
	Construction planning Management	Complexity in construction projects Limitations in 2D drawings	Improved communication Immersive interaction
	Simulation environment		
	BIM		

(Fazel & Izadi, 2018)	Collaborative decision-making AEC industry	Real-time data	AR overlay use in AEC
	Design and fabrication Constructivist AR use for prototyping	Collaborative workflow Efficacy Accuracy	Improved visualisation Improved accuracy Reduced time
(Mutis & Ambekar, 2019)	AEC industry	Visualisation	AR use
	AR use for design walkthroughs TAM	Communication Time and cost variables Immersive communication	Improved user interface Cloud-based data Lack of training for AR use Device limitations related to battery and weight AR use
(Kim et al., 2018)	AEC industry	Communication in construction	AR use
	Engineering ICT AR user experience	Sustainable practices Real-time data	AR prototype Improved decision-making Improved collaboration User satisfaction
	BIM and AR integration Industry 4.0		
(Chalhoub & Ayer, 2018)	AEC industry	Communication between stakeholders	MR use on electrical systems
	Electrical sector	Ambiguity in 2D drawings	Improved stakeholder communication
	Construction Use of MR in construction and electrical sector	Real-time data Complexity in electrical systems	Improved accuracy Reduction in errors(Lin et al., 2019)
(Lin et al., 2019)	AEC industry	Air flow is invisible so difficulty in understanding	AR system overlay
	Building industry	Sustainable demand	Improved awareness
	Heating, ventilation and air conditioning (HVAC) systems AR use in fluid dynamics for indoor air flow	Technology advancements	Improved decision-making in HVAC systems Real-time data
(Wu et al., 2019)	Investigates mixed reality (MR)	Cognitive learning ability	User acceptance

	Technology is only used in the workforce Limited use is explored at a student level Experience of technology is minimal for young professionals	Skill-based hand skills Ethical standards	
(Elmousalami et al., 2025)	Engineering and construction industry automation	Sustainable development AI integration	Improved sustainability Improved decision-making
(Ahn et al., 2019)	Sustainability AI framework Construction sector	Compliance Cost management Challenges in interpreting 2D drawings	AR use in construction
	Engineering HCI	High errors in interpreting drawings Real-time data	Digital overlay Improved layout accuracy
	Use of AR with projection	Efficiency in construction	Reduction in drawing interpretations
	Minimise need to understand 2D drawings		Improved performance

It can be observed that factors influencing AR use in the AEC sector include duplicates and semantic duplicates. These encompass items such as communication, real-time data, complexity, cost management, and challenges. The above 60 factors driving AR technology use in the AEC sectors can be grouped into 7 groups, including real-time data, communication, efficiency and safety, immersive environment, learning and training, project challenges, and technology advancements. This is illustrated in Figure 2.4.

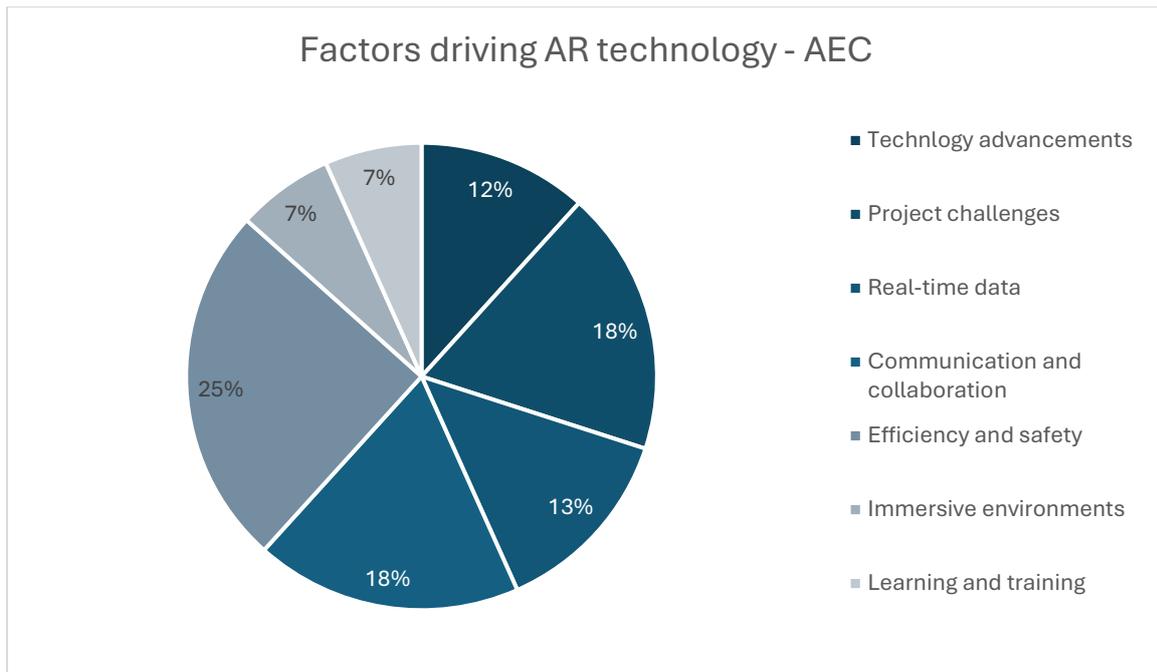


Figure 2.4: Factors driving AR technology use – AEC

It can be observed from the literature review that the main factors driving AR technology in the AEC industry include improved efficiency and safety. Additionally, project challenges, communication, and collaboration are also significant influences.

2.7.2 AR technology use in the engineering industry literature review

AR technology in the engineering sector has become increasingly recognisable, as it offers real-time interactive data and visualisation, bridging the gap between physical and digital assets. The literature review provided in Table 2.2 outlines that using AR technology in the engineering sector improves efficiency, enhances the understanding of complex engineering systems, reduces errors and supports training (Li et al., 2017; Schmitt et al., 2025). Schmitt et al. (2025) find that AR technology in the engineering sector improves efficiency and collaboration; however, it faces challenges related to its cost, complex development and integration within existing systems (Contini et al., 2025; Ong et al., 2020; Palmarini et al., 2018; Tsai et al., 2022). As AR technology is integrated into the current workflow, its use will only expand and become more efficient in the engineering sector.

Table 2.2 : AR technology use in engineering industry literature review findings

Reference	Theoretical lens	Factors driving AR use	Literature review findings
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(De Silva et al., 2019)	<p>AR incorporated with new product development for sustainable growth in business</p> <p>AR is better used in the development stage and to improve product development</p>	New product identification (NPI)	AR technology used, technology useful
(Jimeno & Puerta, 2007)	<p>Industrial and manufacturing industry to incorporate AR</p> <p>The older mentality of the use of AR</p>	Perceived environment	AR technology used, technology useful
(Yusoff et al., 2011)	<p>Based on the technology acceptance model (TAM)</p> <p>Theory: The theory of reason action (TRA)</p> <p>Theory: The theory of planned behaviour (TPB)</p> <p>Theory: Innovation diffusion theory (IDT)</p> <p>Theory: TAM</p> <p>Theory: Unified theory of acceptance and use of technology (UTAUT)</p>	External variables	AR technology used, technology useful
(Ong et al., 2020)	<p>AR can significantly speed up robotic programming tasks</p> <p>AR can reduce the need for expertise</p> <p>AR can theoretically speed up applications</p>	<p>User interaction and play</p> <p>Augmented graphical aids</p> <p>Generation of robot motion</p> <p>Workspace tracking</p> <p>Robot motion planning module</p>	User acceptance
(Torres-Guerrero et al., 2017)	<p>Software engineering is vital for project development</p>	Perspective technique	AR acceptance

(Rostami et al., 2025)	Delphi method of effort – propose a prediction	Effort	
	Aerospace industry	XR technology advancements	XR user acceptance
	Extended reality (XR)	Digital transformation	Improves efficiency
	Cognitive load theory	Improved operational processing	Integration with AI
	Human computer integration (HCI)	Improved safety in training	
	Digital twin theory	Human-centric systems	
(Schmitt et al., 2025)	Milgram’s reality virtual continuum		
	Integration with XR and AI		
	Industrial manufacturing	Real-time data	AR user acceptance
	Communication methods	AR use for hands-free work	Improved speed
	AR use	Immersive interaction	Improved detection of errors
(Cheng et al., 2025)	HCI	Reduce errors	User satisfaction
	Industrial manufacturing		
	Industrial industry	Assembly precision	Virtual replica of an object, differs from AR
	Manufacturing industry	Smart manufacturing	
	Digital twin (DT) theory	Constraints in manufacturing and assembly work	
(Giancaspro et al., 2025)	Real-world manufacturing		
	Visual immersive modelling		
	Engineering sector	Immersive environment	Immersive AR use
	Educational environment	Mobile AR technology	AR improves learning
	Constructivist theory	Mathematical concepts to learn	
Motivational learning with AR technology			
Visual communication for learning			

(Contini et al., 2025)	Engineering sector	Sustainable designs for production lines	Improved accuracy
	Manufacturing industry	User-friendly automated system	Improved usability
	Design production systems	Immersive real-time feedback loop	Improved performance
	Ergonomic efficiency AR and VR to support real-time simulation		Reduce errors
(Nalbant & Uyanik, 2021)	Engineering sector	Growth in digital technology	XR use
	David Marr's and Larry Roberts' early theories for computer vision principles	Real-time simulation needs	Immersive experience
	Extended reality (XR)		Multi-layer framework
	HCI Digital twin Blockchain AI integration		
(Jiang et al., 2024)	Education sector	Engagement in learning	AR use in education in STEM
	Science, technology, engineering and mathematics (STEM)	Cost management	Improved learning
	Constructivist learning	Challenges in STEM	
		Immersive interaction	
(Tsai et al., 2022)	Manufacturing industry	Real-time visualisation	AR with digital twin integration
	Engineering sector	AR with AI	Implementation is a challenge
	AR technology		
	Digital twin framework Collaboration between automation and user		
(Lee & Akin, 2011)	Maintenance industry	Real-time need for maintenance information delivery	AR use in maintenance
	Industrial operations	Complexity in equipment systems	Immersive communication
	Engineering sector		Real-time overlay
	AR use in maintenance, inspections and troubleshooting		

(Palmarini et al., 2018)	AR use for task information		
	Maintenance industry	Hands-free work	AR use
	Engineering	Real-time information	Improved productivity
	Aviation, manufacturing, military and automotive	Reduction in training	Improved accuracy
(Angrisani et al., 2020)	TAM	Integration with digital twin	Improved decision-making
	HCI	Safety	Reduction in errors
	Literature review		
	Manufacturing sector	Enhanced accuracy	Brain computer interface (BCI) integrated wearable AR system
(Ibáñez & Delgado-Kloos, 2018)	Industrial sector	Worker efficiency	Improved efficiency
	Engineering	Reduce thinking	Reduction in stress
	HCI	Real-time monitoring using AR	
	Industry 4.0		
(Baek et al., 2019)	Optimise tasks and performance		
	AR technology		
	STEM industry	Immersive learning environment	Improved learning
(Li et al., 2018)	AR use in learning	STEM concepts	Improved engagement
	Constructivist	Engaging	STEM understanding
	Building industry	Collaborative	AR user interface
	Facilities	Situational awareness	AR system use in facilities
(Li et al., 2018)	Operations and maintenance	Real-time accuracy	Real-time data
	Engineering	Reduction in human error	Immersive information
	AR system integration		Reduction in delays
	Improved accessibility		
(Li et al., 2018)	Simultaneous localisation and mapping (SLAM) technique for AR use		
	Manufacturing industry	Real-time data	AR use
	Engineering	AR use across locations	Prototype system
	HCI	Collaborative	Real-time interaction
(Li et al., 2018)	AR use for decision-making	Problem-solving	Improved task efficiency
	AR use for tasks		Improved accuracy

(Deshpande & Kim, 2018)

Manufacturing industry
 Mechanical assembly
 Engineering
 Education industry
 AR use for problem solving in assembly production

Efficient training
 Technology alignment
 Real-time data

Improved problem-solving
 Improved time on the assembly line
 Reduction in errors
 Improved efficiency
 User satisfaction

It can be observed that factors influencing AR use in engineering include duplicates and semantic duplicates. These encompass items such as real-time data, collaboration, perceived usefulness, immersive interaction, and training. Additionally, further categorising the factors driving AR technology can help identify which benefits are considered more important than others. Figure 2.5 outlines the 8 groups derived from the 72 factors driving AR use in the engineering sector.

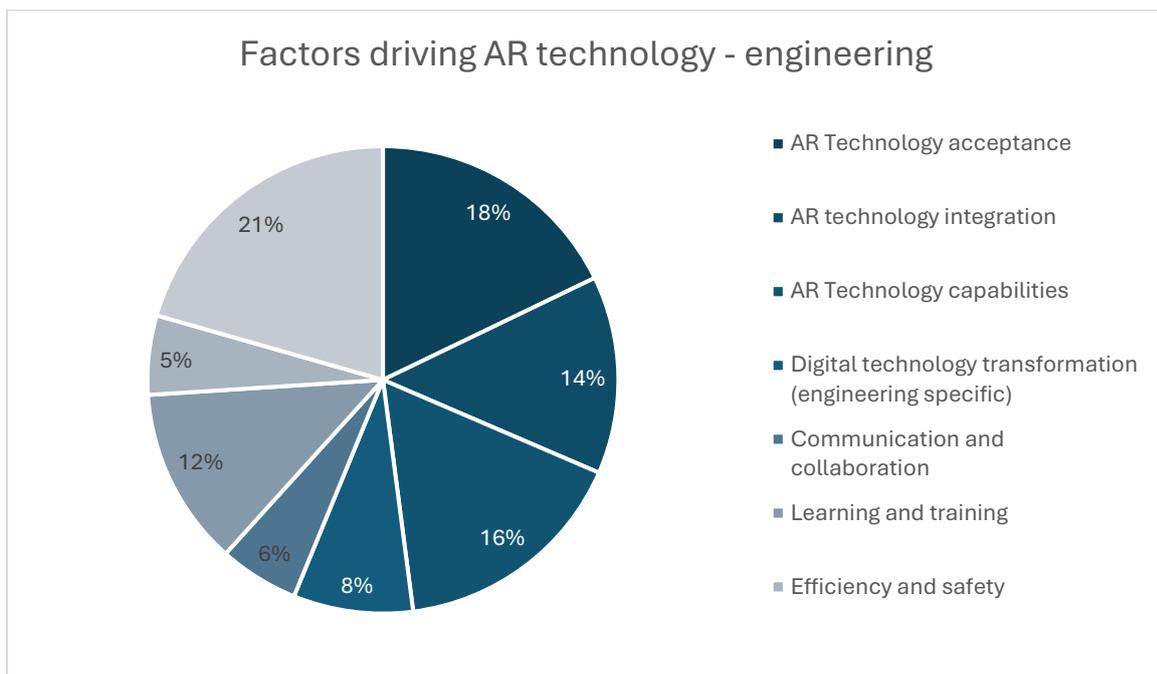


Figure 2.5: Factors driving AR technology use – engineering

It can be observed from the literature review that the main factors driving AR technology in the engineering industry include improved efficiency and safety, followed by AR technology acceptance and AR technology capabilities, which also have a significant influence.

2.7.3 AR technology use in the construction industry literature review

The construction industry is rapidly integrating AR technology into its current workflow. Utilising AR technology in construction provides an immersive, real-time visual data overlay. The research literature, as outlined in Table 2.3, shows that AR technology provides accuracy and streamlines processes by detecting defects and monitoring progress, resulting in fewer errors and better collaboration with stakeholders (Arvikar et al., 2025; Bórquez et al., 2025; Liao & Luo, 2025). It is evident that using AR for training in the construction industry to develop skills is highly effective (Yunus et al., 2025), and integrating AR technology with BIM and the internet of things IoT results in an increase in accuracy and efficiency (Bórquez et al., 2025). However, limitations still exist with AR technology in the construction industry, including its incompatibility with outdoor settings and challenges in integrating it with existing systems (Arvikar et al., 2025; Harikrishnan et al., 2021).

Table 2.3 : AR technology use in the construction industry literature review findings

Reference	Theoretical lens	Factors driving AR use	Literature review findings
(Alizadehsalehi & Yitmen, 2019)	AR solves that problem before the execution phase AR increases motivation Understands the design and process better	Perceived usefulness Easy to learn Easy to adapt in the real world Increases creativity	AR technology used, technology useful User acceptance
(Didehvar et al., 2018)	Kolmogorov-Smirnov approach Promote technology and project management success Barriers and drivers in technology acceptance	Perceived usefulness Behaviour Ease of use Task attributes Company attributes Technology attributes Stakeholders	User acceptance
(Liao & Luo, 2025)	Construction and building sectors AR technology adoption Machine learning	Construction defect reduction Environmental aspects Real-time integrated solutions	Performance improvements User acceptance of AR BIM acceptance

	Computer science principles used in engineering BIM modelling Information visualisation	AR technology and BIM	Real-time modelling systems
(Bórquez et al., 2025)	Construction industry HCI	Inefficiency of using manual tools for inspections Automation in real time	User acceptance Improved efficiency
	Construction automation	AI and AR capabilities	Improved speed with inspections, accuracy and data
(Arvikar et al., 2025)	AR user ability Construction industry	Alignment	AR use
	BIM	Real-time construction progress	Improved decision-making
	AR mobile platform in construction Lean processes Digital visualisation Scheduling integration	Efficiency in construction	Improved communication Risk mitigation
(Yunus et al., 2025)	Construction, welding industry	Visual communication of learning for students	AR use with Immersive learning
	Constructivist theory	No need for materials	Improved knowledge
	Framework AR use for learning	Cost management	Cost reduction of materials
(Li et al., 2018)	Construction sector	High risk and injury in the construction sector	AR use
	Immersive learning	Safety training limitations	Hazard awareness
	AR use in construction	Cost management	Immersive experience in training
		Real-time monitoring	
(Sangiorgio et al., 2020)	Construction sector	Evaluate design	AR use for decision-making
	AR use for decision-making Immersive interactions	Cost management Sustainability	Real-time feedback Improved design accuracy Improved collaboration
		Real-time use	
(Alkan & Basaga, 2023)	Construction industry Assembly phase	Complexity in the construction industry Real-time use	AR use Real-time feedback

(Kolaei et al., 2022)	Construction processes	Digital transformation	Improved accuracy
	AR use for guidance	Reduction in resources	Improved workflow
	TAM Construction industry	Real-time data	Immersive communication
	AR use on site in the construction phase	Minimised defects	Improved accuracy
(Delgado, Oyedele, Beach, et al., 2020)	TAM	Complexity of interpreting 2D drawings	Reduced delays
	Construction sector	Need for real-time communication	Training needs AR and VR use
	AR and VR use in the construction industry	Collaboration	Improved productivity
(Harikrishnan et al., 2021)	TAM Communication		Improved communication
	Construction sector	Need for real-time, immersive communication	Improve communication
	Communication	Challenges with 2D drawings	Improve designs
	TAM	Digital transformation	Reduce miscommunication
(Soto et al., 2022)	AR use Constructivist theory Construction industry	Increase numbers of cyber attacks	Cyber security is poorly incorporated Urgent need for standards
	Cyber security	Digital adoption	
	Risk management Increasing use of smart technology BIM	Digital awareness	
(Li et al., 2018)	Construction sector	Real-time safety	Improved safety awareness
	Construction safety	Enhanced safety training	Improved training effectiveness
	TAM	Immersive interaction	Reduction in safety incidents
(Chen et al., 2011)	HCI Training Construction industry	Safety	Improved safety
	HCI	Situational awareness	Real-time detection
	Machine learning	Communication	Collision risk reduced
	AI and AR integration	Real-time data	

(Ahmed, 2018)	Construction sector	Communication	Immersive visualisation
	Project management	Collaboration	Improved training
	TAM	Safety	Improved real-time data
	Innovation in construction	Training	Improved decision-making
	AR user interface	Real-time decisions	Improved stakeholder engagement
(Moore & Gheisari, 2019)	Industry 4.0		
	BIM		
	Digital twin		
	Construction industry	Reduce incidents	AR use for safety training
(Moore & Gheisari, 2019)	Occupational health and safety (OHS)	Real-time data	Prototype system used
	TAM	Ergonomic	Improved hazard recognition
	AR use in OHS	Training to be immersive	Improved decision-making
	Workplace safety training	Reduce workplace incidents	AR user acceptance
(Malagnino et al., 2022)	Learning through experience	Cost management	Hazard identification
	AR training	Safety training	Hazard awareness
	TAM	Hazard identification	Hazard identification
	Fire safety training	Cost management	AR use system for training
	Education	Educational purposes	Improved knowledge and learning
	Immersive learning through AR to support training		Improved performance

It can be observed that factors influencing AR use in construction include duplicates and semantic duplicates. These encompass items such as real-time data, communication, cost management, and perceived usefulness. The 69 factors driving AR use can be further grouped into 7 categories. These include real-time data, communication, project challenges, efficiency and safety, digital technology integration, and learning and training, as outlined in Figure 2.6.

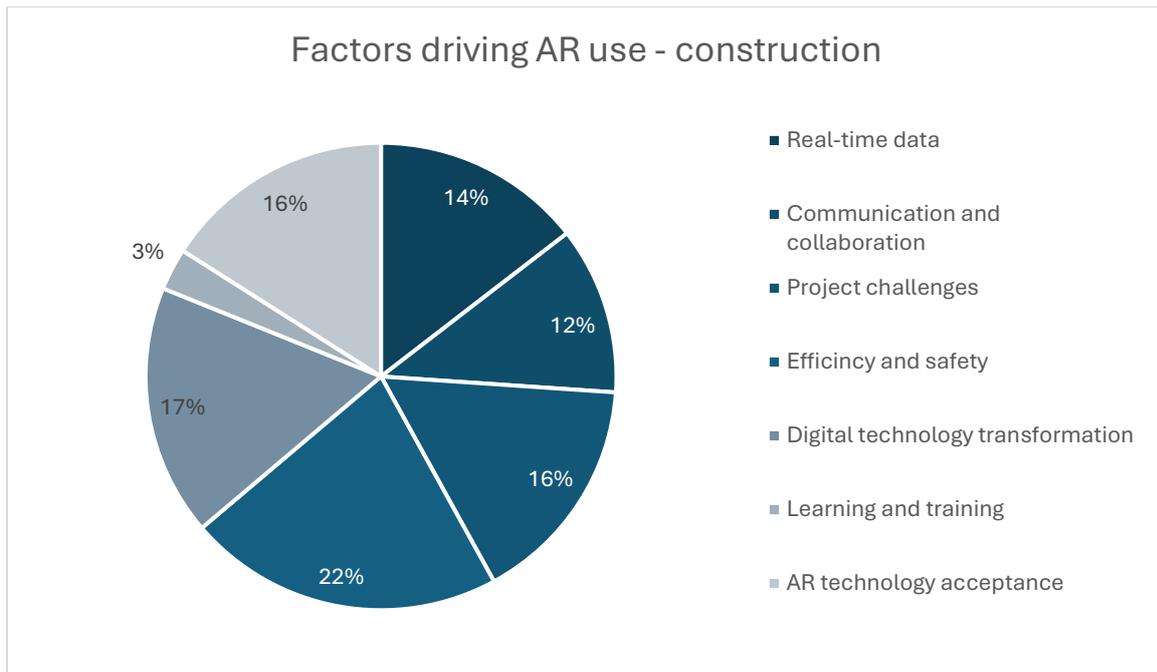


Figure 2.6: Factors driving AR technology use – construction

It can be observed from the literature review that the main factors driving AR technology in the construction industry include improved efficiency and safety, followed by project challenges and real-time data, both of which have a significant influence.

2.8 Gap in the Literature

The three stages of the literature review assisted in finding the gap in the literature. First, a literature review of the factors impacting the user acceptance of technology was conducted. This included digital transformation in all project types, typically in the AEC sector. Second, a literature review regarding factors that impact the user acceptance of AR was conducted. This research identified types of AR technology for all project types. Finally, the literature regarding factors impacting the user acceptance of AR in engineering projects was reviewed. All three areas were analysed and compared to outline the areas that have been studied, with all technologies and all project types, in comparison to AR and engineering projects. Many researchers have explored the factors impacting the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010). However, the gap highlights a lack of qualitative research that provides a comprehensive understanding of the drivers of the user acceptance of AR technology in engineering and construction projects, as well as their dynamics. Therefore, the aim of the research is identifying the performance and outcomes of the user acceptance of technology in engineering projects.

The literature review of the use of AR technology in engineering and construction projects included 56 studies. The literature review included literature on AR technology adoption and implementing digital innovation in engineering and construction projects. The literature review focused on the benefits and challenges of integrating immersive technology in these sectors.

Upon reviewing the literature and research to identify the gap, it has been found that there is:

- A lack of real-world validations for AR technology in the literature;
- Technical limitations and immaturity in the development of a standardised system for AR integration;
- Training and skill gaps;
- A lack of a comprehensive framework for integrating AR technology;
- Perception of AR technology with maturity and cost;
- Inconsistent terminology of AR Technology;
- Limited research on AR systems tested on real-world projects;
- A lack of knowledge and understanding of AR technology in projects (Hajirasouli et al., 2022);
- An established methodology for AR technology has not yet been integrated into large real-world environments (Sangiorgio et al., 2020);
- AR technology in the construction sector has not been fully embraced (Alkan & Basaga, 2023).

It is noted that the main gap in this research is the perception that the engineering and construction sectors find AR technology unsuitable, immature and expensive to implement (Delgado, Oyedele, Beach, et al., 2020). This is due to the level of accuracy required to utilise AR technology in the engineering and construction sectors, and current AR technology is often found to be unsuitable (Delgado, Oyedele, Beach, et al., 2020). In addition to the maturity of AR technology, there are also limitations related to the integration of other systems, the performance of cross-platform systems, low-resolution outputs and issues with real-time data; these limitations are related to immaturity in AR technology (Schmitt et al., 2025).

There are also inconsistencies in the terminology related to AR technology, which is often confused with MR and VR. Therefore, there needs to be standardisation in immersive digital technologies; this standardisation should be clearly articulated and communicated using a general framework outlining these differences (Ghorbani et al., 2024). There is also a lack of

understanding regarding AR technology and its performance output in the construction sector. It would be beneficial to establish guidelines that encourage this industry to adopt AR technology to address this issue (Han & Clevenger, 2025).

Therefore, it is noted throughout this literature review that there needs to be more research regarding AR technology in real-world environments to fully identify the limitations and inconsistencies that are referenced in the literature. There is also a lack of an integrated solution for AR technology and BIM systems to support construction projects (Liao & Luo, 2025).

There are minimal studies on how companies can use AR technology that outline the benefits and issues of AR (Delgado, Oyedele, Demian, et al., 2020) and how to interpret project management and technology management issues when incorporating AR technology (Delgado, Oyedele, Demian, et al., 2020).

There are also limited advancements in the engineering and construction sectors due to their inability to embrace digitalisation (Alkan & Basaga, 2023). Therefore, this technology requires further investigation and remains immature; a complete system and framework have yet to be developed (Delgado, Oyedele, Demian, et al., 2020; Kolaei et al., 2022; Sangiorgio et al., 2020).

2.9 Conclusion

The literature indicates that AR technology, along with other immersive technologies, can benefit engineering and construction projects by enhancing communication, efficiency, design, prototyping and 3D modelling. AR technology is commonly used for 3D modelling, real-time data visualisation, visual communication, immersive experiences and interactive workflows.

However, along with these benefits, there are some challenges. The literature outlined that many organisations lacked AR training and processes for implementing new technologies. It is also noted that organisations that incorporate new immersive technologies are more likely to use AR technology as long as there is a benefit. There is also a lack of commercial standardisation for AR technology and concerns about cybersecurity. The literature review outlines that there is a gap when it comes to successfully incorporating AR technology.

This chapter examines the current literature on AR technology within the engineering and construction industries. It reviews existing research and offers a foundational framework for this study. This chapter builds on the introduction from Chapter 1, which outlines the background of AR technology and its applications in these sectors. The literature review is followed by the description of three methodologies in Chapter 3, which details the research approach used for studying AR in engineering and construction. Data analysis is described in Chapter 4, where findings based on grounded theory are presented. Chapter 5 discusses these findings and explores the research questions, while Chapter 6 offers a summary of the key conclusions.

Chapter 3: Research Methodology

The research methodology chapter covers the methods employed in the thesis, including the research paradigm, the research approach, and the research method. This chapter outlines a detailed data analysis methodology for grounded theory and explains how the DeLone and McLean information systems success model was integrated into this approach. Additionally, the chapter discusses the research procedure used and addresses the ethical risks involved in the study.

3.1 Overview

The research methodology chapter outlines the approach used in this thesis. This research includes a detailed methodology that explains the theory applied to analyse the data obtained. The study details the research paradigm and approach. In addition, it outlines the ethical requirements for data collection and the ethical risks associated with the research, including occupational health and safety considerations for data collection. The study also explains the data processing and research procedures, describing how the research was conducted.

All participants in this research came from three different areas, consisting of individuals in the engineering and construction sectors and software developers who created AR technology. The participant selection criteria were based on a theoretical sampling process; the participants consisted of either developers, users of AR technology or individuals who engaged with AR in their organisation or field.

Constructivist epistemology is utilised in this research, which includes an interpretivist, qualitative approach, with the incorporation of grounded theory to analyse the data. The data analysed outline the dynamics of user acceptance for AR technology in the engineering and construction sectors. The data collection performed for analysis involved an open-ended survey questionnaire, and the interview process followed a semi-structured approach.

The grounded theory approach process involved several steps, including formulating the research question, collecting data through theoretical sampling, identifying open codes, axial codes and selective codes, and subsequently developing a theory. Throughout this process, continuous data analysis was conducted alongside memoing to identify relationships to construct the theory.

3.2 Research Methodology

In this research, interviews, focus groups and questionnaires were used as part of a qualitative method supported by a constructionist approach to answer the research question. The overall goal in this research is to answer the following question: What are the dynamics of the user acceptance of AR technology in engineering projects?

Many researchers have explored factors related to the user acceptance of AR technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010). However, the literature has identified a lack of qualitative research providing a comprehensive understanding of the drivers of the user acceptance of AR technology in engineering and construction projects and their dynamics.

Therefore, the primary objective of this research is to identify the drivers of the user acceptance of technology and the factors that contribute to it. Previous research has lacked the ability to incorporate the usefulness of AR technology and the surrounding environment within the project scope to foster technology acceptance effectively. By utilising grounded theory, a theoretical approach to the methodology is used in addition to a systematic methodology involving a combination of theories and data analysis (Crotty, 1998; Levers, 2013). The grounded theory method, through a series of events, can identify a theory based on the analysed data (Crotty, 1998).

There are many grounded theory methodologies in social research (Crotty, 1998; Glaser, 1978, 1992, 1996, 1998; Glaser & Strauss, 1967). Therefore, regarding the identified research question – ‘what are the dynamics of the user acceptance of technology in engineering projects’ – it can be said that the theory may change and evolve once all the data have been analysed. Glaser and Struss (1976) outlined that the grounded theory method has three qualities that differentiate it from other types of methods. These include that it must conform to the data, be applicable to the data and work with the data. However, a fourth quality was added: it must be modifiable (Glaser, 1978).

It is acceptable to say that grounded theory outlines the developed result through data analysis and social processes (Crotty, 1998; Glaser, 1978, 1992, 1996, 1998; Glaser & Strauss, 1967). Thus, it is acceptable to integrate it with the current research. Considering that previous research has explored factors related to the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010), in the literature, there is a lack of qualitative research providing a big

picture of the drivers of the user acceptance of AR technology in engineering and construction projects and their dynamics. Therefore, the use of grounded theory is relevant to the research, with the goal of ultimately supporting specialists in the adoption of new technologies with project management resources to help organisations deliver projects satisfactorily.

The theoretical perspective, also known as the research paradigm, is an interpretivist approach to this research. Levers (2013) identifies interpretivism as an approach that involves the interpretation and analysis of data. This theoretical perspective identifies the action, experience and interpretation of the participant; therefore, it is defined by understanding the phenomenon through defining the research interpretations and observations in terms of value and theory (Levers, 2013). With the incorporation of interpretivism, the next question to ask is the following: What research approach is best suited to answer the research question?

A qualitative research approach has been utilised in this research, as qualitative and interpretivist research methods work well together. This provides a fundamental overview of the research descriptively, allowing the research questions to be explained in a descriptive manner. A qualitative approach is a descriptive method that provides a complete, holistic view (Ponelis, 2015).

The use of interpretivism as the research paradigm, integrated with a qualitative approach, allows the research question to identify the research problem. Grounded theory was used to interpret and analyse the data, therefore identifying any themes that develop (Levers, 2013). This will outline the identified gap from the research, leading to a theory. This approach will enable the theory to be identified and developed from the data obtained from the research question (Levers, 2013), and allows the research to be modified.

This research includes an interpretivist, qualitative approach with the incorporation of grounded theory. Grounded theory is used to analyse the data, and the data used for this research are primary data collected through questionnaires, interviews and focus groups.

3.3 Research Paradigm

The research methodology is used to identify 'how' and 'why' projects succeed with the aid of technology through user acceptance. Furthermore, when identifying AR technology, the aim is to determine how AR technology differs in use in engineering- and construction-type

projects compared to other projects not in this field. The question posed is the following: How does AR increase project success, and can this contribution be defined and measured? Therefore, the research requires data from the engineering and construction sectors concerning the use of AR technology. In addition, it needs information from software developers who create AR technology.

It can be said that AR technology for engineering and in new project development is more about real-time automated processes rather than simulations (Alizadehsalehi & Yitmen, 2019; De Silva et al., 2019). This recognises that AR technology provides a real-time advantage, and this is not confined solely to the engineering and construction sectors. However, when individuals were interviewed regarding the limitations of this technology, it was mentioned that AR availability and training are necessary, although it can be argued that the AR experience of technology is minimal for young professionals (Ong et al., 2020). On the contrary, users who identified with using this product stated that minimal training is required.

The data method utilised for this research is dependent on answering the research questions. The research paradigm incorporated in this study is interpretivism. The use of interpretivism allows interpretation and data analysis (Levers, 2013). Interpretivist principles focus on the participants' movements, knowledge and opinions (Levers, 2013). The interpretivist paradigm is defined by identifying research observations and interpretations based on their value and knowledge and therefore understanding the phenomenon that is transcribed and correlates with the overall framework (Levers, 2013).

There has been extensive literature on the research paradigm. Crotty (1998) noted that there are four elements that should be considered when defining research. The four elements include epistemology, the theoretical perspective, the methodology and the methods (Crotty, 1998), as detailed below:

1. Epistemology should contribute to the theoretical perspective;
2. The theoretical perspective identified follows the methodology;
3. The methodology chosen directs the method.

Figure 3.1 outlines the research methodology for this research, which is further detailed below.

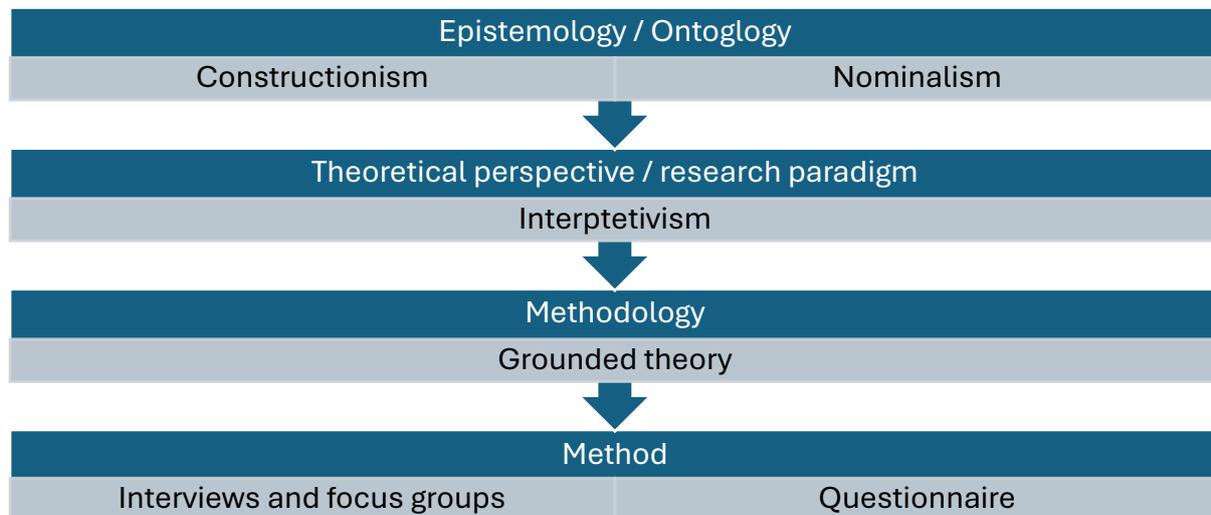


Figure 3.1: Research methodology for this thesis

Epistemology is defined as how we know things (Crotty, 1998) or as a theory of knowledge (Walliman, 2006). Crotty (1998) identifies a range of epistemologies. First, objectivist epistemology is defined as a reality that exists both inside and outside of consciousness (Crotty, 1998). Constructionism epistemology, on the other hand, is defined as the view that there is no objective truth waiting to be discovered; however, it is waiting to be constructed (Crotty, 1998). Lastly, there is subjectivism, an epistemology that falls somewhere between objectivism and constructivism, where meaning or knowledge is created (Crotty, 1998). Epistemology and ontology tend to surface alongside each other. Ontology is defined as a theory of social entities (Walliman, 2006) or the existence of things (Crotty, 1998). Crotty (1998) identifies realism as the reality that exists outside of consciousness, similar to constructivism and idealism, where reality is perceived as existing within consciousness. As constructivist epistemology is incorporated into this research, it needs to be reflected in the research paradigm.

Table 3.1, which contains the taxonomy of research paradigms (Crotty, 1998), is used to ensure the reliability of the research. This requires the justification of the methodology implemented, thus recognising the theoretical assumptions that underpin the research findings (Crotty, 1998). It is important to identify the research method; in this research, interviews, focus groups and open-ended survey questionnaires are used. The description of the interview process outlines the techniques used, the settings, the observations and how focused or involved the participant is (Crotty, 1998). Regarding the open-ended survey questionnaire, this process can be completed at any location of the participant's choosing.

Grounded theory outlines and proposes the outcome. It also generates a conceptual framework (Charmaz, 2006) and involves a phenomenon being observed (Tarozzi, 2020). When utilising grounded theory, the fit between the data and the theory needs to be adequate; the theory also needs to be relevant to the research area that is being investigated. Additionally, the theory must be useful and work in the context of the research, and lastly, the theory needs to be modifiable, so that new data can be integrated into the findings (Tarozzi, 2020).

Regarding investigating the types of research paradigms to use for this research, according to Crotty (1998), the theoretical perspectives are positivism, interpretivism, critical inquiry, feminism and postmodernism. When identifying which approach to social science would be beneficial to research in relation to technology, the work of Neuman (2014) is useful. Table 3.1 provides a summary of the different methods of social science described by Neuman (2014). Note that Neuman (2014) recognises critical inquiry as critical social science.

Table 3.1: Summary of approaches to social science (Neuman, 2014)

	Positivism	Interpretive social science	Critical social science	Feminism	Postmodernism
1. Reason for research	- Discover natural laws - Predict events - Control events	- Social action is understood and described	- Smash myths - Empower people - Change society	Empower people: - Advance values - Nurture others - Equality	Express one-self: - Playful - Entertain - Stimulate
2. Nature of social reality	- Stable preexisting patterns - Discovered order	- Human interaction created fluid definitions	- Multiple layers - Hidden underlying structures	- Gender-structed - Power relations - People oppressed	- Chaotic - Fluid - No plan - No terms
3. Human nature	- Self-interested - Rational individuals shaped by external force	Individuals who: - Create meaning - Make sense of their world	- Creative - Adaptive people - Unrealised potential - Trapped - Illusion	Gendered beings: - Unrealised potential - Trapped - Unseen forces	- Creative - Dynamic - Unrealised potential
4. Human agency	- Illusion of free will - Action shaped by	Individuals who:	- Bounded autonomy - Free choice	- Structural limits based on gender	- Great volition - All structures are illusionary

	external social pressures	- Have significant volition	- Develop meaning	- Have freedom	- Make choices	Structurally limited	Limits can be moved	Confined choices	New thinking	Breach limits											
5. Role of common sense	- Less valid than science	- Distinct	Ordinary people:	- Use powerful everyday theories	False beliefs	- Hide power	Objective conditions	False beliefs	- Hide power	Objective conditions	Essence of social reality:	- Superior Scientific	- Bureaucratic forms of reasoning								
6. Theory looks like	Logical deductive system:	- Definitions interconnected	- Axioms	- Laws	Logically connected:	- Laws	- Facts	A group meaning system:	- Generated	- Sustained	- Described	A critique: Reveals true conditions	- Helps people take action	A critique: Reveals true conditions	- Helps people see a better world	A	performance or expression:	- Amuse	- Shock	- Stimulate	
7. An explanation that is true	- Laws	- Facts	Logically connected:	- Laws	- Facts	The individuals who are being studied:	- Resonates	- Feels right	Helps individuals with tools to change the world	Supplies ideas	- Supplies tools	- Helps liberate people from oppressive relations	No one explanation is true	All is true for those who accept							
8. Good evidence	- Precise observations	- Others can repeat	Precise observations	- Others can repeat	Integrated in the context of fluid social interactions	Informed by a theory:	- Penetrates the surface	Theory that has gender structures	- Has aesthetic properties	- Resonates with people	- Inner feelings										
9. Relevance of knowledge	- Instrumental observations	- Knowledge enables individuals to control events	Instrumental observations	- Knowledge enables individuals to control events	Practical orientation used:	Knowledge helps	- Share	- Empathetic	- Life worlds	- Experiences	Dialectical orientation is used:	Knowledge	- See deeper	- Alter deeper structures	Knowledge raises awareness	- Empowers people	- Makes change	Formal knowledge	- No special value	- Can amuse	- Bring enjoyment
10. Place for values	- Science is value-free	- No place for value except if there is a topic	Science is value-free	- No place for value except if there is a topic	Integral social life values:	- No wrong values in groups	- Only different values	Value position on all science	- Some right	- Some wrong	Values are essential	- Feminist ones preferred	Values are integral to research	- Value positions are equal							

The word 'paradigm' is defined as an alignment of theory and research (Kuhn, 1970). In a scientific approach, this is acknowledged as a comprehensive method of thinking, including the assumptions made, the type of research methods utilised and the questions that need to be answered (Neuman, 2014). Therefore, with regard to paradigms, the positivist social science approach is the most widely used and oldest approach; interpretive and critical social science have existed for more than a century. Lastly, feminist and post-modern social science are the two newest techniques (Neuman, 2014).

There are three major approaches to social science: interpretive, critical and positivist. With positivist social science being the oldest of the social sciences, there have been as many as twelve varieties of this paradigm (Crotty, 1998). Therefore, there has been an evolution of positivism, as depicted by positivism and post-positivism (Crotty, 1998). However, positivist social science is an approach in social science that draws on natural science to uncover causal laws, make observations and conduct value-free research (Neuman, 2014). The positivist approach suggests that there is a cause-and-effect correlation that is derived from a causal law (Neuman, 2014).

The primary purpose of critical social science, or critical inquiry, is to change the social world by identifying the fundamental foundations of social control, interpersonal interactions and inequity, thus empowering people (Neuman, 2014). Critical social science recognises that beliefs, philosophies and our own opinions impact how we perceive observations (Neuman, 2014). Critical social science defines social science as a way of making a better world by helping people change circumstances through identifying real truths that go beyond the misconceptions of reality, contesting exploitation and empowering individuals (Neuman, 2014).

All social science approaches have different ways of addressing research questions. Table 3.1 (Neuman, 2014), which summarises the various approaches in social science, provides a holistic view. Despite their differences, these approaches focus on a common goal: methodically producing theoretical knowledge through investigation (Neuman, 2014).

To identify the paradigm to use, an analysis was conducted. First, the research takes place in the engineering, IT and technology disciplines, focusing on the identification of the dynamics of the user acceptance of technology, specifically augmented reality for engineering and construction projects. Therefore, the appropriate method for this research is interpretivism.

The interpretivist paradigm aims at classifying meanings and interpretations (Walliman, 2006). Interpretivists value and focus on the participants' personal actions, experiences and viewpoints (Levers, 2013). The process for interpretivism is based on using judgment and principles to understand social and human experiences (Crotty, 1998). The interpretivist paradigm involves comprehending a phenomenon by describing all the research interpretations and observations in terms of value and theory, thereby outlining the explanation of the overall and complete framework (Levers, 2013).

Extensive research has explored factors related to the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010), but it is evident in the literature that there is a lack of qualitative research providing an understanding of the drivers of the user acceptance of AR technology in engineering and construction projects, as well as their dynamics. Therefore, when addressing the research question – ‘what are the dynamics of the user acceptance of technology in engineering projects’ – some considerations and fundamental questions regarding technology have been considered, including the following:

- How do we identify the theory of the user acceptance of technology?
- What are the barriers to and facilitators of the user acceptance of technology?
- What is the fundamental baseline of the user acceptance of technology?
- What are the lessons learned about the user acceptance of technology?
- Can this theory be demonstrated?

These questions generate complexity and the representation of purpose. Therefore, they can be addressed with interpretivism.

The aim of using interpretivism in this research is to understand the theory behind the user acceptance of technology in engineering- and construction-type projects, as well as to understand how different individuals adhere to this context. Social settings and an analysis of language and its meaning, along with the identification of relationships within this context, can be employed to enhance project success. It can be said that the interpretivist approach to this research involves seeing things from the participants' point of view through interpretation and their experiences. This paradigm describes the participants' lived experience of using or thinking about using this technology.

The purpose of using the interpretivism paradigm is to gather data to provide an interpretive clarification of the theory, thus revealing social reality from another person's perspective by

revealing their interpretation, significance and principles (Crotty, 1998). Therefore, regarding technology and user acceptance, Didehvar et al. (2018) identify that project failure due to poor project management and performance can be reduced by encouraging management to use technology, which increases project success. Thus, it can be seen that the interpretivism approach can be used for this research in the technology field, as it can identify different perspectives and the environment in which technology is used and where the influence of management can be observed.

The primary data used for this research and data collection incorporate interviews, focus groups and open-ended survey questionnaires. The data collected include data from software developers, engineers in leading and management roles, and construction managers and leads. Interviews were one type of qualitative data used in this research, and the interview process followed a semi-structured approach, where a set number of open-ended questions were asked; however, these questions led to the identification of other topics. Questionnaires were another type of qualitative method used in this research. This method was utilised because it allowed the participants to answer questions through Qualtrics without the necessity of speaking with the participants. This is a structured format that is quick and easy for participants to use at their convenience.

The use of interpretivism applies to this research paradigm when considering the research question – ‘what are the dynamics of the user acceptance of technology in engineering projects’. This question is idealistic and can reveal how different people perceive and accept technology. This research paradigm is also relevant to a qualitative approach, as it allows the research question to identify the research problem. In addition, grounded theory is used as the methodology to allow the research to be modified as the theory develops. The grounded theory approach is employed to analyse the data, and the data collection for this research consisted of primary data gathered through questionnaires, interviews and focus groups.

3.4 Research Approach

Grounded theory generates a conceptual framework (Charmaz, 2006), and as with any theory, the research process begins with the use of multiple sources of data. Data collection has primarily taken place over a digital interface, which is the preferred form of data collection for participants and has become the new ‘norm’ since the Covid-19 pandemic. Correct processes and procedures have been followed during this research to ensure that the data collected have been sourced ethically and accurately, as detailed above. In

addition, to ensure that the data are protected, correct data management and record keeping have taken place.

The literature has identified a lack of qualitative research that provides a holistic view of the drivers of the user acceptance of AR technology in engineering and construction projects, as well as their dynamics. However, it can be seen that researchers have explored factors influencing the user acceptance of technology (Carter & Salimath, 2019; Crossan & Apaydin, 2010; Eggers & Kaplan, 2013; Halaweh, 2013; Taylor, 2010). Thus, none of the drivers provides support for the theory. Consequently, one of the challenges of this research is recognising the key drivers of the user acceptance of technology, in addition to identifying contributing factors. To understand this, grounded theory is employed with a qualitative approach, as earlier research studies have not had the ability to fully integrate technology usefulness into the understanding of technology acceptance.

The objective of this research is to outline the user dynamics of technology in engineering and construction projects, with a focus on enhancing project success. To develop sufficient data to support the theory, the original data analysis had to be broadened to include engineering and construction projects, and data needed to be gathered from individuals working in various roles across different types of leadership dynamics, not just project managers. Therefore, the following types of primary data are used to carry out the research:

1. Interviews;
2. Focus groups;
3. Questionnaires.

We need to understand that data are elusive and ephemeral (Walliman, 2006). Thus, data extraction may seem tedious and uncertain; however, all data are valuable when collected, and knowledge is gained through this process. Therefore, when collecting data, there is a process of hierarchy and understanding that can enable the research problem to be identified, which is outlined as follows (Walliman, 2006):

1. Theory: This is an abstract statement on how the phenomenon works. It makes a claim about the phenomenon.
2. Concepts: Smaller concepts help build the theory.
3. Indicators: These are phenomena that build the concepts.
4. Variables: These are factors of the indicators.
5. Values: This refers to data in raw form and units of measurement.

Figure 3.2 illustrates the process hierarchy.

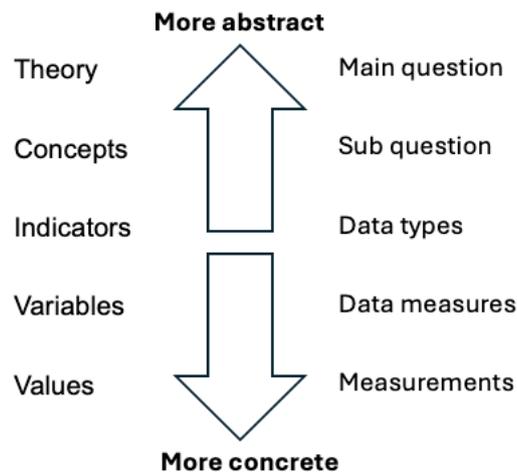


Figure 3.2: Levels of abstraction (Walliman, 2006)

Primary data are used in this research. Primary data are defined as data that are observed and recorded at the event being studied (Walliman, 2006). Without these primary data, the phenomenon would not take place.

3.5 Research Method

The research method utilised in this study primarily involves collecting primary data, which includes conducting interviews with participants, conducting focus group discussions with two or more individuals and administering open-ended surveys that allow the participants to answer questions in their own time. These open-ended questions and questionnaires help to ensure that the data collected are relevant to the research objectives.

3.5.1 Interviews

Interviews are the main type of qualitative data used in this research. The interview process followed a semi-structured approach, where a set number of open-ended questions were asked; however, these questions led to other topics being identified. With this type of research, interviews are the preferred method of qualitative data collection, as this approach allows the researcher to clarify questions that may be ambiguous and identify other key areas of interest. This method also encourages the participant to be complete in their answers.

All interviews were carried out via digital means, as the Covid-19 pandemic identified a need for this type of process. Using digital means to gather data through interviews is perceived as face to face, as one can still interpret body language and verbal cues in participants'

responses. All interviews were recorded with the participants' approval, even though the data were anonymous. After all the interviews, notes were also taken and continuously analysed to interpret the interviews.

Therefore, semi-structured interview methods were set up during the research, thus ensuring that any questions from the participant were answered. A semi-formal and unstructured interview process with a total of 10 questions for participants in the engineering and construction field and a total of 11 questions for software developers was used. This type of structure allows participants to identify and discuss matters of their choice. The interview participants included software developers, engineers in leading and management roles and construction managers and leads. The factors that are considered during the interviews include the following:

- the recording of interviews;
- the selection of participants.

3.5.2 Open-ended survey questionnaires

Questionnaires in this research are used to collect qualitative data. This method was utilised because it allowed the participants to answer questions through Qualtrics without the necessity of speaking with the participants. This is a structured format that is quick and easy for participants to use at their own convenience. It can also be used for a large population covering large geographical areas (Walliman, 2006). This method allows the user to be anonymous when describing their thoughts on a topic, without any uncomfortable or difficult questions that may arise during an interview. The questionnaire was completed online through the Qualtrics platform; however, it can be seen that receiving responses took some time, as most participants did not immediately complete this task. The questions asked were open-format-type questions. Please see Appendix E and Appendix F for the open-ended survey questionnaires that were used. This format allowed the participants to reply in any way that they felt was applicable and gave them freedom of expression (Walliman, 2006).

The design process for the open-ended questionnaires began with completing a draft of the literature review, which was crucial in identifying the current gap in AR technology within the engineering and construction sectors. The literature review identified the following gap: real-world scenarios were predominantly limited to experienced personnel, and most studies were conducted within educational settings or controlled experimental environments.

Recognising this gap highlighted the need for qualitative data and led to the development of

the open-ended questionnaires outlined in Appendix E and Appendix F, which are designed for digital technology users or developers.

Following the initial drafting of the open-ended questionnaires, development continued until the questionnaires were open and aligned with the grounded theory methodology. The open-ended questionnaire was arranged in a logical sequence, starting with participants' definitions of AR technology, followed by topics related to benefits, challenges, and user acceptance. This structure of the open-ended questionnaires ensured participants gradually settled into the interviews, focus groups, and survey questionnaires, ensuring that the data collected would be suitable for the grounded theory methodology with coding and theory development.

The questionnaire contains a total of 10 questions for each area of study in engineering and construction. There was a total of 11 questions for software developers. This was set up through Qualtrics, in affiliation with Victoria University. The set of questions has been developed by identifying gaps in the literature review. Using Qualtrics allows the participant to answer the questionnaire in their own time. This setup included the consent form and the participant information form, which were provided prior to the questions. These forms were dated and signed by the volunteers, indicating their acceptance and confirmation of participation in the study, before any data were obtained, according to the ethics process.

3.5.3 Focus groups

A focus group consists of a group of individuals who are assessed together in a group setting. This setup is similar to the interviews; however, there is more than one person in attendance.

The focus group interview process followed a semi-structured approach, where a set number of open-ended questions were asked; however, these questions prompted the discussion of other identified topics. All focus group interviews were carried out via digital means, due to the Covid-19 pandemic. All focus groups were recorded with the participants' approval. Following the focus group interview, notes were recorded and analysed to interpret the discussion.

Therefore, semi-structured interview methods were used throughout the research to ensure that all participant questions were addressed. A total of 10 questions for participants in the engineering and construction field and a total of 11 questions for software developers were

used in the focus groups. The focus group participants included software developers and construction managers and leads. The factors initially considered during the focus groups included the group structure and size, along with the individual status; however, due to the limited number of focus groups conducted, the individual status became the main focus.

3.6 Data Analysis: Grounded Theory

The research methodology utilised in this research is grounded theory. Using grounded theory outlines and informs the outcome. The development of grounded theory originated with Barney Glaser and Anselm Strauss, and it was presented in the book *The Discovery of Grounded Theory* (Glaser & Strauss, 1967), which outlined the primary points and provided an overview of grounded theory using a systematic approach to collect qualitative data. Grounded theory was developed in the 1960s, as there was an increase in qualitative research and an increase in empiricism (Goulding, 2002).

Grounded theory can be traced back to the symbolic interactionism movement, which originated with George Herbert Mead (1863–1931) and Charles Cooley (1864–1929), whose interests were to elucidate the divergence between sociology and psychology (Goulding, 2002). Symbolic interactionism is a theory on group behaviour and individual human behaviour and conduct (Goulding, 2002).

Grounded theory can be defined as a form of social research in which data have been systematically obtained (Goulding, 2002), therefore building a theory that correlates with the evidence provided by data (Neuman, 2014). Grounded theory allows the theory to be built from the data, enabling the data and the theory to interrelate with one another (Neuman, 2014). Therefore, grounded theory is best incorporated when there is minimal known information and when both the data and analysis are derived from the participant (Glaser, 1978).

Glaser and Strauss (1968) stipulate that the developed theory, when incorporating grounded theory, should do the following:

- Be able to be put into practice;
- With behaviour, provide a style or guide for research;
- Identify a lens through which to view behaviour;
- Identify a theory that can be verified with new research;
- Identify the prediction or description of an explanation of behaviour;

- Aid in theoretical advances in sociology.

Over time, grounded theory has constantly evolved through a continuous collaboration between both data and analysis (Corbin & Strauss, 1990; Crotty, 1998; Glaser, 1978, 1996; Glaser & Strauss, 1967; Goulding, 2002). It can be said that Glaser has remained consistent with his earlier work on grounded theory, defining it as a method of discovery, where data are outlined as categories using direct empiricism, with social and set procedures (Charmaz, 2006). However, Strauss has evolved in this direction, thus supporting the technical process (Corbin & Strauss, 1990). This theory can be utilised with qualitative methods (Corbin & Strauss, 1990), quantitative methods (Glaser, 1992) or quantitative and qualitative methods (Glaser, 1998), or it can be used with a constructivist approach (Charmaz, 2006). These are just a few of the problems that can be approached utilising grounded theory.

The grounded theory research process is not always linear; grounded theory allows the user to stop and start whenever an idea is generated. More often than not, the methodology gives the user more than one direction.

The grounded theory process involves several key steps, this includes :

1. Formulate the research question;
2. Collecting primary data;
3. Identify initial codes (open coding);
4. Identify concept codes (open coding);
5. Identify relationships (axial coding);
6. Analyse and compare the identified codes with existing codes;
7. Repeat steps 2–6 (theoretical saturation);
8. Define the core concept (selective coding);
9. Write the theory (forming a theory).

3.6.1 Open coding

Utilising the grounded theory framework, open coding serves as the initial step in the analysis. In this study, we performed open coding by reviewing the data using NVivo software and identifying codes derived from selective keywords and the understanding of sentences. Once this was achieved, the selected words were categorised accordingly. Additionally, memoing was conducted; this was facilitated through Microsoft Excel.

3.6.2 Axial coding

Axial coding occurs during the review of open codes. This process involves forming groups based on common themes, which helps establish relationships. In this study, NVivo software was utilised; however, much of the relationship formation through memoing was conducted using Microsoft Excel. This platform allowed the use of different tabs, facilitating the organisation and presentation of all relevant information and allowing the viewing of previous changes and corrections.

3.6.3 Selective coding

Selective coding occurred during the analysis of the relationships. In this study, NVivo software was used to capture the coding; however, Microsoft Excel was utilised for memoing to sort through the relationships and group those relationships into further core concepts. After every interview and focus group, and after the last survey was conducted, the codes were reevaluated to ensure that the categories and relationships were accurately grouped.

3.6.4 Forming theory

The identified codes formed the relationships, and with the incorporation of grounded theory, the theory that aligned with the data was developed (Neuman, 2014). This approach allowed the theory to grow directly from the data, creating a strong connection between the two (Neuman, 2014). During this research, constant data review took place; it occurred not only after every interview was conducted but also periodically to ensure that the codes and relationships were correctly grouped. This research method first developed a taxonomy of relationships and then compiled it into a framework, which allowed the theory to emerge from the analysed data.

3.7 DeLone and McLean Information Systems Success Model

The DeLone-McLean information systems success model is a framework that is multidimensional and measures success through the information quality, system quality, service quality, intention to use (use), user satisfaction, and net benefit; this is illustrated in Figure 3.3 (DeLone & McLean, 2003). This research leans on this framework as a theoretical lens while using grounded theory to guide the emerging categories and codes and ensuring that core concepts and relationships are derived from the data analysis (Charmaz, 2006; DeLone & McLean, 2003; Mardiana et al., 2015).

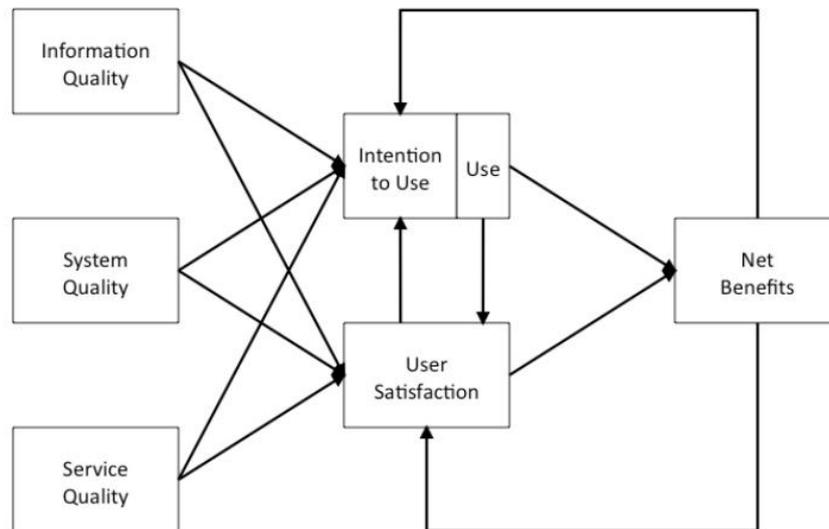


Figure 3.3: Information system success model (DeLone & McLean, 2003)

The DeLone and McLean information system success model highlights that information system success is independent, where net benefits are influenced by system use and user satisfaction through system and information quality (DeLone & McLean, 2003). Therefore, the DeLone and McLean model is used as a guide that aids in identifying patterns in the data analysis; this is valued because it provides a structured lens for evaluating AR technology across engineering and construction projects.

Using grounded theory, the DeLone and McLean model was used to support the development of the theory. Grounded theory requires the codes and relationships to be formed from the participants' experience and explanations, and the DeLone and McLean model serves as a tool that guides without restricting the coding process, aligning with the idea that IS success is interconnected and requires an understanding of how systems, information, service, use, and benefits interact in real-world projects (DeLone & McLean, 2003).

The use of both grounded theory and the DeLone and McLean information system success model ensures that the data analysis and final theory are based on real data while being guided by IS success. This is further illustrated in Figure 3.4.

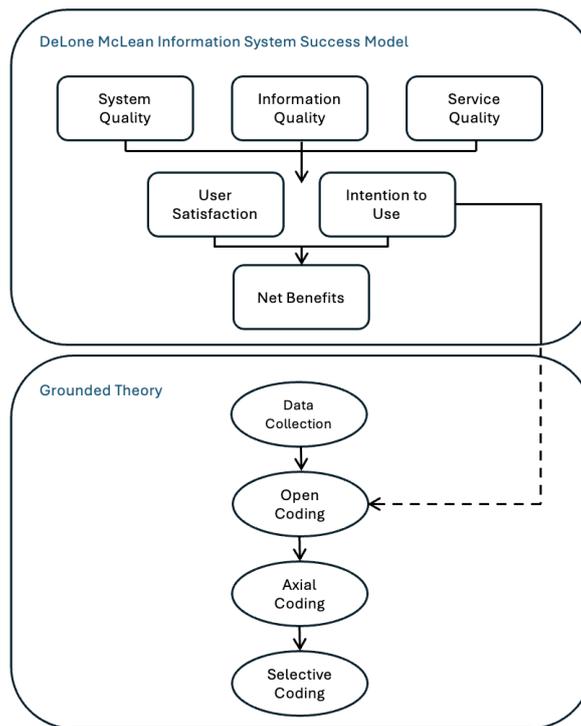


Figure 3.4: DeLone and McLean information system success model and grounded theory model adaptation

3.8 Research Procedures for Companies

To ensure that the research programme is safe for all participants, all research leads will conduct the following processes prior to the start of the research, if the research is not being completed online.

3.8.1 Process 1

An onsite Safe Work Method Statement (SWMS) is filled out, and an inspection of the area of the research site takes place to ensure the safety and health of all participants and facilities. This will need to be documented and signed by the research project lead and all participants involved.

3.8.2 Process 2

The onsite Health and Safety Management Plan is communicated to the participants and the company. This document is kept within the research area.

The onsite Health and Safety Management Plan is signed by each participant involved in the research before the research is conducted.

This document is within the research programme to ensure the following:

- Each participant signs the document;
- Each participant understands their responsibilities;
- All Health and Safety rules have been identified.

3.8.3 Process 3

A site induction will take place prior to the start of the research.

The site induction will need to outline the following:

- Company requirements;
- Evacuation plan;
- Emergency numbers;
- First aid kit;
- Health and safety processes.

The induction is determined by the company involved. This will change for each company involved, as it may involve different locations and emergency procedures; however, an additional induction form for the research programme is provided.

Please note that all interviews and focus groups were completed online, so the research procedure for companies was not required. However, it was planned prior to the Covid-19 pandemic to obtain interviews face to face.

3.8.4 Ethics Approval for Data Collection

An ethical process has been implemented to ensure that participants understand and voluntarily participate in the research. In addition, it is ensured that companies understand their privacy agreement for the research, thus ensuring that ethical principles and values are adhered to throughout the research.

The ethics application has been submitted and approved; a revised version was approved on 15 November 2021 to incorporate overseas applicants from Colombia.

This research involves human participants, primarily practitioners in the engineering and construction field, in addition to software developers. The data collection includes the following:

- Questionnaires;
- Interviews;
- Focus groups.

To ensure that all participants involved in this research understand the study and consent to participate, a demonstration of the values and principles of ethics is conducted.

To ensure that the data collected are ethically acceptable, the following documents are adhered to:

- The National Statement of Ethical Conduct in Human Research;
- The Victoria University’s Code of Conduct for Research;
- The Australian Code for the Responsible Conduct of Research.

3.9 Ethical Risk Associated with the Research

To ensure that the data collected do not have any ethical issues, an ethical risk management plan has been developed during the research to mitigate any risks associated with using human participants. To ensure that the data collected are fit for the research purpose and ethical, a risk analysis has been conducted to identify the risks and develop a mitigation plan. The top two integrity and ethical issues that may arise during the research are detailed in Table 3.2.

Table 3.2: Risk analysis for human participants and researchers

#	Risk	Impact	Mitigation
1	Company privacy	Participant: - Vulnerability to the company - Non-ethical Researcher: - Legal - Management of data - Policies and procedures are not adhered to with ethics and integrity	- Company anonymity - Following ethical policies and procedures - Following legal procedures - Company policy - Adhering to codes of research and professional conduct - Informed consent given - Intellectual property is managed accordingly

2	Confidentiality	Participant: <ul style="list-style-type: none"> - Participant vulnerability - Non-ethical - Relationship status differential Researcher: <ul style="list-style-type: none"> - Legal - Management of data - Policies and procedures are not adhered to with ethics and integrity - Power differential in relationships 	<ul style="list-style-type: none"> - Participant anonymity - Following ethical policies and procedures - Following legal procedures - Participant policy - Adhering to codes of research and professional conduct - Informed consent given - Human rights - Intellectual property is managed accordingly
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To ensure that all issues are mitigated, as outlined in Table 3.2, a participant information form has been given to all participants involved in the research. Therefore, processes and procedures are followed to ensure that all risks to the human participants and the researcher are mitigated.

3.10 Occupational Health and Safety Risk for Data Collection

3.10.1 Occupational Health and Safety Policy

The Health and Safety Policy is designed to ensure that all participants involved accept and adhere to it, outlining the commitment to maintaining a safe working environment. This also outlines the first step in the Management Plan that shall be adopted in this research.

This policy has been developed with the well-being of all individuals during the research in mind. Each participant who has been involved in the study is important and plays a vital role in the research.

3.10.2 Core foundations

The core fundamentals in the Occupational Health and Safety Policy are listed below:

- To adopt the methodology outlined in this research with regard to risks;
- To define the responsibilities of each participant in this research;
- To ensure that all processes and procedures are documented during the research;
- To identify the process and procedures with Occupational Health and Safety inspections;
- To ensure that applicable training is given prior to the research;
- To ensure that each and every participant knows that safety comes first.

3.10.3 Objectives

The fundamental objectives in the Occupational Health and Safety Policy include the following:

- To ensure incident-free research;
- To ensure that in all planning and activities, health and safety come first;
- To ensure that communication, training and inductions are given to all participants involved;
- To ensure that each participant participates in the safest manner;
- To identify any risk involved in the research by conducting risk assessment continuously during the programme;
- To ensure that all measures are taken to eliminate any incidents in the programme.

This policy identifies that the health and safety of each participant is the responsibility of the researchers and Victoria University. To ensure that the participants are safe, researchers have a responsibility to provide a safe research environment without health risks. To ensure that the requirements in this policy are met, regular communication with the participants and companies involved in the research will take place to identify any issues or risks associated with this research programme.

3.10.4 Requirements

The researcher will adhere to the following:

- They are responsible for policy implementation.
- They will adhere to the guidelines and rules involved in the research.
- All process and procedures are agreed upon, and regular discussions are held with the participants and companies involved.

- They will ensure that regular assessments and audits are performed throughout the research.
- They will ensure that all necessary information and training are given to the participants and companies involved in the research.

The companies and participants involved in the research must comply with the following:

- They must ensure that each participant considers their own health and safety and the health and safety of others.
- They must ensure that all safety processes and procedures are followed.
- They must ensure that all facilities are treated with care.
- They must ensure that all incidents are reported to the researcher and the company.

This policy is to be reviewed regularly in the event of changes to the research. This policy requires the cooperation of all participants and companies to ensure a safe research environment during the programme.

3.11 Conclusion

The research methodology chapter outlined the research epistemology, research paradigm, research methodology and research method. This includes the online platform approach using Qualtrics for the open-ended survey questionnaires and the process for interviews and focus groups. It details the data analysis, which was performed through grounded theory, and the analysis process that took place. In addition, it covers the ethics approval process and the data collection process.

The research methodology chapter is the third section of this study; it explains how the research was conducted. It follows Chapter 1, the introduction, and Chapter 2, which presents the literature review, discussing current research. Chapter 4 focuses on data analysis, detailing how the data were examined. Chapter 5 presents the discussion of the research findings. Finally, the conclusion summarises the research contributions

Chapter 4: Data Analysis

The data analysis chapter explains how the data were collected and utilised. This includes discussing the open-ended survey questionnaires, the interview responses, the data analysis process, and how grounded theory was applied. From grounded theory, the data analysis shows how the open, axial, and selective codes were developed and how the relationships and theories were formed. Based on the data analysis and grounded theory, this chapter details the organisational deliverables, the project inputs, the technology inputs, and the project outputs derived from the data. Additionally, it describes the taxonomy developed, the framework, the relationship chains, and the feedback loop.

4.1 Overview

The research consisted of collecting data from 27 open-ended survey questionnaire responses and conducting 23 interviews, in addition to two focus group sessions, with two participants in each session. During the interviews, both structured and semi-structured formats were employed to gather data, resulting in over 200 pages of information. The interviews were conducted over the period from July 2021 to November 2024. This period of data collection incorporated various developments, such as the Covid-19 pandemic, and online platforms were introduced between 2021 and 2022. All interviews were conducted using Zoom, Microsoft Teams and Google Meet.

4.2 Open-Ended Survey Questionnaire Response

The open-ended survey questionnaires were designed to ensure that each question would capture the necessary data effectively. These open-ended survey questionnaires were implemented using the Qualtrics platform, which facilitated in the data collection and ensured the safekeeping of the results, which were obtained on a secure platform. In addition to the primary task of collecting open-ended survey questionnaire data, the Qualtrics platform played a crucial role in securing consent forms from participants, ensuring that all ethical guidelines were adhered to. Furthermore, it was utilised to present information to participants, ensuring their understanding of the open-ended survey questionnaire's purpose and addressing any potential concerns that they might have had regarding their participation.

This research utilised two distinct open-ended survey questionnaires that were targeted at different professional groups within the industry. The first open-ended survey questionnaire was designed specifically for engineering and construction managers, aiming to gather insights and data relevant to the engineering and construction sector and to outline challenges and operational practices. Meanwhile, the second open-ended survey

questionnaire was tailored for software development managers, focusing on their experiences and perspectives with augmented reality and technology advancements. By utilising these two individualised open-ended survey questionnaires, the research aims to capture a comprehensive understanding of the differing managerial approaches and requirements across the construction, engineering and software development sectors.

A total of 65 individuals gave their consent to participate in this study, which focused on the engineering and construction group of participants. Of these, 10 agreed to take part in the software development open-ended survey questionnaire, while 55 agreed to respond to the construction and engineering open-ended survey questionnaire. Within the engineering and construction group, we collected a total of 24 responses to the open-ended survey questionnaire, resulting in 21 pages of data. This dataset offers insights into the engineering and construction field, outlining organisational needs and challenges. The open-ended survey questionnaire conducted among software developers generated three responses, but those responses generated a total of 13 pages of data. This is outlined below in Table 4.1.

Table 4.1 : Open-ended survey questionnaire data

Data type	Engineering	Software developers
Consent	55	10
Open-ended survey questionnaire response	24	3
Pages	21	14
Word count	5478	1058

4.3 Interview Response

During the interviews, video conferencing platforms were utilised; Zoom, Microsoft Teams, and Google Meet were used to facilitate the interviews. These platforms enabled remote communication, allowing interviews to take place in real time, despite Covid-19. Zoom, Microsoft Teams and Google Meet are easy-to-use platforms that most individuals are acquainted with.

Furthermore, the Qualtrics platform played a vital role in the organisation and administration of the consent forms, alongside providing essential information for participants prior to their interviews. Utilising Qualtrics ensures that all information is readily available and securely stored. This contributed to enhancing the overall participant experience with an easy-to-use platform and ensuring that all necessary protocols were adhered to before the interviews commenced.

This study was designed to collect data through two distinct sets of interviews, aimed at exploring perspectives within the engineering and construction industries, as well as the software development and technology sectors. The first set of interviews consisted of discussions with engineering and construction managers. The second set of interviews was conducted with software development managers. Their input highlighted the digital technology approaches between the construction and engineering sectors and how the software industries contribute to this, outlining the importance of adapting to evolving technologies. Through this dual-perspective approach, the study aims to produce findings that may enhance our understanding of AR technological advancements in the engineering and construction field.

In this research study, a total of 23 interviews were conducted, along with two focus groups. This resulted in 237 pages of interview data, accumulating over 75,000 words. The duration of the interviews varied, from 30 minutes to greater than an hour for one focus group. It is noted that nine interviews were conducted with construction managers, providing perspectives in the construction industry, and six interviews were held with engineering managers, providing perspectives in the engineering sector. The remaining eight interviews were conducted with software professionals, who shared their experiences and viewpoints as they relate to technology in engineering and construction projects. This diverse range of interviews provided a comprehensive understanding of technological advances and AR in the engineering and construction industry. This is outlined in Appendix L.

The study involved a diverse group of participants, including engineering leads, managers and directors, who were interviewed to gather insights on AR technology in their selected fields. Out of a total of 23 interviews conducted, five came from large organisations employing over 1,000 individuals, all of which operated within the engineering sector. Furthermore, an additional five participants were associated with the construction industry, representing companies that had more than 500 employees. The study also highlighted that all nine software developers were working at smaller firms, with fewer than 100 employees. In addition to the individual interviews, the research included the perspectives of two focus groups. This is detailed in Appendix M.

Based on the data gathered from the 23 participants, one individual reported having no prior experience with AR. Interestingly, this participant is from the engineering sector where AR technology is utilised within the organisation. It is essential to highlight that this specific individual had not engaged in any AR training, either from their organisation or through self-

directed learning. In contrast, the other participants had access to AR training provided by their organisations or had taken the initiative to learn AR independently. In the code developed to indicate the areas from which the volunteers derive, E signifies engineering, C indicates construction and S stands for software. This is summarised in Table 4.2.

Table 4.2 : AR training and purposes

#	AR experience	AR purpose	Source of AR training
E1	Y	Engineering	Organisation
E2	Y	Engineering	Organisation
E3	Y	Engineering	Organisation
E4	Y	Engineering	Organisation
E5	N	Engineering	None
C6	Y	Construction	Organisation
C7	Y	Construction	Organisation
C8	Y	Construction	Organisation
C9	Y	Construction	Organisation
E10	Y	Engineering	Organisation
E11	Y	Engineering	None
S12	Y	Software	Organisation
S13	Y	Software	Organisation
S14	Y	Software	Organisation
C15	Y	Construction	Organisation
C16	Y	Construction	Organisation
C17	Y	Construction	Organisation
S18	Y	Software	Organisation
S19	Y	Software	Organisation
S20	Y	Software	Organisation
S21	Y	Software	Organisation
S22	Y	Software	Organisation
S23	Y	Software	Organisation

The collected data indicated that among the 23 participants interviewed, 5 were female and 18 were male. This suggests that the majority of participants are male, highlighting a gender trend in the software, engineering and construction fields. Additionally, the age distribution includes two participants aged between 20 and 29, while another two participants were in

the 40–49 age group. This shows that participants are aged between 20 and 50 years, with a span of 30 years in age differences. Among the participants involved in the interviews, a total of 21 fell within the 30–39 age range, suggesting that this age group constitutes a significant portion of the data. Having a large dataset on this age group implies that the individuals aged 30–39 are not just participants; they are the driving force behind advancements in software, engineering and construction. This is detailed in Table 4.3.

Table 4.3 : Data background

Total	Age	Male	Female
1	20–29 – 4%	100%	0%
20	30–39 – 88%	80%	20 %
2	40–50 – 8%	100%	0%

4.4 Data Analysis

The following research question is considered: What are the dynamics of the user acceptance of technology in engineering projects? The data collected were obtained through grounded theory. By utilising grounded theory, this research outlines and discusses its outcomes. There are various methodologies of grounded theory in social research (Abels et al., 2006; Crotty, 1998; Glaser, 1978, 1992, 1996, 1998; Glaser & Strauss, 1967). Grounded theory outlines the results that have been developed through data analysis and social processes (Crotty, 1998; Glaser, 1978, 1992, 1996, 1998; Glaser & Strauss, 1967). Therefore, based on this research, it is considered appropriate to integrate this into the existing framework. The grounded theory process includes the following steps, as shown in Figure 4.1:

1. Formulate initial research questions.
2. Collect data through theoretical sampling.
3. Divide transcripts into initial codes (open coding).
4. Identify concepts to create codes (open coding).
5. Organise codes into intermediate relationships (axial coding).
6. Analyse additional excerpts and compare them with existing codes.
7. Repeat steps 2–6 until theoretical saturation is reached.
8. Define the advanced codes (selective coding).
9. Write the grounded theory (forming a theory).

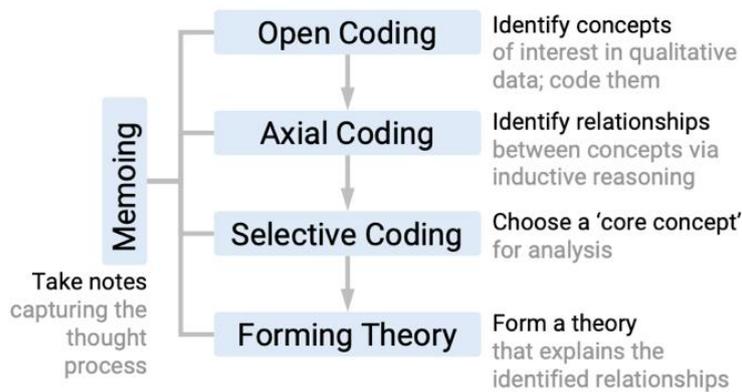


Figure 4.1: Grounded theory framework (Chandrasegaran et al., 2017; Dillon, 2012)

4.5 Grounded Theory

The analysed data were derived from a grounded theory approach; they were gathered from 27 open-ended survey questionnaire participants and 23 interview candidates. Data collection was conducted through a theoretical sampling process, ensuring that the selected participants were relevant to the research question. Initially, these data were broken down into a set of initial codes to identify key concepts and themes within the responses. These initial codes underwent a revision process and were systematically organised into relevant open codes, facilitating a clearer understanding of the data's content.

Once the open codes are established, axial codes are then formed. This phase involved a detailed analysis of the relationships between the identified open codes to identify any connections and patterns within the data. Once axial codes are developed, the process of selective coding is introduced. During selective coding, core concepts are derived from the relationships found among the axial codes. This step led to the development of the theory and framework.

4.6 Open Coding

The open codes derived from the qualitative data analysis totalled 248 codes, all of which are listed in Appendix H. The open coding process employs a thorough, line-by-line analysis methodology, allowing the systematic formulation of these open codes. Line-by-line analysis not only facilitates the creation of codes but also captures the subtle nuances in the study (Charmaz, 2006).

In relation to the findings, among the references collected, cost management emerged as the most frequently cited code, with a total of 133 references sourced from both interviews

and open-ended survey questionnaires conducted during the study. Table 4.4 outlines the top 50 open codes, illustrating the key themes and patterns identified in the data.

Table 4.4 : Open codes

#	Name	References in interviews and open-ended survey questionnaires	References of codes
1	Cost management	19	133
2	Training	18	65
3	AR equipment	14	56
4	Productivity (efficiency)	11	55
5	Capabilities	14	49
6	Ease of use	11	47
7	3D virtual environment	11	43
8	AR limitations	14	43
9	Visual display	16	31
10	Understanding of AR	18	30
11	Augmented graphics	8	29
12	Positive impact	15	29
13	Marketing	5	25
14	AR user case	10	24
15	Time management	8	24
16	User acceptance	10	24
17	Collaboration	12	22
18	Design aspect	7	22
19	Headsets used	9	22
20	Real time	9	21
21	General overview of AR future	16	20
22	Data privacy	6	19
23	New technology – exposure	11	19
24	Interaction	9	17
25	Accuracy	8	16
26	AR benefits	9	16
27	Education	10	16
28	Problem-solving	9	16

29	Software integration	8	16
30	Applications on devices	8	15
31	Modelling	9	15
32	Project needs	5	15
33	Software applications	8	15
34	Stakeholder communication	4	15
35	AR technology advancements	9	14
36	Learning	4	13
37	Project feedback	8	13
38	Project visualisation	9	13
39	Customisation	5	12
40	Prototyping	8	12
41	Construction	5	11
42	Data overlay	7	11
43	Scope management	6	11
44	User expectation	7	11
45	Visual communication	4	11
46	Workflow	3	11
47	Written communication	5	11
48	Artificial intelligence (AI)	6	10
49	Functionality	6	10
50	Health and safety	4	10

4.7 Axial Codes

Through the analysis of the data, each of the 248 open codes has been grouped into 49 axial codes, which can be found in Appendix I. The grouping of the codes is an essential part of the axial coding process, which incorporates a strategic approach to categorise the initial open codes into subcategories of axial codes (Corbin & Strauss, 1990; Glaser & Strauss, 1967).

The axial codes were developed by grouping the open codes into relationships, which then formed the axial codes. For example, all open codes related to communication were grouped under the category of 'communication management'. This is further detailed in Table 4.5 below.

Table 4.5 : Axial code grouping – Communication management example

Selective code	Communication management	Axial code reference
Axial code	Verbal communication	236
	Written communication	246
	Project feedback	156
	Questions and answers (Q&A)	173
	Visual aids – handover	239
	Visual communication	240
	Visual instructions	242
	Stakeholder communication	200
	Stakeholder engagement	201
	Communicating project needs	47

The purpose of axial coding is to itemise and sort through large amounts of qualitative data, effectively sorting through the data and grouping them into subcategories after open coding (Charmaz, 2006). Therefore, axial coding plays an essential role in bringing the data together to determine the relationships between the categories (Corbin & Strauss, 1990). Furthermore, a comprehensive outline of the axial codes can be found in Table 4.6, which provides the 49 axial codes, the number of assigned open codes and the number allocated to the grouped open codes.

Table 4.6 : Axial codes

#	Axial codes	# grouped open codes	Underlying open code references
1	Project deliverables	5	185, 186, 150, 224, 31
2	Organisational deliverables	5	144, 244, 141, 159, 182
3	Financial aspects	4	60, 184, 172, 157
4	Legal and contractual	3	58, 133, 179
5	Licensing and subscriptions	6	238, 247, 225, 190, 84, 42
6	Regulatory aspects	6	40, 46, 175, 178, 79, 137
7	Cognitive ergonomics	1	103
8	Safety	5	89, 135, 136, 102, 90 77, 151, 155, 160, 152, 93, 163,
9	Early technology adoption	8	128
10	Project strategic management	5	139, 209, 217, 109, 167
11	Project design	4	68, 69, 70, 71

			165, 166, 62, 20, 94, 95, 131, 56,
12	Project development	15	241, 15, 50, 55, 14, 180, 76
13	Project deliverables	5	158, 67, 75, 153, 162
14	Schedule deliverables	4	220, 221, 174, 183
			32, 82, 53, 54, 85, 119, 83, 222,
15	AR sectors	10	145, 107
16	Advertising	3	206, 120, 23
17	Environmental and sustainability	3	88, 87, 177
18	Generational factors	2	129, 248
19	Expert skills	5	207, 92, 204, 219, 189
			86, 121, 192, 10, 11, 38, 191,
20	AR applications and platforms	9	127, 39
21	AR capabilities	5	194, 196, 197, 41, 112
22	Software analysis	1	27
23	Device compatibility	6	73, 125, 126, 49, 243, 203
24	Integration	4	21, 24, 195, 61
			37, 100, 101, 99, 106, 130, 132,
25	Hardware and equipment	10	169, 18, 25
26	Technology user connection	3	212, 214, 215
27	Machine learning integration	3	98, 9, 33
28	Computer-based modelling	5	51, 237, 34, 124, 205
29	Technology automation	2	36, 74
30	3D virtual environments	8	1, 2, 3, 4, 198, 35, 96, 104,
31	Data analytics	3	63, 64, 65
32	Data management	2	66, 115
			6, 134, 228, 230, 231, 232, 233,
33	User acceptability	13	78, 245, 81, 154, 105, 193
34	Adaptability of new technology	2	8, 234
35	Augmented reality advantages	5	12, 13, 19, 17, 29
36	Project challenges	4	142, 123, 44, 108
			216, 218, 118, 211, 210, 16, 22,
37	Technology challenges	11	26, 229, 227, 5
38	Efficiency	3	168, 176, 146,
39	Project evaluation	4	148, 117, 161, 208
40	Quality control	5	170, 171, 235, 110, 91,
41	Practical solutions	6	138, 140, 59, 213, 164, 143

42	Quality improvement	5	147, 57, 72, 43, 30
43	Performance criteria	2	122, 113
44	Project collaboration	4	48, 181, 52, 45
45	Training environment	6	7, 187, 188, 223, 149, 28
46	Learning environment	4	80, 226, 111, 97
47	Education environment	2	114, 116 236, 246, 156, 173, 239, 240,
48	Communication management	10	242, 200, 201, 47
49	Stakeholder management	2	199, 202

4.8 Selective Coding

The analysis identified 18 themes derived from a total of 49 axial codes; this is further detailed in Appendix J. The identified themes illustrate the findings that contribute to the research question, thereby providing a conceptual framework. Further details are provided later in this chapter.

The selective codes were developed by further analysing the axial codes. The axial codes were grouped into core concepts for the analysis. For example, all axial codes related to 'performance and quality assurance' are grouped together, forming a selective code. This example is detailed in Table 4.7.

Table 4.7 : Selective coding – Performance and quality assurance example

Selective code	Performance and quality assurance	Axial code reference
Axial code	Efficiency	3
	Project evaluation	4
	Quality control	5
	Practical solutions	6
	Quality improvement	5
	Performance criteria	2
	Project collaboration	4

Selective coding as part of the grounded theory methodology allows the data to be integrated and brings the data together (Corbin & Strauss, 1990). With the initial phase of open coding, the data are analysed, and codes are formed. Once the open codes have been correctly categorised and axial coding subcategorised, central themes can be outlined in the

selective coding process (Charmaz, 2006). Selective coding is investigated in the final stage of the analysis, where central themes emerge. This enables the refinement of findings to accurately reflect the concepts presented in the data. The selective codes are outlined in Table 4.8.

Table 4.8 : Selective codes

#	Selective coding	# Axial codes	Underlying axial code references
	Organisational deliverables and		
1	project scope	2	1, 2
2	Financial aspects	1	3
3	Legal and regulatory deliverables	3	4, 5, 6
4	Safety deliverables	2	7, 8
5	Early adopters	2	9, 10
6	Project management	4	11, 12, 13, 14
7	Specific use cases	3	15, 16, 17
8	Expert skills and development	2	18, 19
9	Software and hardware integration	7	20, 21, 22, 23, 24, 25, 26
10	Artificial intelligence (AI) integration	1	27
11	Automation and 3D environments	3	28, 29, 30
12	Data privacy and management	2	31, 32
13	User experience and AR use	2	33, 34
14	Technology advancements	1	35
15	Technology and project challenges	2	36, 37
16	Performance and quality assurance	7	38, 39, 40, 41, 42, 43, 44
17	Knowledge and lessons learnt	3	45, 46, 47
18	Communication	2	48, 49

An overview of each of the 248 open codes, listed alphabetically, that shows how many times each code was mentioned in the interviews, focus groups and open-ended survey questionnaires is provided in Appendix H. Additionally, all 49 axial codes are outlined and numbered in order, with their relationship to the open codes explained in Appendix I. Lastly, each selective code is numbered and referenced with the axial codes, as detailed in Appendix J.

4.9 Cross-Sector Overview of Engineering, Construction, and Software Development

The data analysis is performed separately for the engineering, construction, and software development sectors. Across these three areas, the data analysis reveals strong alignment. All areas highlighted in blue represent duplicate open codes that are the same across other sectors. The top 15 open codes in each category are listed in Table 4.9.

Table 4.9: Top 15 open codes in each sector, with similar codes highlighted

#	Engineering	# of codes	Construction	# of codes	Software developers	# of codes
1	Cost management	18	Cost management	16	Cost management	42
2	Visual display	12	Productivity (efficiency)	15	AR equipment	29
3	User acceptance	11	Easy to use	14	AR limitations	21
4	Time management	10	AR user case	11	Training	15
5	AR limitations	8	Headsets used	11	Marketing	14
6	Training	8	Workflow	11	AR user case	12
7	3D virtual environment	7	AR equipment	9	Capabilities	11
			General overview – Future of			
8	AR equipment	7	AR	8	Project visualisation	11
					3D virtual	
9	Easy to use	7	New technology – Exposure	8	environment	10
					Applications on	
10	Productivity (efficiency)	7	Data overlay	7	devices	10
11	Visual communication	7	General understanding of AR	7	Education	10
	General understanding of					
12	AR	6	Training	7	Headsets used	10
13	Real time	6	Visual display	7	Project needs	10
14	AR availability	5	Accuracy	6	Scope management	10
15	AR benefits	5	AR limitations	6	Visual display	10

Further data analysis across all three sectors showed that many open codes have common themes, such as cost management, productivity, visual display, ease of use, and training, which are demonstrated across all the sectors. It is also noted that cost management ranks first in all three sectors.

Further analysis was conducted on the top 15 open codes in all three sectors. These codes were examined across all 248 open codes to identify which codes appeared in all three industries and which were specific to a single sector. This is highlighted by the areas marked in blue in Table 4.10.

Table 4.10: Top 15 open codes in each sector, with highlighted similarities across all 248 open codes

#	Engineering	# of code s	Construction	# of code s	Software developers	# of code s
1	Cost management	18	Cost management	16	Cost management	42
2	Visual display	12	Productivity (efficiency)	15	AR equipment	29
3	User acceptance	11	Easy to use	14	AR limitations	21
4	Time management	10	AR user case	11	Training	15
5	AR limitations	8	Headsets used	11	Marketing	14
6	Training	8	Workflow	11	AR user case	12
7	3D virtual environment	7	AR equipment	9	Capabilities	11
8	AR equipment	7	General overview – Future of AR	8	Project visualisation	11
9	Easy to use	7	New technology – Exposure	8	3D virtual environment	10
10	Productivity (efficiency)	7	Data overlay	7	Applications on devices	10
11	Visual communication	7	General understanding of AR	7	Education	10
12	General understanding of AR	6	Training	7	Headsets used	10
13	AR	6	Visual display	7	Project needs	10
14	HE: Real time	5	Accuracy	6	Scope management	10
15	AR availability	5	AR limitations	6	Visual display	10

Open codes such as visual communication in engineering and project visualisation in software development initially appeared within their specific sectors but show common alignment. Similarly, time management in engineering, workflow in construction, and scope management in software development also show alignment and are related in theme. The only exception was marketing, which was relevant for software developers; this makes sense because the engineering and construction sectors do not require product marketing, as they use the product directly. Even when unique codes are specific to one or two groups, they generally align with the overarching theme of the code, indicating that, despite differences across all three sectors, the core needs to remain consistent.

In addition, when examining the organisational size, it is noted that all software development companies have fewer than 100 employees. All engineering companies have over 1,000 employees, and in the construction industry, half have more than 1,000 workers, while one has fewer than 100; however, most of the work is subcontracted, which would equate to more than 1,000 workers.

A comparison of the data analysis results has been conducted for engineers, construction professionals, and software developers, demonstrating the synergies among these groups. It also highlights their perceptions of AR technology integration. The data analysis reveals common codes across all three sectors, emphasising the benefits of and barriers to adopting AR technology. Although some unique codes are identified, this is based on their sector-specific needs. Overall, the identified synergies across all three areas indicate a need for digital transformation in the engineering and construction sectors, requiring specialised personnel to develop tailored software solutions for each industry.

4.10 Relationship and Theory

The 49 relationships that were formed in the axial coding process, which in turn identified the 18 core concepts outlined in the selective coding process, highlight the main areas for the user adoption of AR technology. Through this analysis, a taxonomy is created that explains the identified relationships. In addition to this taxonomy, further study has outlined that the 18 core concepts can be grouped into six key categories that represent a project cycle when AR technology is incorporated into a project, forming a framework for the user adoption of AR technology.

Therefore, the relationships and theory outlined in this research, formed through the analysis of data using grounded theory, created a taxonomy of relationships for the user adoption of AR technology. The taxonomy has three levels of data: the 248 open codes, the 49 axial codes and the 18 selective codes that were developed. In addition to this taxonomy, the data analysis formed a project framework that outlines the 18 selective codes grouped into 6 categories. With further data analysis, 11 relationship chains and 2 feedback loops were also identified, forming a causal loop diagram; all of this is further detailed in this chapter.

The relationship and theory derived from the data analysis, formed through grounded theory, outline 18 core concepts and a taxonomy of the data, as well as a theoretical framework that can be used when integrating AR technology into projects. This includes six categories: organisational deliverables, project input, technology input, project output, communication and knowledge. This is detailed further below:

1. Organisational deliverables: This category includes both the project scope and organisational scope, which subsequently inform financial, safety, regulatory and legal considerations.

2. Project input: Encompassing early adopters, this category transitions into project management and specific use cases, as well as expert skills and development.
3. Technology input: Operating at the same hierarchical level as project input, this category focuses on technology attributes. This includes aspects such as artificial intelligence (AI) and automation, leading to software and hardware integration, device interaction and data privacy management.
4. Output: This category pertains to the user experience, influencing technology advancements, addressing technology challenges and ensuring performance and quality assurance.
5. Communication: This area is integrated into all aspects of the relationships.
6. Knowledge and lessons learnt: This area is integrated into all aspects of the relationships.

In this theoretical framework, communication, knowledge and lessons learnt are conceptualised as a flywheel, illustrating a continuous cycle from organisational deliverables to output, thus flowing through each category. This is detailed in Table 4.11.

Table 4.11 : Relationships

Relationships	Themes
Organisational deliverables	Organisational deliverables and project scope Financial deliverables Legal and regulatory deliverables Safety deliverables
Project input	Early adopters Project management Specific use cases Expert skills and development
Technology input	Software and hardware integration Artificial intelligence (AI) integration Automation and 3D environments Data privacy and management
Output	User experience and AR use Technology advancements Technology and project challenges Performance and quality assurance
Communication	Communication Knowledge and lessons learnt

4.11 Organisational Deliverables

Organisational deliverables are categorised into four areas: organisational deliverables and project scope, financial deliverables, legal and regulatory deliverables, and safety deliverables. These four categories come from the 18 core concepts in the selective coding process. These areas are categorised as organisational deliverables because they emphasise the main organisational aspects and high-level requirements regarding the project scope, project funding, safety, legal and regulatory requirements. These four categories serve as a foundational starting point for any project's outlook, allowing all internal stakeholders to understand the critical elements upfront. As the project progresses and the framework evolves, these deliverables ensure that all necessary components are addressed throughout the project lifecycle.

Organisational deliverables comprise four key areas that are essential for successful project execution. This is detailed in Figure 4.2 below.



Figure 4.2: Organisational deliverable categories

These areas are described as follows:

1. Organisational deliverables and project scope: This component of the framework is essential and outlines the specific requirements of both the organisation and the client. A defined project scope is essential for aligning stakeholders and project expectations. Furthermore, organisational deliverables and the project scope include financial, legal, and safety requirements, thus emphasising the relationships with these categories.
2. Financial deliverables: This area outlines the financial objectives of both the client and the organisation. Important factors include the costs and return on investment. Understanding these financial requirements are essential for assessing the project's needs and long-term success.
3. Legal and regulatory deliverables: This area focuses on the contractual obligations between the organisation and the client. It includes formal agreements and adherence to applicable technology regulations and state laws. Compliance is crucial to mitigate risks and avoid legal complications.

4. Safety deliverables: Safety is a main concern in any project, particularly when new technology or software applications are introduced. This area encompasses all safety measures related to the organisational and client requirements, addressing potential risks, such as user disorientation, that can arise when integrating technologies like AR. Ensuring user safety and comfort is essential for the successful adoption of these innovations.

4.11.1 Organisational deliverables and project scope

Organisational deliverables and the project scope outline the requirements for using this technology and integrating AR to meet business needs and objectives. Client requirements illustrate this, ensuring that project needs are adequately addressed. Additionally, user requirements are considered to support organisational outputs, confirming that the appropriate applications and software are being used. Figure 4.3 depicts organisational deliverables and the project scope.



Figure 4.3: Relationship for organisational deliverables and project scope

Organisational deliverables and the project scope are crucial components of any project. They are interconnected with the financial, legal and safety deliverables. Understanding these relationships and their meanings is essential to interpreting the dynamics of AR technology in the project and its relationships in the framework.

In this study, the project deliverables category includes scope creep, scope management, project debrief and the transparency of project information, as described below.

Project deliverables:

- Scope creep: This refers to when the project may extend in time beyond what was initially intended.
- Scope management: When looking into the project at a high level, the project scope needs to be defined.
- Project debrief: When initiating new technology, the client needs to brief the company on the project and how the technology is intended to be used.

- Transparency of project information: AR relies on a visual method of presenting information that must be clear and concise to meet the requirements of AR technology devices.

In the current study, the organisational deliverables category includes the processes and procedures, workflow, preparation time, project lead time and resources, as defined below.

Organisational deliverables:

- Processes and procedures: Organisational processes and procedures must be followed during the project.
- Workflow: This refers to when AR technology is added to the project workflow.
- Preparation time: This refers to how long the process is.
- Project lead time: This is the duration of the project.
- Resources: This refers to the resources needed for the project.

Some of the relationships mentioned above in relation to organisational deliverables and the project scope will be further elaborated upon below, providing additional context and insights into how the relationships were formed.

4.11.1.1 Relationships extracted from organisational deliverables and project scope

Each of the organisational deliverables and project scope relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for organisational deliverables and the project scope is detailed in Table 4.12, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Organisational deliverables and the project scope form 10 open codes, 2 axial codes and 1 selective code.

Table 4.12 : Breakdown of organisational deliverables and project scope relationships

Selective code	Axial code	Open code
Organisational deliverables and project scope	Project deliverables	Scope creep Scope management Project debrief

	Transparency of project information
	AR user case
Organisational deliverables	Processes and procedures
	Workflow
	Preparation time
	Project lead time
	Resources

Project deliverables → Scope management

The relationship between project deliverables and scope management can be seen as a means of ensuring that the implementation of AR aligns closely with the specific needs and objectives outlined by the client or organisation. Clarifying the client’s requirements impacts scope management, and this is detailed in the quote below:

‘Yeah. So we have like, when we’re scoping out a project, we scope it out in regards to what we need to do on a technical perspective. And we also really get clarity from the client as to the nuts and bolts of what they need us to develop. And then we work very closely with them because we’re creating something bespoke for their use case. So it’s really not so much about us just presenting them with the solution as sort of us finding out what they need, and then guiding them like oftentimes clients will have a wrong idea of strengths and weaknesses of their technology and what can ... be done and what’s easy and what’s hard so we tend to guide them’ (S21).

An additional example of the connection between project deliverables and scope management can be found in the process of outlining the project deliverables. This includes a breakdown of the costs, timelines and schedules associated with the project, which ensures that the client is informed of the entire process.

Furthermore, it can be effective to address the organisational deliverables by incorporating brainstorming sessions. This collaborative approach fosters creativity and innovation, allowing a deeper understanding of the client’s needs and expectations. This methodology is further detailed in the data extract provided below:

‘I asked them about what they’re going to build with the targeted audience, and what they expect it to be. And then I scope it out. So I prepared a scope, I made sure that we covered everything, what needs to be done. And then I will tell them the resource requirement, how

many people will be required, what kind of skill sets were required. And then I will tell them the costing less dimensions, like milestones and timeframes and everything. So we communicate, we take as much information as we can. And then we formulate all these requirements into a scope of work. And then we share with the client and say, This is exactly what you want. Please confirm and then you can start. So yeah. brainstorming sessions will be there. Yes. Yeah, of course understand the vision' (S18).

Project deliverables → Transparency of project information

An example of the relationship between project deliverables and the transparency of project information is outlined in the data extract below. This example demonstrates the necessity of a clear understanding of what the user needs from the technology software designer. Sometimes, this may differ from the client's expectations, and it is essential for the client to be educated on what solutions will best meet their project requirements. This is outlined in the data extract below:

'Brief of like, what it is that they are wanting to achieve. And then defining it is what it is, like I mentioned before that they come to us, and they want one video, but actually getting their understanding of what that is. And then really making it clear of what how they envisage that being used in at the end. And then working back from that. Often, what we find is that it's slightly different. What people think that they want, is what they actually want. They would have seen' (S14).

An example of the relationship between project deliverables and the transparency of project information is provided in the following data extract. This example showcases the implementation of AR technology on the shop floor within the manufacturing line. Through AR, information is presented directly on the products, indicating what items to use and their correct placement. This approach increased project efficiency by significantly reducing the time needed for this part of the project, as it eliminated the need to repeatedly consult written data and determine item locations. Effectively designing information to be transparent with AR technology can ensure a positive outcome:

'So the information is getting really tiny and hard to read, but if you actually have it coming through your goggles, then what you're seeing is presented and you get only the information need for the part that you're working on, rather than having to fish through all the information to find the piece that you're that's relevant for you at the time' (E3).

Another example of the relationship between project deliverables and the transparency of project information is outlined below. An important quality of utilising AR technology is ensuring that the information displayed is transparent during the design phase. The data extract below illustrates how enhanced transparency of project information is incorporated by improved social licensing. This approach provides a safe way to utilise the information provided through AR technology, ensuring that businesses access data relevant to the project and the appropriate individuals involved. Furthermore, this transparency benefits companies that develop software for AR technology by offering a licence tailored to their specific needs and project costs:

'There is a key new term that we've developed or phrase that we've developed with some of the people we're working with at the moment. We call it improved social licence to operate through transparency of project information. So it's that key, right, which is the social licence, giving you that ability' (S19).

Organisational deliverables → Processes and procedures

This example highlights the relationship between organisational deliverables and processes and procedures. The accompanying data extract below outlines the importance of adhering to established processes and procedures and explains the vital role of gathering essential information for the effective integration of AR technology. By following these processes diligently, organisations can transform their work and create impactful content:

'here is an initial process of storyboarding and writing and scope of work and that sort of commercial side of things that sort of stays the same. And then it usually at some content needs to be built. And it's usually 3d models of thoughts doing some sort of thing. And then functions are applied to that. Overall, the processes are the same' (S23).

Another example of the relationship between organisational deliverables and processes and procedures is outlined below. This data extract highlights the crucial role of implementing simple and effective processes within an organisation, especially in the context of project management. Applying best practices in the early stages of a project can have a positive impact on the project:

'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' (SE11).

Organisational deliverables → Workflow

An example of the relationship between organisational deliverables and the workflow is detailed in the data example below. This example demonstrates that there are three key items to look at when selecting AR technology, and one of those key areas is the workflow. When incorporating AR technology into the project workflow, we need to make sure that this will be effective:

'Well, I think it's really part of the selection that we were making, because we I think it's, it's equivalent to, you know, the selection criteria. When we were considering whether these tickets, it's good or not, like the compatibility and also the setup time preparation time, and also the deploying workflow, these kind of three major key items' (C16).

Organisational deliverables → Resources

The relationship between organisational deliverables and resources is essential for a successful project. When implementing AR technology, it is critical to have qualified personnel overseeing the execution of the project. Furthermore, when resources are available, it is essential to ensure that all aspects of the implementation are completed thoroughly to maximise the potential benefits of AR. An example of this is outlined in the data extract below. This example outlines that the challenge of incorporating this technology is ensuring that the right people with the appropriate skill set to implement it effectively are found:

'the real challenge around it is finding resources. Right? So finding people with the skills and capabilities very small pool of people who've got skill sets in this area, especially in Australia at the moment' (C19).

The following extract illustrates the relationship between organisational deliverables and resources; the example outlines that having the resources needed is advantageous, especially when implementation is straightforward. Often, AR technology is available off the shelf and can be user-friendly if the right personnel are involved. In this case, the company has a specialised department dedicated to researching new technologies:

'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 is no real restrictions' (E10).

4.11.2 Financial deliverables

Financial deliverables represent a crucial and comprehensive range of cost considerations that are essential for the successful execution of any project utilising AR technology. These deliverables incorporate a variety of categories, including cost management, return on investment (ROI), quantifiable savings and project funding, which outline all necessary expenditures and financial forecasts essential for smooth project operations. The financial deliverables framework is outlined in Figure 4.4.

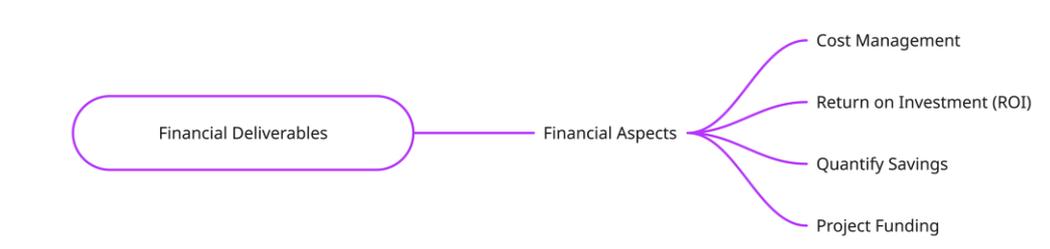


Figure 4.4: Financial deliverables

Financial deliverables have one set of relationships, and this is the financial aspect. Understanding these relationships and their meanings is essential to interpreting the dynamics of AR technology in the project and its relationships in the framework.

In the context of the current study, the financial deliverables category includes cost management, the return on investment, quantified savings and project funding, as defined below.

Financial aspects:

- Cost management: This is the cost associated with AR technology.
- Return on investment (ROI): This is the ROI of incorporating AR technology.
- Quantified savings: This is the predicted savings that the project will achieve.
- Project funding: This refers to the financial funds needed to support the project.

The relationships to financial aspects are further explained. These relationships highlight the importance of financial deliverables to projects.

4.11.2.1 Relationships extracted from financial deliverables

Each of the financial deliverable relationships was derived from the grounded theory approach. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for financial deliverables is detailed in Table 4.13. This table summarises the grounded theory approach to forming relationships and developing a theory for this research. The financial deliverables form 4 open codes, 1 axial code and 1 selective code.

Table 4.13 : Breakdown of financial deliverables relationships

Selective code	Axial code	Open code
Financial deliverables	Financial aspects	Cost management Return on investment (ROI) Quantified savings Project funding

Financial aspects → Cost management

The relationship between financial aspects and cost management indicates that organisations evaluate the costs associated with AR and perform a cost-benefit analysis to ascertain whether AR technology is suitable for their projects. The following data extract illustrates the costs associated with 3D modelling; it also highlights that there can be substantial variations in expense based on the size of the modelling requirements, and this needs to align with the organisational financial deliverables:

'I think that's the other part for your there's a lot of companies, there's some very big professional service companies who do 3d models, and very large, as I'm sure you have seen for your own projects, right. Massive 3d models, you know, that are done for really marketing purposes, right. They're incredibly expensive' (S18).

Below is another extract supporting the relationship between financial aspects and the AR cost. This example highlights the innovation involved in incorporating new technology, emphasising that there are costs associated with implementing new systems, and this needs to align with the organisational financial deliverables. The benefits may take some time to materialise; however, once this occurs, the advantages are substantial:

'If you're going into a project going, Hey, we can be innovative and use this new technology, and sort of 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 bit 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' (E10).

Financial aspects → Return on investment (ROI)

The relationship between financial aspects and the ROI for implementing AR technology is essential. An effective integration of AR technology should have measurable benefits. Understanding how the ROI influences both the adoption and utilisation of AR is essential for internal stakeholders looking to integrate AR technology.

An example of the financial aspects on ROI is illustrated in the data extract below. This extract outlines the correlation between financial aspects and the ROI. Utilising AR technology not only enhances the training experience by simulating real-life dangers in real time but also leads to significant cost savings and an improved ROI for stakeholders:

'You're doing this at scale of it can be a safety ROI that there's maybe some hands on stuff that you can train people in and even if you prevent one death or serious injury, like if it's a case where it's worth the cost. So I think it's really about for businesses, justifying the cost of development with a use case and ROI' (S21).

An example of an ROI can be seen when new technology is implemented in organisations. Although the initial cost may appear significant, it is crucial to consider that this is just the beginning of numerous projects moving forward. Analysing the ROI over a five-year period shows that it will yield positive returns across the business. The most challenging aspect of adopting new systems or technologies is the initial implementation. This is further illustrated in the data extract below:

'As mentioned above, cost /ROI would be a big factor; being able to utilise the technology not just for one project or application but being able to maximise it through ongoing projects or various applications across the business' (SE11).

Financial aspects → Quantified savings

The relationship between financial aspects and quantified savings highlights the importance of organisational deliverables in ensuring quantifiable savings when implementing new

technology in projects. The example below illustrates that, in this case, there were significant savings in labour when implementing AR technology. This implementation allowed for a more streamlined production flow, resulting in reduced man-hours and a lower overall job completion time. In this instance, implementing AR technology allowed for savings, and this is one of the main reasons that new technology is being incorporated:

'I guess there's two ways. So, you know, I talked about being able to quantify the savings to the company in terms of labour, yeah. So that's, I guess, the bottom line the company cares about is money. What most people care about is money' (E3).

Financial aspects → Project funding

The relationship between financial aspects and project funding is crucial to ensuring that there is funding for new technology in projects. Understanding this relationship is essential for ensuring that projects have the necessary funding to succeed. The example discussed below highlights the significance of understanding the value of AR technology. This example explains how funding can become unreliable, particularly in response to external factors such as organisational restructuring. In such situations, it is important to navigate the financial aspects to maintain support for innovative initiatives:

'So we did all the scoping and everything, but it was also okay, but then suddenly, they have some restructuring and then they were like other audits are not going ahead. So yes, it was good use case. They really wanted and it would really adding value to them. But many time, the management they have maybe they don't see the advantage of doing these or maybe they they're not educated enough, how they can leverage these. So there are a few factors as well like then to understand that what they're getting and what the value that' (S23).

4.11.3 Legal and regulatory deliverables

Regulatory and legal considerations encompass contractual obligations, permissions and the regulatory aspects of commercial applications. These elements are detailed further, alongside technology regulations and contractual stipulations related to AR usage. Regulatory and legal deliverables are prominently highlighted in Figure 4.5.

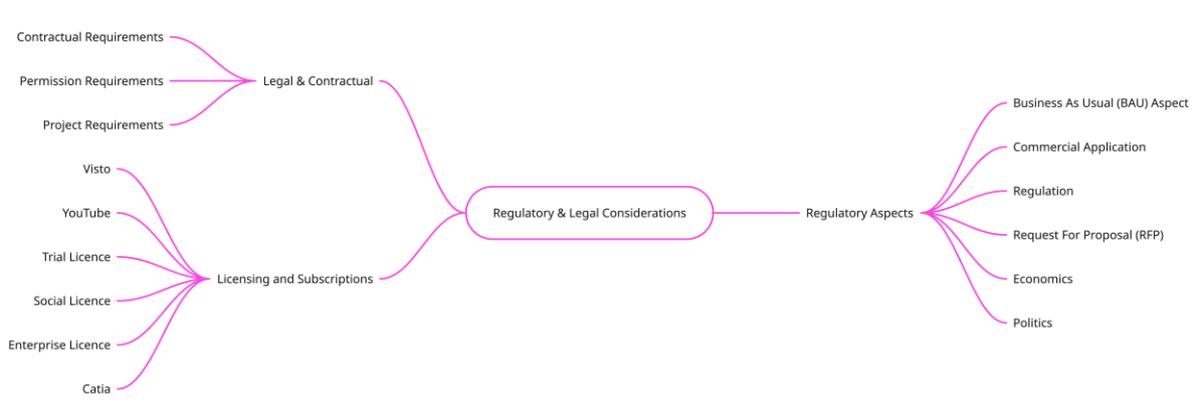


Figure 4.5: Regulatory and legal deliverables

The framework includes a section for regulatory and legal deliverables, which is linked to both organisational deliverables and the project scope. In this current study, legal and contractual considerations include contractual requirements, permission requirements and project requirements, as defined below.

Legal and contractual considerations:

- Contractual requirements: There are contractual requirements between organisations and the client.
- Permission requirements: This refers to permission and authorisation requirements for software.
- Project requirements: This refers to the project requirements and the terms and agreements.

In this study, the licensing and subscriptions category includes the use of Visto, YouTube and Catia, which may involve obtaining a trial licence, a social licence or an enterprise licence, as defined below.

Licensing and subscriptions:

- Visto: A licence is required to use Visto corporately.
- YouTube: YouTube can be used for education purposes corporately.
- Trial licence: A trial licence can be used before purchasing a corporate licence when using software.
- Social licence: This is an agreement between the organisation and stakeholders for the transparency of project information.
- Enterprise licence: This refers to an organisation's licence for software.
- Catia: A licence is required to use Catia corporately.

In this research, regulatory aspects include business-as-usual aspects, commercial applications, regulations, the request for proposal, economics and politics, as described below.

Regulatory aspects:

- Business-as-usual (BAU) aspect: This refers to the organisational BAU delivery of projects.
- Commercial application: This refers to the commercial use of AR technology.
- Regulation: This refers to the regulations of AR technology.
- Request for proposal (RFP): This is related to the tender stage and RFP requirements.
- Economics: This refers to the external influence impacting AR technology.
- Politics: This refers to the political influence impacting AR technology.

The relationships and the supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.11.3.1 Relationships extracted from regulatory and legal considerations

Each of the regulatory and legal considerations relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for regulatory and legal considerations is detailed in Table 4.14, which outlines the grounded theory approach to forming relationships and developing a theory for this research. The regulatory and legal considerations form 15 open codes, 3 axial codes and 1 selective code.

Table 4.14 : Breakdown of regulatory and legal considerations and their relationships

Selective code	Axial code	Open code
Legal and regulatory deliverables	Legal and contractual	Contractual requirements
		Permission issues
		Requirements
		Visto

Licensing and subscriptions	YouTube Trial licence Social licence Enterprise licence
Regulatory aspects	Visto YouTube Trial licence Social licence Enterprise licence Catia

Legal and regulatory deliverables → Regulatory aspects

The relationship between legal and regulatory deliverables and technology regulation highlights an increase in the digitalisation of projects. With this growth, various issues concerning regulatory and legislative requirements have emerged. Therefore, it is essential to ensure that any new technology implemented meets the specific project needs and is safe to use.

An example of the relationship between legal and regulatory deliverables and technology regulation is illustrated in the data extract below. This example highlights the extent to which technology is heavily regulated, particularly concerning the increasing digitisation of projects. As more projects incorporate digital elements, there is a concern regarding technology regulation. This is particularly evident in Australia, where large organisations have been targeted by cyberattacks and personal data have been compromised. Therefore, it is essential for regulatory aspects to integrate technological advancements to safeguard user data effectively:

‘Increased digitisation of workflows has issues regarding regulation and relevant legislation. The leading edge of technology tends to be less heavily regulated, and this can lead to invasions of privacy and other rights’ (SE10).

It is important to acknowledge that technology evolves rapidly and is often influenced by political needs. As a result, understanding the implications of these technological changes is crucial, particularly in the context of political influence. This significance is supported by the data extract provided below:

'But also, as we learned, one of the really important things that's, you know, become a feature of our product is the design has changed so rapidly, which we didn't understand. We were going through crazy iterative processes with the client, about design changes that were either influenced by politics, or by community, or by budget, or by whatever it is, right' (S19).

Legal and regulatory deliverables → Contractual requirements

The relationship between legal and regulatory deliverables and contractual requirements is essential when dealing with third parties and/or tender processes. It needs to be noted that careful deliberation when signing a contract needs to take place to ensure that all areas of contractual needs are met and agreed with:

'Actually, because the contract requirement. Because in our world of the BIM world, the AEC world for digital engineering, we have a requirement for we have LOD, I'm not sure if you aware of the LOD level of details about the model. So we have, like, 100 to 500 where 500 the most extensive one would hire you to have a model that's exactly the same, or, you know, relatively close to the wheel well' (C15).

Legal and regulatory deliverables → Licensing

The relationship between legal and regulatory deliverables and licensing is outlined below. This example illustrated that companies will purchase an enterprise licence when incorporating AR technology and software, allowing all members of the organisation to use this technology under one umbrella:

'It's getting easier, because we were using, well with visto is on our project portfolio. So basically, when we do project, we use visto, and since last year, they have integrated the AR function. So it's pretty easy to do. We just use it on site directly, so there's no need for a separate item, because we have an Enterprise license with so all our projects, it will be set up as a project if we have a model, then the team has a chance to use it directly' (C15).

4.11.4 Safety

Safety deliverables encompass various critical components, including human factors, equipment safety, physical limitations and the overall health and safety implications related to the AR devices. When integrating AR technology into any project, it is essential that safety considerations are prioritised before any technical implementation takes place. This commitment to safety can be effectively demonstrated through risk assessments and testing phases leading up to the deployment of the technology. Safety is represented in Figure 4.6.



Figure 4.6: Safety deliverables

Safety has two sets of relationships, and this includes cognitive ergonomics and safety. Understanding these relationships and their meanings is essential to interpreting the dynamics of AR technology in the project and its relationships in the framework.

In this research, the cognitive ergonomics category includes human factors, as defined below.

Cognitive ergonomics:

- Human factors: This refers to how individuals act within their environment.

In the current research, safety includes equipment safety, physical limitations, physical safety, health and safety and ethics, as defined below.

Safety:

- Equipment safety: This refers to safety aspects when using AR technology.
- Physical limitations: This refers to eliminating physical limitations with AR technology.
- Physical safety: This refers to the physical safety of the user when they use a headset.
- Health and safety: This refers to general health and safety aspects.
- Ethics – technology: This refers to users’ ethical consideration of technology.

The relationships and supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.11.4.1 Relationships extracted from safety deliverables

Each of the safety deliverables relationships was derived from the grounded theory approach. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis outlined in the safety deliverables is detailed in Table 4.15, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Safety deliverables and their relationships form 6 open codes, 2 axial codes and 1 selective code.

Table 4.15 : Breakdown of safety deliverables and their relationships

Selective code	Axial code	Open code
Safety deliverables	Cognitive ergonomics	Human factors
	Safety	Equipment safety Physical limitations Physical safety Health and safety Ethics – technology

Cognitive ergonomics → Human factors

The relationship between safety and the use of AR technology includes both the physical safety of wearing the device and the user’s awareness of their surroundings. AR technology enables users to see their environment enhanced with digital overlays. However, there are instances when individuals become immersed in the augmented elements that safety can be compromised. This raises significant safety concerns, as users may inadvertently put themselves at risk. The excerpt below illustrates this safety issue:

‘Firstly safety of what I’m seeing and how the how my feedback or responses are being captured, or where that data is going. So privacy and safety is key, but also physical safety, because when you when you’re wearing augmented like an augmented reality headset, not to bump into things in the real world and hurt yourself. So safety is would be like physical safety, like I was saying where you’d bump into things while wearing the headset, that would be concerning. So as long as there are like warnings or something to say, hey, there’s you might bump into this. Or just to make sure people are aware of the surrounding still while using that headset. And it depends on what application they’re using it for. If they’re holding still while putting together a creating some sort of artwork and wearing this headset, it’s much safer. But if they’re on the move, walking around a space while using it, I reckon safety would be a concern’ (E4).

Safety → Health and safety

An additional example of safety and AR use is illustrated by the data extract below. This extract highlights that the implementation of such technology can establish a correlation between a reduction in safety incidents and the use of AR. In vehicles and motorcycles, technology such as heads-up displays (HUDs) and helmet-mounted displays (HMDs) inform users of information. Integrating this technology in aviation could potentially mitigate safety risks, enhancing overall operational safety in the aircraft industry. This application of AR not only streamlines information but also supports pilots and crewmembers in making decisions that can prevent accidents and improve safety standards:

'I'm looking forward to the use of AR by pilots. Right now most of the information the pilots are presented are on displays in the cockpit. You could argue this is a form of augmented reality I guess. In commercial and military application the use of head up displays (HUD) and helmet mounted displays (HMD) push this further. I'd like to see AR make it into the general aviation world of flying. Done right, this should work towards reducing the amount of aviation incidences caused by lack of situational awareness' (SE21).

Introducing AR technology in a new environment can lead to confusion for new users. In this instance, AR technology was implemented in a manufacturing settings. A specific challenge was observed on the manufacturing line, where some employees faced difficulties with vertical movement, particularly when looking up and down. To address this issue, several modifications were made to improve accessibility and create a more user-friendly experience with AR tools. These enhancements not only reduce disorientation but also facilitate a smoother workflow for all personnel involved:

'So we found that first when they were sort of trying in it, they were like, Oh, this is a really crappy job. It takes forever. And we said, we're gonna go get you the goggles, and the first operator put them on, and it's like, oh, this is awesome. But then he found it was hard to look up and down with the glasses on. So because it's a two man operator job, anyway, we had it was about working out the best sort of sequence for the process as well. So we had one operator put the goggles on and tell the other guy what to install wear, so we had one person directing and the other person doing, and that made it easier, because they weren't trying to do two things at once' (E3).

Safety → Physical limitations

Using AR technology can effectively eliminate physical complications in real-time displays. Using AR technology can eliminate safety issues by reducing or removing access to construction sites with hazardous conditions. The example below demonstrates that AR

technology can be utilised at a wind farm to navigate and overcome these physical challenges:

'I think, would be overcoming the fear of physical limitations. So again, you know, like that sort of link to the first point, which is, especially for these large infrastructure projects, you can experiment with your device, without the burden of, you know, the physicality of, you know, a 70 metre tall, you know, transmission power or a 250 metres tall wind turbine, we can't just plunk that, you know, out of nowhere onto a piece of land and see how that looks. But you can do that in augmented reality. So, you know, that's a huge driver, for people for, you know, in our context in engineering construction, on the uptake of the technology, which is overcoming those physical limitations' (S19).

4.12 Project Input

The project input consists of four key selective categories, including early adopters, project management, specific use cases and expert skills and development; this is further detailed below and displayed in Figure 4.7:



Figure 4.7: Project inputs

1. Early adopters: This category encompasses the experiences of early adopters and considers the accuracy of the design, AR functionality, prototyping processes, AR implementation strategies, project deliverables and overall project strategy.
2. Project management: This aspect includes critical elements such as decision-making processes, workflow optimisation, adherence to established processes and procedures, effective project handover, strategies to reduce the travel time, the management of delivery pressures, the utilisation of real-time data, problem-solving techniques, time management practices and resource allocation.
3. Specific use cases: This category highlights specific use cases, various AR application cases, marketing strategies, environmental challenges and interactions with environmental factors.
4. Expert skills and development: This encompasses the technical perspectives required for the project and the expertise of subject matter experts (SMEs), as well as skills relevant to engineering and construction.

Systematically categorising the project inputs establishes a robust framework that directs the needs of the project in this framework.

4.12.1 Early adopters

Early adopters play a crucial role in project deliverables, which include design and development. This process involves various design aspects, customisation, functionality, feasibility and AR development. The project design not only outlines the project's direction but also identifies its needs and deliverables, along with the overall strategic direction.

Early adoption leads to effective project management, the identification of specific use cases and the application of specialised skills during development. It is essential to recognise the importance of innovation and the adoption of new technologies in our increasingly digital environment. Implementing proven systems and engaging early with relevant stakeholders are critical for successful project development. The early adopters framework is shown in Figure 4.8.

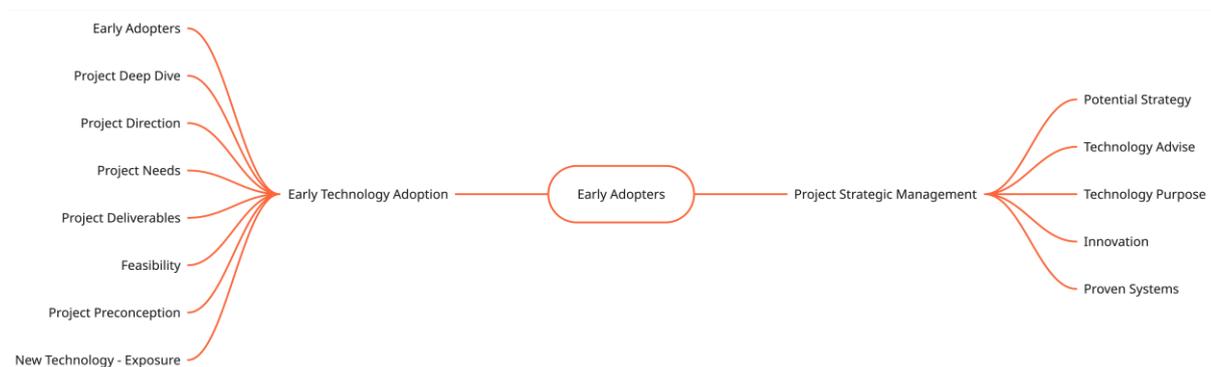


Figure 4.8: Early adopters

Early adopters have two sets of relationships: early technology adoption and project strategic management. Understanding these relationships and their meanings is essential to interpreting the dynamics of AR technology in the project and its relationships in the framework.

In this research, the early technology adoption category includes the early adopters, project deep dive, project direction, project needs, project deliverables, feasibility, project preconception and new technology exposure, as described below.

Early technology adoption:

- Early adopters: This involves identifying key items in the early stages of the project.
- Project deep dive: This refers to the high-level scoping of the project.
- Project direction: This refers to the overall guidance and objectives of a project and what is required.

- Project needs: This refers to the specific requirements and objectives that must be met in order to complete a project.
- Project deliverables: This refers to the specific outcomes that are expected to be completed by the project.
- Feasibility: This is the high-level practicality of the project.
- Project preconception: This is the initial conception of how the project will be delivered.
- New technology exposure: This refers to the exposure to new technology.

In the current research, project strategic management, which includes the potential strategy, technology advice, technology purpose, innovation and proven systems, is described below.

Project strategic management:

- Potential strategy: This is the project approach used to successfully deliver the project.
- Technology advice: This is the professional advice given for technology direction.
- Technology purpose: This refers to the purpose of integrating a particular technology into the project.
- Innovation: This refers to how innovation in strategic planning outlines the opportunities for technology integration for the project.
- Proven systems: This refers to integrating proven systems in projects, as per BAU.

The relationships and the supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.12.1.1 Relationships extracted from early adopters

Each of the early adopter relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis outlined for early adopters is detailed in Table 4.16, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Early adopters and their relationships form 13 open codes, 2 axial codes and 1 selective code.

Table 4.16 : Breakdown of early adopters and their relationships

Selective code	Axial code	Open code
Early adopters	Early technology adoption	Early adopters Project deep dive Project direction Project needs Project deliverables Feasibility Project preconception New technology – exposure
	Project strategic management	Potential strategy Technology advice Technology purpose Innovation Proven systems

Early technology adoption → Early adopters

The following extract outlines the relationship between early adopters and the integration of AR technology. It highlights the need for innovation and the requirement for reliable systems when integrating new technology. Additionally, the extract outlines the challenges of being the first to implement a new system and adapt to change, particularly in larger organisations, where numerous processes and procedures are in place. Furthermore, it clearly demonstrates the significant impact of AR usage on early adopters:

‘So it’s only an environment that really, there is no set way that they do things that this sort of technology can kind of stand up. And it won’t be until that’s more commonplace that more people get on board. So finding those early adopters is going to be a sort of real key. Because people don’t really know as much as they talk about innovation and things like that. It’s hard to be the first people easier use like, particularly in aerospace, like you want to use proven systems and technologies rather than being trailblazers’ (E10).

An additional example highlighting the experiences of early adopters and the utilisation of AR technology is presented below. This example illustrates that AR technology is still in its early days compared to VR technology. However, it also emphasises how AR is emerging as a prominent tool similar to VR, indicating a growing trend in its adoption and application. The details of this progression are captured in the following extract:

'Yeah, yeah. So let's say with VR, as well, like you always have that relapse, early adopters do this for years. And before there was any technology available. And then you have, like a silent majority, or whatever that came in before it comes mainstream. So I think we're at a stage now with augmented reality. its still very much early adopters. Yeah, maybe a couple of exceptions' (S21).

The relationship between the implementation of AR and its practical application is extremely important. When AR technology is integrated into a project, it allows users to have an immersive experience. This implementation process identifies existing challenges but also helps clearly define the main objectives behind adopting AR technology. The data transcripts below outlines how effective AR implementation can lead to significant improvements and outcomes in various projects:

'At the moment is usually they're happy about it. And if they're happy about it, then it'll get implemented. I don't think the timelines and the project have been, like long enough, and the amount of projects haven't happened to get big amounts of data citizens, whether people are experienced with good or average of that. Yeah, if there's not much feedback at the moment, as far as that we're happy. And then after that, it's probably going to be okay' (S23).

The following data extract provides an additional example of AR implementation and application. This example outlines the appropriate circumstances for utilising AR technology while identifying problems that require resolution. An example of this is workflow management and the challenges that may arise during the integration of AR technology. Additionally, the use of AR can potentially reduce some of these difficulties, enhancing the overall efficiency and effectiveness within various tasks in the construction industry:

'Yeah, I think first of all, I will, we will look into our causes to find out what's the problem...and what is our objective to implement this? As I said, do we want to improve efficiency, or do we want to save costs somehow, but of course, it's not necessary. So I would, first of all, understand our pain point in our workflow, or the way people will improve. And then based on that, I will try to implement or, you know, look into the technology from the AR, or maybe even our technology where this can fit in for we so you know, our workflows issue, the challenges. And then, in general, the next thing I'll do to contact them... on either call or email' (C17).

Early adopters → Project deliverables

The relationship between early adopters and project deliverables is essential for the success of a project. By integrating AR into the project framework, organisations can improve their ability to achieve specific deliverables and ensure that the intended outcomes are delivered.

To ensure that all deliverables meet the requirements, it is essential to integrate AR throughout the project. Utilising AR technology within the project environment facilitates a comprehensive evaluation of deliverables against the set criteria, thereby enhancing the likelihood of achieving project objectives. An example of this is outlined in the data extract below; this example outlines that there needs to be a clear understanding of the project requirements and deliverables. This can be accomplished by implementing regular meetings:

'So product is not going to fit everyone's requirements. In the same way, but it's still important. Again, it's more, it's a sales process, right, which is going leading with an understanding of the client's broad requirements, and putting your best foot forward in terms of presenting the feature sets of your application that match the majority of the clients requirements. And they're not met, they may not reach all in terms of process we use and it's quite common in text based Discovery sessions. Right. So discovery is essentially one with series of meetings with clients to extract the project definitions, requirements, deliverables, you know, outcomes that they sort of looking for, we do of course, you know, our best to match all of those to the current feature sets and capabilities of the of the application' (S19).

Another example of this can be found in the data extract below. This example outlines that when new technology is introduced in the construction sector, certain individuals may not recognise its importance immediately. This lack of awareness often remains until they begin to understand the benefits. Once implemented, AR technology can enhance the project outcomes, leading to increased efficiency and effectiveness in construction processes:

'Definitely it is, wherever he is acceptable acceptance from individual people. Yeah. And I think at this point of time, it's almost like one to nine. One is subset nine is reject, yeah, it's actually a bit difficult to convince them or, you know, to show them what the, what the tech can do, and whether this is really happened to me. And even if they consider this helping them. I think they, they, you know, this is one of like, 9000 things that you could do on site. So they might consider this is not their priority or that important. And either they will miss it, or they will just ignore it. Until, at the very least, so especially a case that they want, we want to apply some new tech to get some to get something done' (C16).

Early adopters → New technology exposure

The relationship between early adopters and new technology exposure is detailed in the data extract below. Exposure to new technology refers to the advantages of incorporating innovative technologies into projects. Adopting new technology might involve higher initial expenses and presents potential risks that must be considered over time; however, being exposed to new technology is beneficial, and once it is accepted by companies and individuals, it can bring efficiency and productivity. The example highlighted below illustrates that exposure to new technology for individuals and organisations brings benefits, as this suggests that they are more susceptible to change. Therefore, adapting to new technology will be easier:

'I think the it's it's more the appeal is more towards people who had more exposure to technology and different types of technology and new technologies. Yeah, so I think that's that the differentiation in terms of who is more likely to use it? Not so much by age or seniority? It's more so how much exposure they've had to using technology and I guess, yeah, newer mediums of technology' (S19).

Another example of new technology exposure is detailed in the data extract below:

'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 written necessarily in a business sense' (E10).

The relationship between early adopters and new technology exposure is also outlined in the data extract below. This example highlights that integrating new technology necessitates an investment of resources and commitment:

'It could be, because of you know, this is still new technology, it's not like a mobile phone that everyone will get one. So you might have to prepare a lot of information before you, you know, we talked about like a company situation, you have to, you know, get your finance, commercial approved, so they can get these technologies in the company, I think that could be the major issue' (C17).

Project strategic management → Potential strategy

The relationship between project strategic management and the potential strategy is fundamental for effective strategic planning and the delineation of project deliverables. The

project strategy encompasses the comprehension of the vision and the direction of the technology, as well as its intended applications. It also involves identifying the most effective methodologies for employing AR technology.

In the environment of strategy and innovation, it is essential to rely on proven systems that demonstrate tangible benefits. An example of this is elaborated upon in the following data extracts. The example below outlines a strategy within the construction field. There is a digital strategy manager, as well as a digital engineering manager; both managers work on implementing both new and existing technologies. In this instance, the digital engineering manager is more field-oriented compared to the strategy manager, but they work closely together:

'Well, I'm actually from start to end, but like more in the overview and how they integrate the digital strategy. We do have a delivery manager, like digital engineering manager, so because my position is really on the strategy side, to record like the project, what digital tools they use' (C15).

The following data extract illustrates the relationship between project strategic management and the potential strategy, detailing that for larger organisations, investigating new technologies can be challenging. Therefore, it is essential to have a defined strategy for implementing new technology. Proven systems should be prioritised as reliable solutions; however, technology is growing rapidly, and using outdated technology will eventually hinder the success of the project. Additionally, a comprehensive approach to technology integration is necessary to ensure a smooth transition and the effective adoption of innovative tools within the organisation:

'Personally, myself, I like to get involved in these things kind of as early as possible. But as you're sitting in most businesses, these days, there's a lot of pressure to deliver, and a lot of lack of resources, and all those sorts of things. And that kind of prevents people from exploring and investing in new ways of doing things. So it's only an environment that really, there is no set way that they do things that this sort of technology can kind of stand up. Because people don't really know as much as they talk about innovation and things like that. It's hard to be the first people easier use like, particularly in aerospace, like you want to use proven systems and technologies rather than being trailblazers' (E10).

Project strategic management → Innovation

The relationship between project strategic management and innovation is illustrated in the data extracts below. The following example suggests that innovation is often pursued when there is an intention to enhance value and further emphasises that both individuals and companies are inclined to embrace innovation when the aim is to add value. It is also observed that larger corporations tend to remain committed to existing practices, often adhering strictly to the status quo rather than exploring new opportunities for innovation:

'Resistance to change is everywhere. And, you know, until they're proven otherwise, it tends not to happen, right? So, you know, they try to if that whole value segment, how does this add value? Right? So, if people are looking to these sort of more engaged in moving forward of technology and trying to be innovative, then the acceptance is there, but a lot of people, particularly big companies are very much about, let's stick to the status quo' (E10).

The relationship between project strategic management and innovation emphasises how strategic management integrates with innovation. When innovation is incorporated into projects, it enables new methods of operation. The example below illustrates the significance of adopting new technology in projects and how innovation represents the acceptance of such technology:

'And, you know, until they're proven otherwise, it tends not to happen, right? So, you know, they try to if that whole value segment, how does this add value? Right? So, if people are looking to these sort of more engaged in moving forward of technology and trying to be innovative, then the acceptance is there, but a lot of people, particularly big companies are very much about, let's stick to the status quo' (E10).

The relationship between strategic management in projects and innovation is further explained in the following. This example highlights how innovation drives the pursuit of new projects with a strategic focus, aiming to engage with innovative practices and solutions actively:

'Absolutely. And it's also an additional unknown in a time perspective as well, right? If you're going into a project going, Hey, we can be innovative and use this new technology, and sort of get involved in that perspective' (E10).

An additional example of this relationship is illustrated below. This example demonstrates that innovation is positively correlated with the use of AR, as AR technology is proposed to

enhance the project's efficiency and expand its overall capabilities. Integrating AR will streamline processes and significantly improve project outcomes:

'Because this thing is not like it's still not like the company business as usual tech? Yep. That's per project or per even the construction manager or per task. I mean, if there's some crucial task, they wonder they are seeking for our tech to do something new or something more efficient, then we will try to help him propose this, you know, AR technology' (C16).

4.12.2 Project management

Project management deliverables encompass a range of tools and workflows that integrate processes and procedures, facilitate decision-making, promote the transparency of project information and enhance problem-solving capabilities. Furthermore, these deliverables include time and resource management, which comprises time and motion studies, effective time management strategies, resource allocation, real-time data analysis, response times, project lead times and delivery requirements. This information is described in more detail below and in Figure 4.9.

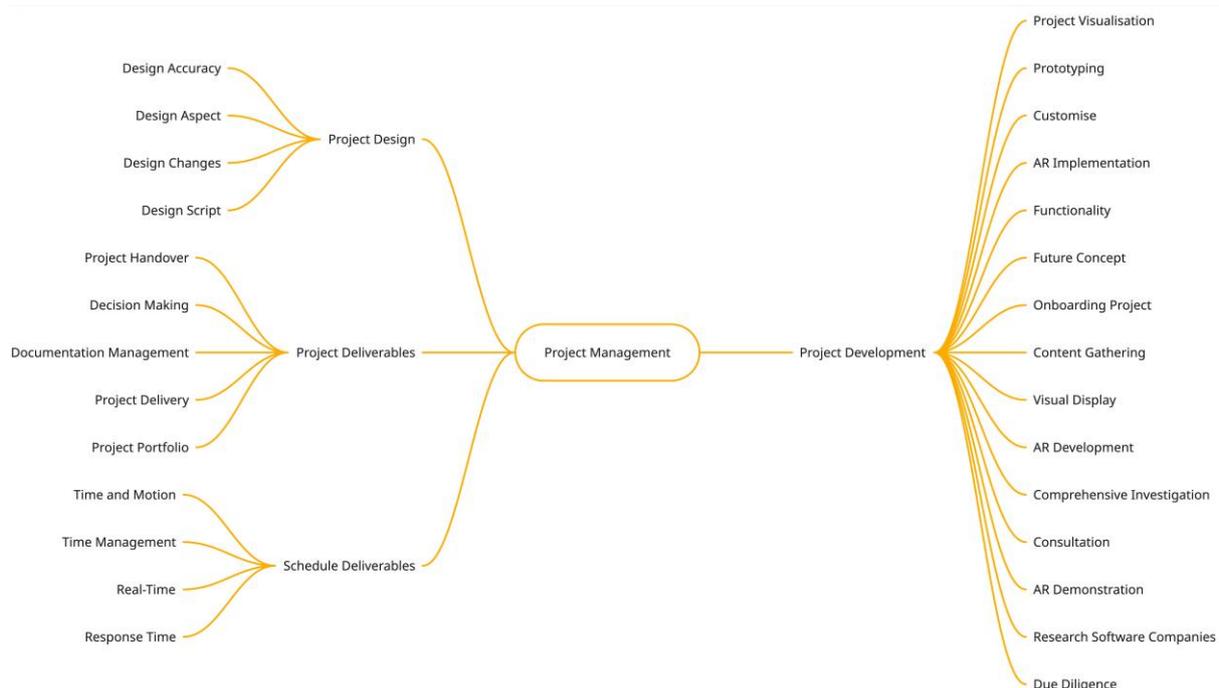


Figure 4.9: Project management

Project management has four sets of relationships. These relationships are project development, project design, project deliverables and schedule deliverables. Understanding these relationships and their meanings is crucial for interpreting the dynamics of AR technology within the project and its interactions within the framework.

In this research, project development, including project visualisation, prototyping, customisation, AR implementation, functionality, the future concept, the future project stage, the onboarding project, content gathering, visual display, AR development, comprehensive investigation, consultation, AR demonstration, the search for an AR designer, research software companies and due diligence, is detailed below.

Project development:

- Project visualisation: This refers to when AR technology is used for the digital visualisation of the project.
- Prototyping: This refers to when a preliminary digital version of the project is made using AR technology.
- Customisation: This refers to when a customised version of AR technology is used to suit the project's needs.
- AR implementation: This refers to when AR technology is incorporated into the project.
- Functionality: This refers to when AR technology is utilised to achieve the project's objectives.
- Future concept: This refers to when AR technology is utilised for concept purposes.
- Onboarding project: This refers to the initial questions posed before project initiation.
- Content gathering: It is initiated in the early stages of the project and involves gathering content.
- Visual display: The visual display should be developed in accordance with the requirements.
- AR development: This refers to the AR technology requirements in the project.
- Comprehensive investigation: This involves thoroughly identifying the project needs.
- Consultation: This involves identifying project requirements and understanding client expectations.
- AR demonstration: This refers to when AR technology is used for a demonstration prior to implementation.
- Research software companies: This involves identifying software companies that fit the project needs.
- Due diligence: The project requirements are reviewed to confirm that the necessary steps have been taken to assess the project's feasibility.

In this research, the project deliverables category, including project handover, decision-making, documentation management, quick project delivery, scaling up or down and the project portfolio, is defined below.

Project deliverables:

- Project handover: This refers to the requirements for the AR technology once it is handed over to the client.
- Decision-making: This refers to the decision-making process and those who make the decisions.
- Documentation management: This refers to the documentation process during the development of the project.
- Project delivery: This refers to delivering the clients' project needs in relation to AR technology.
- Project portfolio: This refers to when AR technology is integrated into the project portfolio.

In the current research, the schedule deliveries category, including the time and motion, time management, real time and response time, is defined below.

Schedule deliverables:

- Time and motion: The time and motion involved in a specific work task are observed.
- Time management: This involves managing and implementing AR technology and determining its relation to the time spent on project tasks.
- Real time: This refers to when AR technology utilises a real-time data display.
- Response time: This refers to when AR technology is utilised to improve the response time using a visual data display.

In this research project, the project design category includes the design accuracy, design aspects, design changes and design script, as defined below.

Project design:

- Design accuracy: This refers to when AR technology is utilised to ensure an accurate design for the project.
- Design aspect: The type of AR technology used is tailored to the project's specific needs.
- Design changes: Initial design changes are used to support the project objectives.
- Design script: This includes AR technology wants and project needs.

The relationships and supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.12.2.1 Relationships extracted from project management

Each of the project management relationships was derived from the grounded theory approach. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for project management is detailed in Table 4.17, which outlines the grounded theory approach to forming relationships and developing a theory for this research. The project management relationships form 28 open codes, 4 axial codes and 1 selective code.

Table 4.17 : Breakdown of project management relationships

Selective code	Axial code	Open code
Project management	Project design	Design accuracy Design aspect Design changes Design script
	Project development	Project visualisation Prototyping Customisation AR implementation Functionality Future concept Onboarding project Content gathering Visual display AR development Comprehensive investigation Consultation AR demonstration

	Research software companies
	Due diligence
Project deliverables	Project handover
	Decision-making
	Documentation management
	Project delivery
Schedule deliverables	Project portfolio
	Time and motion
	Time management
	Real time
	Response time

Project development → Visual display

The correlation between project development and the visual display is clearly demonstrated through the data presented. This relationship indicates that every project has requirements and specific needs. The visual display of AR technology is a large influence on project development. When integrating new technology, an implementation strategically is essential; specifically, this example below details the process of conducting maintenance on an aircraft. It highlights the importance of developing step-by-step guidelines that outline the necessary tasks and resources required for effective maintenance execution in a visual display:

'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 like conveyancing say you're doing maintenance on aircraft or something in your had a setup is familiar with inside the landing gear augmented reality could point a maintenance person to a particular line to say that's what you need to do, and bring up information that actually shows what they need to do step by step' (E10).

The data extract below outlines the significant impact of the visual display. This example focuses on initiatives that have already been implemented at this manufacturing plant. The implementation of AR is driven by engineering requirements, making visual display essential. This example discusses how reducing printing and using AR technology not only reduces the need for physical printing but also a need for visual representation. Additionally, the integration of AR allows real-time data visualisation:

'in the, like preconception side of things. But I think based on where we've got, where we've used them, we've now got a whole bunch of examples where I think we'd like to implement them from us. It all stems from the engineering requirements. So we can look at the engineering requirements and say, Okay, this is the information we need to impart, and then we give that to the programming team. So to say, like, usually, where it's information that we're printing out on paper visually is sort of where we've targeted to implement it. So where we've got a visual representation of our engineering that we then print out on paper for the for the team on the floor, where, like, I printed on paper when we visually display it for them. Yeah, in rather than 's so that's, I guess, for the most of the applications we've incorporated so far, where the sort of requirements have been communicated. It's like, here is the information in 3d in a model that we'd like to present in 3d in real life' (E3).

Project development → Prototyping

The relationship between project development and prototyping is vital in the product design process. A prototype offers valuable insights into the product's capabilities. This understanding not only clarifies the design requirements but also greatly aids in successfully developing the final product. Additionally, this concept is detailed in the accompanying data extracts, which offer further context and examples to highlight the importance of integrating prototyping with AR in product design:

'people seeing things that we've done previously... And then we go through a bit of a sort of bit of a process, like an initial meeting, and then send through a quote. One thing that we do often is send through with the quote, like a very basic prototype, or something relatively basic, but gives us sort of understanding of like one. It gives us an understanding if that's the sort of thing that they're wanting, but then also short, I think it helps them see something' (S12).

An additional example of the relationship between project development and prototyping is detailed in the following data extract. This example highlights the importance of having a prototype, as it provides clients with a tangible preview of the concept that can be developed. Furthermore, this interactive approach allows clients to express their preferences and suggest any modifications that they believe are essential to meeting their needs:

'it's more about like, when you want it, we did discuss the realistic one, you know, interview with the environment and discuss, you know, the design, but how many clients would wear these kinds of Reality Devices to discuss this. Some of them will prefer to just make a

prototype, as you mentioned about like these prototypes, they were just trying to make a physical prototype instead of like jumping into AR/ VR' (C17).

Project deliverables → Decision-making

The relationship between project deliverables and decision-making is significant. AR technology enhances decision-making capabilities and reduces potential risks. This impact of AR technology on decision-making is supported by the following data extract. The following example outlines how AR technology enhances the construction industry, particularly in the realms of planning and estimating measurements. By enabling precise 1:1-scale visualisations, this technology facilitates changes in design. Furthermore, this technology provides real-time data and analytics; this helps with identifying potential risks associated with construction projects. This is further detailed in the data extract below:

'The use of this technology assist with my day-to-day tasks when it comes to estimating or planning for a project in construction. The technology is more advance as it will help me with mapping out all the utilities that potentially changed the design of the project or the potential risks required to be mitigated prior to commence of the project and preliminary findings' (E1).

The following supporting data extract outlines the importance of ensuring that the individual purchasing technology for the project understands its benefits and potential impact on users. By identifying both the end-users and the specific applications of the technology, we can facilitate a smoother integration and optimal use, thereby determining the best solutions, tailored to the end-users' needs:

'So the person who is directly involved in the purchasing decisions, they need to understand what it is and what it can bring to them. And who will be the target audience and what they can do. So even you show them a lot of advantages of doing this, this can add a lot of value. But many times they will be like now, because maybe they they're lacking knowledge or maybe they don't know what can be done or how their target audience will react' (S18).

Another decision-making aspect of purchasing AR technology is the consideration needed for setting up AR technology and ensuring that the right set-up is implemented for the project. Different engineering projects may require varying types of AR technology, including headsets, projectors, head-up displays, computers and phones. This is outlined in the extract below:

'I suppose part of the challenges of actually making the decision to move towards an AR tech setup is that there are a few different variants out there. And making sure that you're using the right one is probably a complicated thing to understand from the get go' (E10).

The following data extract offers an overview of the various types of digital technology. It outlines the processes involved in establishing a detailed table comparison with digital technologies, enabling informed decision-making that aligns with the organisational requirements of both the project and the users' needs. This approach ensures that the chosen AR solution is beneficial and tailored to meet the strategic goals and project needs of the business:

'We have a table comparison, you know, with the different software in we always start out there and climate in our equipment, if he matched and, you know, putting some marks over there, and then we will, in the end or come up with a better picture of which software which one there is going to provide a much more suitable software for us. And then you make a decision based on, you know, the analytics that we have done on different software' (C16).

Project design → Design accuracy

The relationship between the project design and design accuracy is critical for the validation of design concepts and ensuring that the original design intent is evident. Accurate design is essential in AR technology use and is one of the primary advantages AR technology offers. Design accuracy uses AR technology to create overlays in real-world environments. This not only enhances the visual experience but provides technical assurance, where design accuracy is essential for effective evaluation and decision-making. The importance of this relationship is further emphasised in the data extract provided below, which outlines the impact of design accuracy:

'think it would be similar to what say, like bringing the virtual world integrate with the build world, so that your, for us in the AEC industry, that your design intent will be able to inspect it and also validate, you know, on the whole process, no matter this design phase or construction phase, you bring your things or before it is built, you can, you know, superimpose with the environment, so that you will have a sense of what the project will be. Your building will be. And after or in the process of construction, you can also use it for validation' (C15).

Another example of design accuracy can be found in the following data extract. This example highlights two verification processes commonly utilised in the construction industry.

The first process involves the use of AR technology, which overlays digital information onto the physical environment. This allows the real-time verification of the construction site against the original design intent, ensuring that the proposed plans are being accurately followed.

The second process focuses on the inspection details to confirm their correctness and the accuracy of their locations. By incorporating AR technology, this inspection process is enhanced, providing real-time visual feedback and enabling project managers to understand what steps need to be taken next. Thus, AR technology becomes a tool in ensuring both verification and accuracy in design details, ultimately contributing to construction projects:

'The first one is for as built verification, so it's like getting instant, or, you know, progressing review. So we're bringing the model on the phone, or the iPad, and it will bring on site and we overlay with existing the store has in store condition to check is displacing. Or at least it you know, depending on the accuracy of that model, we will at least to see whether the object sits in relatively close location as per the design intent. That's the one thing we do for verification, the other is for a check. So like the one case that we're using the project is there. They are going to install a very complicated steel structure on the roof. And they want to see and check and inspect whether the fixing items and details were there and they're in the accurate position. So we will bring the steel structural model including all these particular details, fitting details, and then we will position the AR model using QR code to get more accuracy into the overlay and check whether these positions are correct or not. At this same time, the team can use it to see what's coming up in the next few weeks, because they can see the whole model whereas not just one For or, you know, where it's not just 2d drawings on paper' (C16).

Schedule deliverables → Real time

The relationship between schedule deliverables and project design is crucial for leveraging the full potential of AR technology. Real-time data play a fundamental role in the functionality of AR, as they enable the seamless integration of virtual elements into the real world. The impact of real-time data on AR use is clearly illustrated in the following excerpt. This example highlights that the availability of real-time data and 3D modelling at a 1:1 scale significantly benefits the project progress:

'the benefits of this is just being able to see that information. It makes it so much easier if you can, without having to use your hands to pick up a tablet or a desktop. Having that information straight there. Does make that so much easier' (S14).

Another example is detailed in the data extract below, outlining how AR technology is a game changer for infrastructure projects. The remote utilisation of this technology facilitates remote work, allowing access to real-time information that streamlines project execution and enhances efficiency:

'This would be a game changer when implementing AR in infrastructure projects. This would allow companies to work remotely without having to go out to site. Accessing real-time information and executing' (SE24).

Project development → AR development

The relationship between project development and AR development clearly demonstrates the positive effects of AR technology on project development. The implementation of AR offers numerous benefits, including enhanced problem-solving and defect resolution. When challenges arise during the construction process, AR technology facilitates real-time decision-making and streamlines communication. This minimises project delays and optimises resource allocation. Overall, utilising AR technology in construction projects results in more efficient operations and better project outcomes:

'...we can get a faster response to the problem that we found from the AR on site so that we can fit back to the design team, or maybe even the construction team to make adjustment of the workflow or you know, works. Yeah' (C17).

The relationship between project development and AR development is beneficial when implementing AR technology, and developing new processes will help create content that can be used for developing the needs of the project. The impact of project development and AR development is supported by the following data extracts. The extract below provides an example of an engineering team implementing AR technology. Once it was implemented, small issues arose. The team worked closely with the technicians on the floor to address these challenges while examining the current processes. This particular issue required adjustments to the process and the use of the headsets to develop a more efficient way of performing the job:

'So we found, I guess, what I'm trying to say is we found that the initial barriers, a willingness to try, but then working through those sort of teething problems of with them, yeah, what is the new best way to do this job, and sort of working out the new process and what works best' (E3).

An additional example of the relationship between project development and AR development is outlined in the following data extract. This example delves into the use of 'storyboards', which incorporate a visual methodology for identifying and developing the project's requirements. This approach is akin to conducting brainstorming sessions, where the specific needs and objectives of the project are constructed. Utilising storyboards serves as an effective strategy to comprehensively explore and address the project needs for all stakeholders and end-users, ensuring that their requirements are acknowledged and integrated throughout the development process:

'There is an initial process of storyboarding and writing and scope of work and that sort of commercial side of things that sort of stays the same. And then it usually at some content needs to be built. And it's usually 3d models of thoughts doing some sort of thing. And then functions are applied to that. Overall, the processes are the same' (S23).

An additional example of the relationship between project development and AR development is outlined below; this example outlines enhanced project outcomes. One critical factor in this success is the establishment of clear and straightforward processes and procedures. The following data extract outlines how well-defined processes that are easy to follow can facilitate the effective incorporation of AR technology. This example highlights simple yet effective methodologies that are easily understandable and can be seamlessly integrated:

'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' (SE11).

Schedule deliverables → Time management

The relationship between the use of AR and the reduction of the travel time is clearly evident. AR technology allows users to access and utilise this technology from the comfort of their homes or offices, thereby reducing the need for physical travel. For instance, an individual working on a rural wind turbine farm can make use of AR technology without having to physically visit the site, thus saving time and resources. The impact on the travel time is evident in the data extracts below, which clearly demonstrate how the use of AR technology reduces the travel time. In this instance, the company utilising AR technology stated that they could not effectively manage projects without it. In this particular case involving a wind turbine project in a rural area, the technology significantly saves travel time

for project managers and other stakeholders, enabling them to visualise the project live from their home or office:

'They've pretty much come back and said that they wouldn't be able to run another project without a tool like this. It stopped them having to travel to the sites... So they are able to log in. And we can see when they do log in as well. So they're logging in almost daily and seeing what's happening' (S14).

Another example is outlined below, demonstrating that company employees do not need to travel domestically or internationally to oversee projects. This can be done by utilising AR technology, which provides a 1:1-scale representation of work in real time within the office environment. AR technology provides real-time data that stakeholders can access at their convenience, enabling them to view the progress of projects from anywhere and at any time. By leveraging AR, organisations can reduce travel costs and time:

'The difference would be having to go to one of their showrooms as compared to being able to see it at your place. So it's it's probably quite different what the tech can allow you to do. And then even, like the virtual sort of site tools that we're doing, the alternative is flying the board of directors to Brazil. Okay, so it's, yeah, it's, I suppose it's quite, quite big in what you can do virtually. Yes, it's eliminating the people have to go to where that yeah, if we use a product, or if you're showing a place having it's eliminating the need for them having to physically go there' (S12).

The relationship between project management and time management in this particular instance concerns the lack of resources and the pressure to deliver. It emphasises the need for resources and the exploration of ways to implement this type of technology. The data extract below outlines that businesses tend to prevent looking at exploring new ways of doing things if there are pressures on the project such as delivery and lack of resources:

'Personally, myself, I like to get involved in these things kind of as early as possible. But as you're sitting in most businesses, these days, there's a lot of pressure to deliver, and a lot of lack of resources, and all those sorts of things. And that kind of prevents people from exploring and investing in new ways of doing things' (E10).

Another example of this relationship is outlined in the data extract below. It highlights that there are constraints on projects, indicating that to be innovative and explore new technologies, one needs the support of the project manager and/or the company. The

organisational backing is crucial for integrating innovation with new technology. Without endorsement, the potential for advancement may be significantly lowered:

'Particularly when you're under time and pressure constraints, right. So people don't like to force new things when they're under the pump to deliver. And it's also an additional unknown in a time perspective as well, right? If you're going into a project going, Hey, we can be innovative and use this new technology, and sort of 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 bit 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' (E10).

The relationship between project management and time management is evident. By integrating AR technology into various tasks, users can often save significant amounts of time. As a result, individuals and organisations can benefit from improved workflow and better allocation of their resources. The data extract below outlines how AR technology has increased productivity by reducing the amount of time it takes to complete a task:

'we've got examples where, like, if you did a time and motion study on not having the goggles. So the example I was talking about if we did a time and motion study on that person, and they were having to walk across, look at the picture of the various pin locations, walk back, pick up the pins and put the job in, and we took the time to do that job, and that's and that person's movements, etc, and then we did it again with the goggles, because we had two people on before, because the sheer time it took to walk back and forth and sort of, and the scale of the product, we still use the same two people, but the job happened much quickly, because there was no walking back and forth and time wasting, because it all the time then was spent with the goggles was just insert fasteners here. Insert fasteners here. Insert fasteners here. And so what we could actually show was, rather than it taking, you know, in the order of two hours to get the pins in, it suddenly came down to about 30 minutes. So that's a saving for two people for an hour and a half' (E3).

Another example that involves the installation of specialised equipment within a hospital is detailed below. This process is facilitated through the utilisation of AR technology, which provides a visual overlay of the equipment's positioning and dimensions. This approach not only enhances the accuracy of the installation but also results in significant savings in both time and cost:

'even on site when they were installing something like the hospital project, they have equipment on install inside, very expensive. They actually not just install it, even someone has decided and tested, you know, and they do it in all other project, but each single room, actually, they will be with physical what they install the real thing and then test whether it can be used or not. So I think, for this part, the virtual, interactive like tool, or, you know, the things that I've been trying to help them, will be able to save time and cost, where they at least test it virtually, like the position and the rider, the operation workflow, and then they install it on site' (C15).

An additional example is outlined below. This example demonstrates that organisations are implementing AR technology as a cost-effective and efficient solution for operational effectiveness. The integration of AR within business processes allows for improved productivity, streamlined workflows and enhanced project management efficiency. As a result, projects are completed with greater accuracy and time savings, leading to substantial overall enhancements in organisational performance:

'The factors I believed that drives big corporation and businesses to implement the use of this technology because its cost-effective and time saving, with a low maintenance cost to the business and assist with preliminary findings' (E1).

4.12.3 Specific use cases

Specific use cases are categorised under project input, encompassing areas such as licensing and social use, including enterprise licensing, Catia and Visto. This category also incorporates environmental and sustainable initiatives, particularly focusing on renewable energy, environmental interactions and related projects.

Moreover, marketing is included in this category, as it targets specific audiences and involves AR packages designed for this purpose. Additionally, there are consumer applications and entertainment sectors that address various use cases, including those in the entertainment, residential, medical and engineering fields. The specific use cases framework is shown in Figure 4.10.

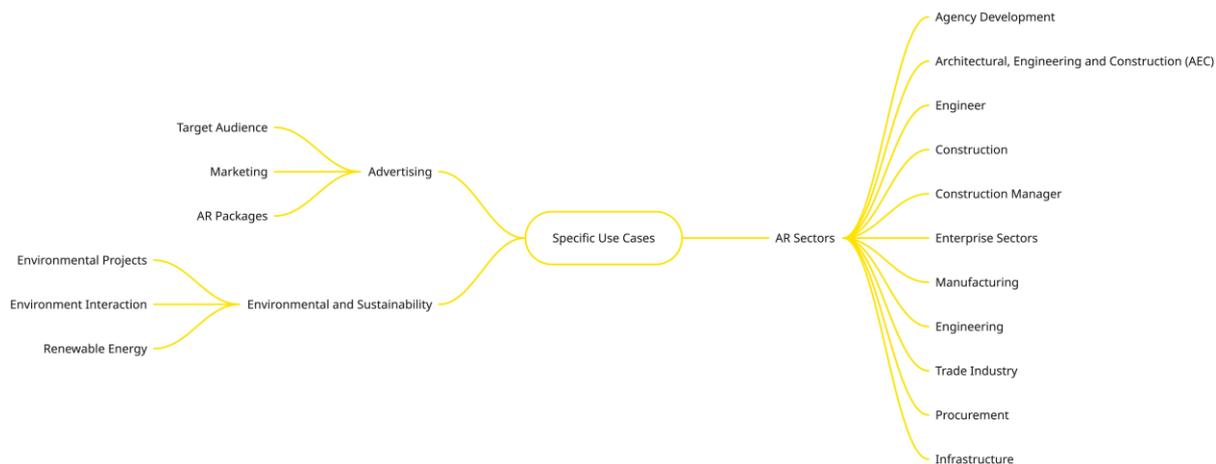


Figure 4.10: Specific use cases

Specific use cases have three sets of relationships: the AR sectors, advertising and environmental and sustainability. These relationships highlight the key areas where AR technology is utilised. In this research, AR sectors include agency development, architectural, engineering and construction (AEC), engineers, construction, construction managers, enterprise sectors, manufacturing, engineering, the trade industry, procurement and infrastructure, as defined below.

AR sectors:

- Architectural, engineering and construction (AEC): This terminology is used to describe the AEC sectors.
- Construction: This refers to when the construction sector utilises AR technology.
- Construction managers: This refers to when construction managers utilise AR technology.
- Manufacturing: This refers to when the manufacturing sector utilises AR technology.
- Engineering: This refers to when the engineering sector utilises AR technology.
- Engineers: This refers to when engineers utilise AR technology.
- Trade industry: This refers to when trade workers utilise AR technology.
- Procurement: This refers to when the procurement sector utilises AR technology.
- Infrastructure: This refers to when the infrastructure sector utilises AR technology.
- Enterprise sector: This refers to when the enterprise (entertainment) sector utilises AR technology.

In the current research, the advertising category includes the target audience, marketing and AR packages, as defined below.

Advertising:

- Target audience: The target audience for utilising AR technology is identified.

- Marketing: Software developers target their intended audience for marketing.
- AR packages: Different AR packages are developed for different users to purchase.

In this research, the environmental and sustainability category includes environmental projects, environmental interactions and renewable energy, as defined below.

Environmental and sustainability:

- Environmental projects: This refers to when AR technology is utilised in environmental projects and studies.
- Environment interaction: This refers to how AR technology engages with its surrounding environments.
- Renewable energy: This refers to when AR technology is utilised within renewable energy projects.

The relationships and the supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.12.3.1 Relationships extracted from specific use cases

Each of the specific use case relationships were derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for specific use cases is detailed in Table 4.18, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Specific use cases form 16 open codes, 3 axial codes and 1 selective code.

Table 4.18 : Breakdown for specific use cases and their relationships

Selective code	Axial code	Open code
Specific user case	AR sectors	Architectural, engineering and construction (AEC) Engineers Construction Construction managers

	Enterprise sectors
	Manufacturing
	Engineering
	Trade industry
	Procurement
	Infrastructure
Advertising	Target audience
	Marketing
	AR packages
Environmental and sustainability	Environmental projects
	Environment interaction
	Renewable energy

AR sectors → Engineering

The relationship between specific AR sectors and engineering highlights the engineering use of AR technology. Understanding this relationship is essential for engineering projects that want to effectively incorporate AR technology. The data extract below provides an example of an engineering specific use case in the early stages of a project, addressing project objectives and requirements. This analysis will determine whether AR technology is suitable for the project and how it is incorporated:

'in the, like preconception side of things. But I think based on where we've got, where we've used them, we've now got a whole bunch of examples where I think we'd like to implement them from us. It all stems from the engineering requirements. So we can look at the engineering requirements and say, Okay, this is the information we need to impart, and then we give that to the programming team. So to say, like, usually, where it's information that we're printing out on paper visually is sort of where we've targeted to implement it. So where we've got a visual representation of our engineering that we then print out on paper for the for the team on the floor, where, like, I printed on paper when we visually display it for them. Yeah, in rather than 's so that's, I guess, for the most of the applications we've incorporated so far, where the sort of requirements have been communicated. It's like, here is the information in 3d in a model that we'd like to present in 3d in real life' (E3).

An example of an environmental specific use case is outlined below. This example outlines the development of AR technology for an environmental engineering project, and the developers are interested in the earlier stages of the project. It is essential to understand the

client's needs in order to ensure that they receive the most suitable product when incorporating AR technology:

'We started working with wind farms, right? Yes, yes. And wind farms, we're early. And in fact, I think we've literally, that first wind farm got off who forgot the name that XXX, I think it was. And we did all deals. That was it. We did the first 360, sort of on location. Here, the birds see the frogs in the creek, it was all part of the very early stages of what we're specialising in, which is the feasibility studies due diligence stage, which is the community consultation stage. So what we're focused on is not the high end engineering and millimetre perfect representation, immersive experiences for engineering and project execution. Were very much focused on the much earlier stages of the marketing and the community consultation phases' (S19).

AR sectors → Construction

The relationship between AR sectors and construction is important, given the diverse functions that AR can fulfil within the construction industry. AR enhances various aspects of construction, particularly in the realms of design and planning, where it allows the visualisation of complex structures and facilitates more informed decision-making.

In the modelling phase, AR technology aids in creating accurate three-dimensional representations of projects, enabling stakeholders to assess designs in a real-world settings. Inspections benefit significantly from the integration of AR, as it allows the real-time overlay of digital information onto physical environments, improving the accuracy and efficiency of assessments. An example of this is highlighted in the data extract below, which illustrates that AR technology can be utilised in all stages of a construction project, which is significant for construction projects:

'it's something that can transition from a product that supports all stages of construction. Now, that goes even to handoff, right? So after building handoff, and you've got a visual reference of the model, you can do training, you can do inspections, you can do digital twins, you can do and sort of extending that's the true commercial success for a platform and product in this market is going to be getting it across the full lifecycle. Around the commercials on large construction projects' (S19).

The following data extract illustrates the evolving relationship between AR sectors and construction. This example highlights how AR is increasingly integrated with construction

technologies such as building information modelling (BIM). This integration enables the effective implementation of AR within construction workflows:

'I think that like two years ago is still like a trial, or maybe even like a research area? Investigation, because I think it's because the technology is not that well known, and also in some of the functions without BIM, but I think this year, or maybe even last year, I think the technology is quite ready for some of the workflow that will work alone. So we will be we are implementing solid base in our project' (C17).

AR sectors → Architectural, Engineering and Construction (AEC)

An example of the connection between AR sectors and the architectural, engineering and construction (AEC) sectors can be found in the data extract provided below. This extract outlines that the AEC sectors are experiencing significant advantages due to advancements in digital technologies due to AR technology:

'We can use it actually. But for the other part, like digital engine, two, seems way well for AECs, mainly on the desk before AEC well, like Catia and also the other tools in the manufacturing world, they have also stepped in the AEC industry. So in general, I'm really good at a variety of Camp software and also AEC industry software. Well, for the AEC part, basically, is all the best, yeah, you know, the whole families. And also for manufacturing, is really those parametric engine like Catia digital project and the early phase, like even co engineers or things like that' (C15).

Advertising → Marketing

The relationship between advertising and marketing is vital for businesses looking to integrate innovative technologies. Marketing promotes AR products and communicates how these technologies can address various business needs and enhance operational efficiency.

The engineering sector stands to benefit from thorough research into AR technology products. The example in the following data extract is taken from research focused on emerging technologies and methods to enhance efficiency. This research provides insights into the advantages of AR technology, highlighting its transformative potential within the engineering field. The data extract below demonstrates that the simplest forms of AR technology can be bought off the shelf, and no expert is needed:

'you can go out and get the stuff off the shelf. And anybody can use it. So you basically put the headset on and off you go, you don't need to be an expert, simple configurations and stuff like that it's already being built in' (E10).

The following example from the data extract illustrates that many businesses are exploring AR technologies, acknowledging that various sectors may have distinct needs. These needs can arise from specific business objectives or be shaped by observations and research conducted in the field. The data extract also indicates that larger companies primarily utilise detailed 3D modelling for marketing purposes, although this can frequently be a costly undertaking:

'I think that's the other part for your there's a lot of companies, there's some very big professional service companies who do 3d models, and very large, as I'm sure you have seen for your own projects, right. Massive 3d models, you know, that are done for really marketing purposes, right. They're incredibly expensive' (S19).

Environmental and sustainability → Environmental challenges

AR technology can bring environmental challenges, especially related to lighting conditions. One significant issue occurs when users are outside, where natural sunlight can filter through the AR lens. This interference often makes the images and information displayed by the AR technology difficult to see clearly.

The data extract below provides an example of how the impact of bright ambient light can reduce the contrast and visibility of virtual elements, making it challenging for users to engage with the content effectively. To enhance the overall experience and ensure clearer visibility, it is advisable to utilise AR technology indoors, where lighting can be controlled and distractions from external light sources are minimised:

'Microsoft HoloLens, expensive. And also, if the background is not like a dark or if the background is not proper, if it is very bright, and they can't see it, right? These are the challenges that have like, even there's a planning module or something. Yeah, but if the background is too bright, they can't see the model. So if they had the proper red background, or very, very dark background or something, then then only it will work. For the main challenges. It can model work in every use case, or every scenario, you have to have a proper environment to work' (S18).

An additional example of environmental challenges is provided in the following data extract. This example highlights that mixed reality (MR) technology outperforms virtual reality (VR) technology with regard to lighting elements:

'MR, they didn't question basically has this function already passed through it actually, although there's really the bright lights still affecting, you know, the customisation of your AR element, the augmented element, but in a VR environment, because it was all closed. So it's actually better than you were using HoloLens actually, except you're not really seeing the real world, there might be still a very small latency that could possibly danger to anyone who's using it. If you're running using that VR, I don't really recommend that' (C17).

Environmental and sustainability → Environment interaction

The relationship between the environmental and sustainable category and environmental interaction with AR technology is outlined through the integration of AR technology in interactive settings. This technology utilises a data overlay, which enhances the user's experience by allowing them to engage with both the physical world and their digitally enriched surroundings simultaneously. By providing additional layers of information and virtual elements, AR enables users to interact with their environment. This dual perception not only enhances the understanding of the physical space but also encourages more active participation in the environment. The data extract below outlines that an expensive model is not necessary to interact with the environment using AR technology. This technology allows users to see real-world surroundings, a feature not available in VR:

'So you don't actually need a very expensive device to look in very fancy, or, you know, realistic environmental model. The interactive interactivity, is increasing, I think. Because the problem is VR is you cannot really touch, but AR you see it, you can touch it. So I think that would be the interface' (C17).

Another example of the relationship between environmental and sustainable aspects and environmental interaction aspects is detailed in the data extract below. This example outlines that unlike traditional headsets that rely on a limited viewing window through lenses, this particular headset utilises cameras that display the user's surroundings on a larger screen. This design effectively eliminates the constraints associated with a small viewing window, thereby enhancing the user experience in AR interactions:

'And what they're seeing in their environment is taken from cameras on the headset. So that, yeah, so that is a different way of approaching it than having like a small screen that's like, see-through that can interact with the environment' (S21).

Environmental and sustainability → Renewable energy

An example of the relationship between the environmental and sustainability category and renewable energy is illustrated in the data extract below. This data extract highlights that major companies are increasingly adopting AR technology for renewable energy projects. The integration of AR functions and applications tailored to specific products is becoming more efficient as AR use becomes more widespread across the industry:

'So, vis AR is now we're five clients in our first five, you know, sort of foundation clients, were away with some pretty major projects in Australia. We've got people..., who do large, you know, renewable and hydrogen, wind farm solar. And what we're now doing for them is, of course, creating those 3d models for them, the solar panels, the wind farms, the turbines with all of the skills that we've got, as 3d artists, as a business. And then... has been doing over this sort of last year is building out the web design, you know, the application development, and refining that product, so that we can start adding, you know, a long list of features and functionality to, to the application itself' (S19).

4.12.4 Expert skills and development

Expert skills and development are essential components of project inputs and play a critical role in ensuring successful outcomes. This category includes a variety of roles and sectors, particularly those associated with architecture, engineering and construction.

Key sectors within this category encompass construction, engineering and architecture. In addition to these primary sectors, the category also includes various enterprise sectors such as product manufacturing, engineering services, procurement and infrastructure development. Each of these sectors relies on specialised skills and knowledge to tackle complex challenges and deliver high-quality results.

Furthermore, the importance of expertise is vital to incorporating new technology. This includes contributions from SMEs, as well as technical professionals who offer critical insights and solutions. Being tech-savvy is also a valuable asset, as it allows individuals to leverage modern technologies and tools that enhance efficiency and innovation throughout the project lifecycle.

Overall, the integration of expert skills and development is vital for the successful execution of projects across these diverse fields. This is shown in Figure 4.11.



Figure 4.11: Expert skills and development

Expert skills and development have two sets of relationships: expert skills and generational factors. These relationships are vital for expert skills and development; they outline the importance of having the right skills and understanding the generational factors that are relevant to incorporating AR technology. In this research, expert skills and development are related to generational factors, which include the older and younger generation aspects, as defined below.

Generational factors:

- Older generation: This generation is less familiar with utilising AR technology.
- Younger generation: This generation is more familiar with utilising AR technology.

In the current research, the expert skills and development category includes the technical perspective, expertise, subject matter experts, technology savvy and skill sets, as defined below.

Expert skills:

- Technical perspective: This refers to understanding the project scope and technical perspective of utilising AR technology.
- Expertise: This refers to having expertise in advising on and delivering AR technology.
- Subject matter expert (SME): This refers to someone who has subject matter expertise in advising on and delivering AR technology.
- Technology savvy: This refers to individuals who are tech-savvy and eager to learn new technologies.
- Skill sets: This refers to having specific skill sets needed to utilise AR technology.

The relationships and the supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.12.4.1 Relationships extracted from expert skills and development

Each of the relationships extracted from expert skills and development were derived from the grounded theory approach. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for expert skills and development is detailed in Table 4.19, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Expert skills and development form 7 open codes, 2 axial codes and 1 selective code.

Table 4.19 : Breakdown of expert skills and development relationships

Selective code	Axial code	Open code
Expert skills and development	Generational factors	Older generation Younger generation
	Expert skills	Technical perspective Expertise Subject matter expert (SME) Technology savvy Skill sets

Expert skills → Expertise

The relationship between expert skills and expertise for AR technology becomes apparent when clients seek expert guidance. In these instances, clients are specifically looking for insights and expertise from professionals who possess a deep understanding of AR technology. They require a thorough analysis of their unique needs and challenges, which enables the expert to propose effective solutions. This interaction is essential, as the guidance provided by experts is grounded in their specialised knowledge and experience in the field. This allows clients to navigate the complexities associated with AR implementation and to make informed decisions. An example of this is outlined in the data extract below:

‘when we’re scoping out a project, we scope it out in regards to what we need to do on a technical perspective. And we also really get clarity from the client as to the nuts and bolts of what they need us to develop. And then we work very closely with them because we’re creating something bespoke for their use case’ (S21).

Another example of the relationship between expert skills and expertise for AR technology is detailed in the data extract below. This example outlines that having a technical perspective on the AR technology needed for a project is beneficial, as it will guide the client in understanding what is necessary based on their project needs and preferences:

'So it's really not so much about us just presenting them with the solution as sort of us finding out what they need, and then guiding them like oftentimes clients will have a wrong idea of strengths and weaknesses of their technology and what can be done and what's easy and what's hard so we tend to guide them' (S21).

The relationship between expert skills and expertise for AR technology is essential for experts to translate complex modelling concepts into a three-dimensional overlay. By collaborating closely with these experts, the AR technology can be customised to accurately reflect their vision, ensuring that the final product meets their specific needs and expectations. An example of this is outlined in the data extract below:

'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 kind of 3d modelling system into a space, and that's a pretty specific skill set to be able to have' (E10).

The following data extract illustrates another example of the relationship between expert skills and expertise. This example highlights the importance of having expertise to guide and develop AR technology tailored to specific project requirements. Without such expertise, when it comes to creating a custom solution, implementing AR technology will be difficult, as most custom items require specialised skills rather than off-the-shelf products:

'So we might do something with XXX or someone when they want a very specific, you know, bespoke or XR type of experience for something that might be training or marketing components or something. But out of that was born, the knowledge, the skill, the capability and sort of our vision from working with these clients, which is, geez, we should really build a product here. Wow. Which we've now done' (S19).

Expert skills → Subject matter expert (SME)

The relationship between expert skills and SMEs is critical for AR technology integration. SMEs serve as the primary connection in evaluating potential adjustments. In relation to AR

technology, they play a vital role in developing the business case and effectively communicating the benefits and drawbacks of any proposed changes. An example of this is outlined in the data extract below. This example illustrates that SMEs are the ones who request this type of technology for projects; they understand the significance of utilising new technology and how it benefits the overall project:

'But really, when you're talking about SMEs, and you know, studios, and so on the first people who are the only people who are willing to pay for that stuff, eight or 10 years ago, were arts, creative music, you know, companies and so on. So the company was formed in their bases, where it was much more about like a traditional film and TV, film, you know, production, you needed cameras, big VR cameras, big VR headsets. But you needed the skills and capability to shoot, especially in 360 degrees. And it was all, you know, the agencies essentially born out of those skills and capabilities. As augmented reality presented itself. Again, those early applications for that work very much in the marketing space. And you know, the very first applications for it outside of gaming, and the gaming platforms was music and entertainment and the social media platforms, were making some tools available quite early, right, in terms of doing filters, early filters, and things like that. And that was the, you know, the sort of early stages of augmented reality' (S19).

Generational factors → Younger generation

The relationship between generational factors and the younger generation shows that they are more exposed to technology. Additionally, younger individuals tend to use this technology with fewer challenges. The example detailed below is from an engineering and production environment:

'we obviously have a range of, you know, operators who are in their 20s all the way through to operators in their 60s. Yeah, I have, I find, generally, the more a person has exposed to technology at a younger age, the more willing they are to uptake it. But it's the same, I would say it's the same with, you know, the changes that have been made in technology through, you know, just normal cell phones, through the smartphones. And it just takes people who are less familiar with technology in general that little bit longer to jump on board that. Said, I am really generalizing. We've had some of our older members are like, this is awesome because, you know, it's something quite different and exciting for them, so all across the spectrum' (E3).

This example highlights the relationship between generational factors and the younger generation's engagement with AR technology. The data example below explores how

different age groups interact with AR experiences and how software developers are managing and overseeing the enterprise platform of AR technology:

'Like I can broadly define, it's certainly not by age, well, let's say role, we do have clients and, and contacts that are probably the 50s and 60s Right. Now, in that age group. I'm not finding many people who've said, you have experienced the latest VR headset and augmented reality. There are some and we've come across them, but broad, broadly, most people are making the reference to you, I've used VR for gaming, or my children or those not the commercial applications, right. I'd be hesitant if with our small sample group, right to make statements around particularly age group or role types, because it does vary greatly. The older, more experienced engineers and project managers, they're the ones who I said before the one in 10, they're the ones who've seen something like you've seen for bowling, or that they've seen the very latest pass through they've had on a HoloLens. They've seen, you know, VR, that probably the more experienced ones, they've actually the older have had that experience in very sophisticated AR and VR. Yeah. And so to the younger, you know, broadly younger groups is, yeah, we've experienced that we've experienced media or entertainment and gaming experiences, not for enterprise applications. Yeah, we'd be broad, you know, our broad experience with a very small sample group here in Australia' (S19).

4.13 Technology Input

Technology input has four key categories: software and hardware integration, AI, automation and 3D environments and data privacy and management, which are detailed below:

1. Software and hardware integration includes software applications, equipment, software integration, availability, software comparison, authentication, multiple programs, compatibility, web browsers, integration, data integration and hardware and equipment.
2. AI includes machine learning integration, which consists of AI integration, AI imagery and generative AI.
3. Automation and 3D environments include simulation, verification, AR modelling expertise, AR software collaboration, embracing technology, innovation, new technology exposure and technology accuracy.
4. Data privacy and management includes data privacy requirements.

Technology input is detailed in Figure 4.12. This figure highlights the four categories of technology inputs.

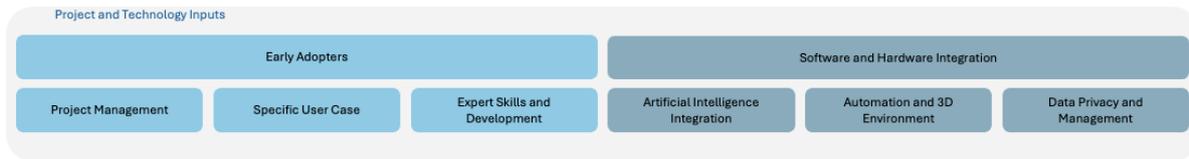


Figure 4.12: Technology inputs

The technology inputs are outlined in the framework, along with all technology-related items.

4.13.1 Software and hardware integration

Software and hardware integration includes a wide range of components, including various applications, custom-built software solutions and distinct software functionalities. It also considers equipment compatibility, user authentication protocols, the ability for multiple users to access the system and seamless cross-platform integration.

In particular, during the input phase, the effective integration of AR technology is heavily dependent on both the software and hardware being utilised. This phase is critical, as it establishes the groundwork for how well AR can be implemented in the project.

It is essential to thoroughly assess what both the software and hardware can offer in relation to the specific requirements of the project. This involves a detailed analysis of the project's objectives and the determination of the precise capabilities needed to achieve them. The goal is to create a high-quality product and ensure that the selected equipment aligns with the project. The diagram in Figure 4.13 illustrates the integration of software and hardware within the technology inputs category.



Figure 4.13: Software and hardware integration

Software and hardware integration has seven relationships, including AR capabilities, AR applications and platforms, device capability, software analysis, integration, hardware and equipment and the technology user interface. These relationships are essential to software and hardware integration. In this research, the AR capabilities category includes the software ecosystem, software layers, software maintenance, capabilities and interaction, as defined below.

AR capabilities:

- **Software ecosystem:** This refers to software systems that are compatible with one another.
- **Software layers:** This refers to layers of information that can be included or excluded based on the client's preference when utilising AR technology.
- **Software maintenance:** This refers to the required software maintenance needs.
- **Capabilities:** This refers to the capabilities of AR technology in relation to various existing software models.
- **Interaction:** This refers to the interaction of AR technology with various existing software models.

In the current research, AR applications and platforms include entertainment applications, medical applications, software as a service (SaaS) applications, the application

programming interface (API), applications on devices, bespoke applications, software applications, native applications and BIM software, as defined below.

AR applications and platforms:

- Entertainment applications: This refers to when AR technology is used for entertainment purposes.
- Medical applications: This refers to when AR technology is used for medical purposes.
- Software as a service (SaaS) applications: This refers to when AR technology is used as an SaaS application.
- Application programming interface (API): This enables different software systems to be integrated and used together.
- Applications on devices: This refers to when AR technology is utilised across any device.
- Bespoke applications: This refers to when AR technology is used to achieve specific objectives set by the client.
- Software applications: This refers to the software applications that are utilised for AR technology.
- Native applications: This refers to the native application that is specifically designed for the AR technology being used.
- Building information modelling (BIM) software: This involves the use of BIM and AR technology.

In this research, the device compatibility category includes device and browser authentication, multiple programs, multiple users, compatibility, web browser accessibility and stealth mode, as defined below.

Device compatibility:

- Device and browser authentication: This is the method utilised for authentication requirements.
- Multiple programs: This refers to AR technology that utilises more than one program.
- Multiple users: This refers to AR technology that utilises more than one user.
- Compatibility: This refers to AR technology compatibility with other devices.
- Web browser accessibility: This refers to when AR technology is utilised via the web browser.
- Stealth mode: This refers to when AR technology is utilised in a mode that is invisible to everyone but the user.

In this research, software analysis consists of AR software comparison, as defined below.

Software analysis:

- AR software comparison: This refers to comparing software through analysis.

In the present research, integration includes AR integration, AR programming, software integration and cross-platform integration, as defined below.

Integration:

- AR integration: This refers to AR technology and hardware integration.
- AR programming: This refers to how AR technology is programmed, as defined by the project.
- Software integration: This refers to AR technology and software integration.
- Cross-platform integration: This refers to AR technology and cross-platform integrators with systems that are not compatible.

In this research, the hardware and equipment category includes the battery life, headset size, headsets used, hardware availability, implementation of hardware, on-site functionality, other devices, quick response (QR code, AR equipment and AR projector, as defined below.

Hardware and equipment:

- Battery life: This refers to the battery life of the hardware and equipment used for AR technology.
- Headset size: This refers to the size of the headset used for incorporating AR technology.
- Headsets used: This refers to the headsets used for the integration of AR technology.
- Hardware availability: This refers to AR technology hardware availability.
- Implementation of hardware: This refers to the hardware implementation of AR technology.
- On-site functionality: This refers to the on-site functionality of AR technology.
- Other devices: This refers to devices used in conjunction with AR technology.
- QR code: This refers to positioning the AR model using a QR code.
- AR equipment: This refers to the AR equipment being utilised.
- AR projector: This refers to the AR projector used as a source for AR use and the AR display.

In this research, the technology user connection category includes technology engagement, technology insertion and the technology interface, as defined below.

Technology user connection:

- Technology engagement: This refers to user engagement with AR technology.
- Technology insertion: This refers to the seamless insertion of AR technology into other software and hardware.
- Technology interface: This refers to a simple AR technology user interface.

The relationships and the supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.13.1.1 Relationships extracted from software and hardware integration

Each of the software and hardware integration relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for software and hardware integration is detailed in Table 4.20, which outlines the grounded theory approach to forming relationships and developing a theory for this research. The software and hardware integration category forms 38 open codes, 7 axial codes and 1 selective code.

Table 4.20 : Breakdown of software and hardware integration relationships

Selective code	Axial code	Open code
Software and hardware integration	AR applications and platforms	Entertainment applications
		Medical applications
		Software as a service (SaaS) applications
		Application programming interface (API)
		Applications on devices
		Bespoke applications
		Software applications
		Native applications
		Building information modelling (BIM) software
		AR capabilities
	Software layers	

	Software maintenance
	Capabilities
	Interaction
Software analysis	AR software comparison
Device compatibility	Device and browser authentication
	Multiple programs
	Multiple users
	Compatibility
	Web browser accessibility
	Stealth mode
Integration	AR integration
	AR programming
	Software integration
	Cross-platform integration
Hardware and equipment	Battery life
	Headset size
	Headsets used
	Hardware availability
	Implementation of hardware
	On-site functionality
	Other devices
	QR code
	AR equipment
	AR projector
Technology user connection	Technology engagement
	Technology insertion
	Technology interface

Device compatibility → Web browser accessibility

The relationship between device compatibility and web browser accessibility is demonstrated in the data extract below. This example highlights the increased emphasis on implementing AR technology through web browsers, as this approach offers greater accessibility for businesses. By eliminating the necessity for specialised headsets, companies can utilise AR applications on various devices, thereby broadening their potential user base and enhancing customer engagement:

'Yes, that was one thing that we sort of saw, where our focus has been, is more on that yet accessing things through a web browser, just because it's a little bit more accessible, sort of probably doing less in that the AR headset space, but just using it on a normal desktop browser. So we've changed a little bit over the years' (S14).

AR applications and platforms → Bespoke applications

The relationship between AR applications and bespoke applications is essential for AR technology integration, particularly within the engineering and construction sectors. Applications designed specifically for AR can be either tailored to meet the unique requirements of a project or modified from pre-existing applications to ensure their compatibility with AR technology. This is outlined in the data extract provided below:

'So we might do something with XXX or someone when they want a very specific, you know, bespoke or XR type of experience for something that might be training or marketing components or something. But out of that was born, the knowledge, the skill, the capability and sort of our vision from working with these clients, which is, geez, we should really build a product here' (S19).

AR applications and platforms → Application on devices

The data extract below outlines the relationship between AR applications and platforms and applications on devices. This example outlines the application requirements for engineering projects, specifically focusing on features and functionalities within the application itself. This alignment supports the project and ensures that it aligns with the business's needs and objectives:

'what we're now doing for them is, of course, creating those 3d models for them, the solar panels, the wind farms, the turbines with all of the skills that we've got, as 3d artists, as a business. And then, as XXX has been doing over this sort of last year is building out the web design, you know, the application development, and refining that product, so that we can start adding, you know, a long list of features and functionality to, to the application itself' (S19).

The relationship between AR applications and platforms and applications on devices is illustrated in the following data extracts. This particular relationship was frequently addressed during the interviews conducted. The primary consideration regarding hardware

and equipment in the context of AR technology use is ensuring that the devices are comfortable, user-friendly and suitable for the project needs.

The data extract provided below highlights the requirement for hardware to be improved in terms of weight and comfort. Additionally, it outlines the importance of considering how AR technology interacts with hardware and equipment. One key insight from the interviews is that improvements in hardware design are crucial for enriching the overall AR experience:

'the hardware at the moment. At least, I think, you know, the hope that we see as with the evolution of the technology is the natural transition from, you know, mobiles and tablets to you know, usable, you know, lightweight, comfortable glasses effectively. Which also takes into consideration how people interact with that that medium, because it's definitely going to be very, very different from your typical flat touchscreen' (S19).

Another example between the relationship of AR applications and platforms and applications on devices utilising AR technology can be found in how software companies present this type of technology as user-friendly. However, the reality is quite different. The operation of hardware and equipment in conjunction with AR technology is not simple. Instead, it involves complex configurations and combinations that can pose significant challenges for users. This complexity is detailed in the following data extract:

'unfortunately, still, it's not as easy as single button push to have an augmented reality experience. Although marketing materials and software companies will promote it as such. The reality is, there's a still a complex combination of device and browser and authentication and permissions and so on that are required to activate that first augmented reality experience, especially if it hasn't been done on that device' (S19).

AR applications and platforms → Native applications

The relationship between AR applications and platforms and native applications is the development of native applications specifically designed for AR. Below, you will find a data extract that supports the effectiveness and potential of using native apps in AR development, highlighting their capabilities and the value they bring to the engineering and construction industries:

'The acceptance very, comes down when it's with this to like, different types of dioptres with AR. And then like the native app, a native app is got its benefits in terms of it uses the devices, processes, so it's probably can do a bit more with it' (S23).

AR applications and platforms → Building information modelling (BIM) software

The relationship between AR applications and platforms and BIM is vital to the AEC industry; BIM is used for three-dimensional modelling, which is capable of being integrated with AR technology. Further details are provided in the data extract below:

'Actually, because the contract requirement. Because in our world of the BIM world, the AEC world for digital engineering, we have a requirement for we have LOD, I'm not sure if you aware of the LOD level of details about the model. So we have, like, 100 to 500 where 500 the most extensive one would hire you to have a model that's exactly the same, or, you know, relatively close to the wheel well' (C15).

AR applications and platforms → Software applications

An additional illustration of the relationship between AR applications and platforms and software applications in relation to web browsers can be found in the data extract below. This extract highlights that there are two primary types of components utilised for implementing AR technology: web browsers and native applications. The choice between these two components largely depends on the specific user case and the requirements of the application:

'For augmented reality, the output is either like a native app build or where they are, like unsure where they are, there's software in the web browser from third party companies that we use that you can then build. And that kind of language is the same decide' (S23).

AR capabilities → Capabilities

An example of the relationship between AR capabilities and utilising AR technology is presented below. This example discusses the current limitations of AR technology within mobile devices and smart glasses. However, there are companies in India and the United States (US) that have transformed the application of AR technology across various devices. These innovative approaches harness the potential of AR to enhance user experiences and provide interactive solutions that have yet to be widely adopted in Australia:

'I'd say our commercial experience is limited to when we talk AR is limited to mobile phones and devices very much in an experiment we've used and deployed on HoloLens, very limited enterprise applications and very early proof of concept work and so on. Yeah. The glasses so I've tried one or two sets have new glasses. So there's a couple of companies in the space that are sort of moving ahead at the moment out of the states. And out of India,

especially, as well. So there's a company called JIO Tesseract out of India. The difference between, you know, especially for us, we look at the website and the technology and go, fantastic, amazing reality about the product execution is, you know, somewhat disappointing at this early stage, so really that, yeah, they're only getting simple things done available at this point text on screen, basic block, you know, basic, basic 3d model objects, very limited field of view, you know, and certainly, of users don't want it' (S19).

Integration → Software integration

The relationship between integration and software integration can be found in the data extract below. It highlights that the development of AR technology requires a variety of tools, with software integration being a fundamental component. Without effective software integration, the functionality and application of AR technology would be limited; thus, it plays a crucial role in the advancement of AR technology:

'we've got some internal tools that we software's tool that we use, but I suppose automates and streamlines the process. That's our Yeah, we use that to deliver these projects. And eventually, that was, our aim is to make that publicly available. At the moment, it's a tool that we use to deliver projects. So we're sort of each project that we work on, we can add in these features, and different things. So that's really cool that swivel. And that's like our little internal 3d mapping tool that we've got' (S14).

Another example of the relationship between software integration and the use of AR is demonstrated in the data extract below. This particular example illustrates the requirements and objectives for implementing AR technology, ensuring that the success of AR devices and overlays is achieved through effective integration. Successful integration significantly benefits the overall success of the project, as it enhances efficiencies and addresses specific challenges relevant to that project:

'Because you did it, we solve or if it meets the objective that we want to apply the end of the session, like what I'm talking about those challenges, and difficulties we have for QA QC. If it to feel that part, like improve our efficiency, we don't need to call surveyor to check those information. We just use the AR device and overlay and see it was like perfect match, then I think this kind of benefits could call in as the success of integration. But at the same time I think that's it. I mean, maybe if we solve the problem we have in our workflow and improve our efficiencies that does it. Sometimes even if it costs a lot, it's still key. Because we will have more certainty, certainly on our work on a project' (C17).

The relationship between software integration and the use of AR technology is outlined in the data extract provided below. This example highlights the efficiency of integrating AR technology, along with the use of overlays and devices, to address project challenges. By leveraging these tools, we can enhance the certainty surrounding project outcomes and facilitate timely delivery to improve the overall project efficiency:

'We just use the AR device and overlay and see it was like perfect match, then I think this kind of benefits could call in as the success of integration. But at the same time I think that's it. I mean, maybe if we solve the problem we have in our workflow and improve our efficiencies that does it. Sometimes even if it costs a lot, it's still key. Because we will have more certainty, certainly on our work on a project' (C17).

Integration → AR integration

The relationship between software and hardware integration and the integration of AR technology is outlined below. This example highlights the importance of merging AR technology with existing systems while also considering its integration with new platforms. When implementing AR technology, it is essential to evaluate the systems currently in use and future system options. This is essential for ensuring the overall success of the project:

'first, we discuss about why you're doing it. Yeah. Who is going to use and what you expect it to be in the future? Are you going to implement more feature? Or are you going to integrate with your with your existing systems or something like that? Yeah. And then based on that, we will give them a scope' (S18).

Integration → Cross-platform integration

Another example concerning integration and AR use is detailed in the following data extract. This example demonstrates how seamlessly AR can be utilised when the appropriate set of requirements is incorporated. Aligning AR technology with the right integration can enhance project success:

'I think you'd get the nature of our product, you've got a model, and you've got a data set lat long and altitude. And it's a very, very, very easy process with our platform to be able to resubmit an XML or something like that at this stage, and just republish with a new design, you know, that could be a new model, and it could be a new placement of that line, whether it be powerlines, or solar, wind farm, in terms of the placement. So that's the nature of the technology lends itself incredibly well to the nature of the industry, which is at those early stages, the designs change so rapidly' (S19).

Software analysis → AR software comparison

The relationship between software analysis and AR software comparison outlines AR use in companies, illustrating the methodologies needed for implementing new technology. For instance, in a construction company, the process involves a comprehensive comparison of project requirements alongside the technology intended for adoption.

This process categorises various technologies to determine which of them is best suited for the project, considering the benefits associated with using each option. The analysis encompasses several factors, including collaboration requirements and the time needed for implementation. By assessing these elements, companies can make informed choices that enhance operational efficiency and project success with AR technology:

'in general, we do have like, because we're not just like putting one when we were doing these kinds of like requirements, strategic requirements for attack. We have a table comparison, you know, with the different software in we always start out there and climate in our equipment, if he matched and, you know, putting some marks over there, and then we will, in the end or come up with a better picture of which software which one there is going to provide a much more suitable software for us. And then you make a decision based on, you know, the analytics that we have done on different software. And the requirement is part of that analytic. Yeah. So, when you talk about that software requirements, you talk about the quality of it, maybe what it's compatible with, basically, everything, you know, three to 50 items I was mentioning is the key free items like collaboratively the deploying time, preparation time, and in this is the front yard, but in that analytic we actually have a full, you know, items that we want to do. But of course, there will be some waiting condition requirement, because some of the very important, the three key items will be very important. So we have a higher waiting, but others could be not as important as different key items that we will have some waiting to come up with the final result of the software was different points' (C16).

Device compatibility → Compatibility

The relationship between device compatibility and compatibility with the use of AR technology is illustrated in the data extract below. This example highlights the critical importance of file compatibility. It is essential to consider how different file types and sizes may impact user ability of AR technology. Larger files may require more time to set up and process, which can affect the overall efficiency of AR technology. Therefore, thorough

attention must be paid to ensuring compatibility to optimise the user experience and performance of AR technology:

'I think it's tech itself, you know, the renders provider in the software itself, is key components. First is really the compatibility of the files, which means you can blow up even types of modal without even doing translation, which is, you know, very back to the model, when you want when I use want to use a model in this project, do I need a lot of preparation time? Do I need to split up everything, four by four, or I can just go up one model and platform supported to streaming only single details to the phone and still get, you know, comparatively good performance' (C16).

An additional illustration of the relationship between device compatibility and compatibility with the use of AR technology is presented in the data extract below. This example highlights the application of AR technology across both Apple and Android devices, outlining the versatility required and the benefits of using both Apple and Android for this technology to enhance the user experience:

'even if it's like if they're compatible with like Apple or Android, that's a factor as well' (C8).

Another example reflecting the relationship between device compatibility and compatibility with the use of AR technology is highlighted in the data extract below. This instance demonstrates the importance of compatibility with various devices and emphasises how user-friendly the technology needs to be for the end-user. In the context of AR technology, seamless interaction is crucial for the success of any project. To ensure that users have a positive experience, it is essential that the technology is compatible with a wide array of devices accessible to all end-users:

'it makes a big difference when the design philosophy of whatever application you're making, works well. So that's both from taking consideration the device that you're using, but also the way that you interact with it. So whether if whether it's a simply purely a visualisation experience, and also, whether you have interaction incorporated with it, there's a big difference when it's, you know, well designed and easily intractable that works with, you know, the days methods of interaction and how that how people intuitively use that software. With AR, because you're dealing with, you know, real world space, 3d space, but also trying to interact with nowadays, currently, you know, a lot of just flat touchscreen devices. So, in terms of the consumer market, you know, that's usually what things are market applications

are marketed to, which end up on mobile devices. So the method of interaction is very important, which is part of how people design their AR applications' (S19).

Another example of device capabilities is outlined below; this example addresses the specific needs of the clients. The example below outlines the transparency of AR technology and its capabilities, and it describes how AR can be a communication tool for organisations to use:

'I guess it's a capability perspective of what, you know, I guess, in the context of Visio, what the clients can achieve, compared to if they didn't have AR. So two things on which work together, which is one being the communication tool. And for people to understand what they can expect to see in their local landscape, or, you know, like, in the story of, you know, taking it to community consultations, and letting stakeholders see, you know, what, for especially large infrastructure projects, how, yeah, you know, adding an element of transparency, but also, you know, enhancing the level of communication between private or public companies, with interested stakeholders, compared to having to do lengthy processes, often in photogrammetry, which is your traditional way of doing Photoshop on a strict viewpoint, you know, using augmented reality really takes that level of communication, transparency' (S19).

An example of device capabilities is outlined below. Aligning the technological capabilities with the clients' expectations can ensure that the implementation of AR enhances the overall efficiency and effectiveness of the project. A comprehensive assessment of these factors is essential for maximising the advantages of AR technology, and further details on this analysis can be found in the data extract below:

'just come to the use case. So if someone really wants to build something for a new audience, or they want to showcase their capabilities, or they want to show to their audience about their leveraging latest technologies to do their work, then these other very, very effective factors to go towards this one' (S18).

Device compatibility → Multiple programs

An example of the relationship between device compatibility and the use of multiple programs is illustrated in the data extract below. This example emphasises that a crucial aspect of AR technology is its ability to accommodate numerous users simultaneously. This feature is particularly beneficial in large organisations, where it may be necessary to engage a large number of users at one time.

Furthermore, by leveraging multiple programs on the device, organisations can significantly enhance the user capabilities and maximise the benefits of their projects, depending on the specific programs required. This is further detailed below:

'The other thing, I'd say, is making sure that they're able to do multi programs or multiple uses. So if you had one set of goggles and it was only suitable for one task, you're then justifying the cost of those goggles on that one task alone, and it becomes a lot harder. Whereas if that one set of goggles can do five or six different programs or five and six different uses on the job, you're getting a lot more benefit for the value of the one set of goggles. So generally, what you find with technology insertion is just about showing the savings or the reasons you would bring it in in a quantifiable manner that justify the cost to the program, the recurring of setting it all up and training and all of those sorts of things' (E3).

Technology user connection → Technology interface

The relationship between the technology user connection and the technology interface in relation to the authentication process is outlined in the data extract below. This example highlights the challenges associated with device and browser authentication when AR technology is utilised. As users interact with AR applications for the first time, they encounter a series of steps that require them to allow various permissions. These permissions are essential for AR technology:

'The reality is, there's a still a complex combination of device and browser and authentication and permissions and so on that are required to activate that first augmented reality experience, especially if it hasn't been done on that device. Previously. So one of the barriers is that some even as we still experiences, that first experience for someone can sometimes be negative because of those complex browser and device and permissions issues that the browser in the technology usually need to connect to things like the camera or the audio and things like that. And you've got to go through a series of sort of permissions on any device to be able to enable that, and especially on mobile, mobile phones, and tablets, and so on. So working from the barrier side, that still, it's still one of the barriers in terms of a seamless, instantaneous augmented reality experience. I think that's when it's just based on devices' (S19).

Hardware and equipment → AR equipment

The relationship between software and hardware integration and hardware and equipment plays a vital role in the successful integration of AR technology across various applications. One advantage of AR equipment is that it is widely available off the shelf, allowing organisations to easily obtain the necessary tools without lengthy procurement processes. Additionally, comprehensive support and resources are often provided by manufacturers, ensuring that users can effectively implement and troubleshoot their AR systems. This combination of accessibility and support not only enhances the user experience but also fosters innovation and growth in the AR space. The data example below indicates that obtaining AR equipment can be as easy as purchasing the items off the shelf:

'you can go out and get the stuff off the shelf. And anybody can use it. So you basically put the headset on and off you go, you don't need to be an expert, simple configurations and stuff like that it's already being built in' (E10).

The relationship between software and hardware integration and hardware and equipment is outlined in the following data extract. This example explains that a smartphone serves as a device for engaging with AR technology. Utilising a smartphone for AR applications is the most straightforward method of accessing this innovative technology, allowing users to experience augmented reality in a simple and accessible manner. This indicates the potential of everyday devices for facilitating the use of advanced technological solutions:

'And the technology is kind of already there on your smartphone to show a dancing hot dog or something on a surface, right. So they're, the simpler the simplification of the technology is there' (E10).

4.13.2 Artificial intelligence (AI) integration

AI encompasses a wide range of components. This includes generative AI, which encompasses Chat generative pre-trained transformer (GPT) and Microsoft Copilot, as well as AI imagery and AI in general.

The use of AI in conjunction with AR technology is becoming increasingly common. Effectively integrating AI into AR functionalities is essential for the successful execution of numerous projects. A comprehensive analysis of all the elements of AI and their relationship to AR is outlined below. The framework diagram in Figure 4.14 illustrates AI integration within the technology inputs category.



Figure 4.14: Artificial intelligence integration

AI integration has one relationship: machine learning integration. In this research, the machine learning integration category includes AI, AI imagery and generative AI, as defined below.

Machine learning integration:

- Artificial intelligence (AI): This refers to integrating AI with AR technology.
- AI imagery: This refers to integrating AI imagery with AR technology.
- Generative AI: This refers to integrating generative AI with AR technology.

The relationships and supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.13.2.1 Relationships extracted from AI integration

Each of the AI integration relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for AI integration is detailed in Table 4.21, which outlines the grounded theory approach to forming relationships and developing a theory for this research. AI integration forms 3 open codes, 1 axial code and 1 selective code.

Table 4.21 : Breakdown of artificial intelligence integration relationships

Selective code	Axial code	Open code
Artificial Intelligence (AI) integration	Machine learning integration	AI imagery Artificial intelligence (AI) Generative AI

Machine learning → Artificial intelligence (AI)

The relationship between machine learning integration and AI is illustrated in the data extract below. This example demonstrates how a particular software developer has effectively integrated AI technologies, specifically through machine learning, to enhance their 3D modelling processes. By leveraging AI, the developer is able to fast-track the 3D modelling:

'Which is utilising augment artificial intelligence, which is really machine learning to change alter the 3d models' (S21).

Another example of the relationship between machine learning integration and AI is highlighted in the data extract below. This example demonstrates that there are numerous ways to integrate AI capabilities into AR technology. This integration not only facilitates the rapid and immediate processing of real-time data but also enables the programming of information to adapt to specific needs and conditions. These advancements improve the user experience through personalised content and interactions:

'So there's a lot of things that you can do with AR, or with AI, especially that wrap around those future concepts of give..., programmatic..., immediacy of the experience, right, which is a plugin different types of conditions, and see that change. Automatically' (S21).

The relationship between machine learning integration and AI is essential for the effective implementation and advancement of AR technologies. AI and machine learning play a significant role in training processes, automating code generation and implementing scripts across various programming languages. Furthermore, leveraging AI enhances research capabilities, enabling the prediction of potential scenarios.

The following data extract shows how AI enables organisations to use AI bots for creating manuals and policies, enhancing training exercises via personalised and interactive methods and accomplishing these tasks more quickly:

'with the AI you'd like you'd be able to feed back to our whole companies like policies, processes, instructional manuals, training everything into some AI bot. And then when the person is in training, they could just ask, well, what's happening with this, and then it will be totally referenced in the human personal way and it will feel like someone's talking to you maybe, yeah, but it's just the robot. You interpreting, referencing all the company's Yep, everything' (S23).

Another example of the relationship between machine learning integration and AI with AR use is presented below. This example demonstrates how AI and machine learning can be seamlessly integrated into AR technology, tailored specifically to the requirements of the project. This integration involves meticulous programming and adjustments based on varying conditions, showcasing the adaptability and potential of these technologies:

'But certainly things like vegetation, growth rates, wind effects, sound effects, all those types of things can be definitely done with machine learning to enhance that experience...the sound of what is a wind turbine sound like when you're on the south side of a wind farm when it's blowing 50? knots? Right? Very different? What if it's blowing the other way? Yeah. So there's a lot of things that you can do with AR, or with AI, especially that will wrap around those future concepts of give, you know, programmatic, you know, immediacy of the experience, right, which is a plugin plug in different types of conditions, and see that change. Automatically' (S19).

Machine learning integration → Generative AI

The relationship between machine learning integration and generative AI is outlined in the data extract below. This example outlines how ChatGPT is used and how software developers can incorporate scripts. This example illustrates how AI technology can enhance AR technology. By integrating AI, content creation and streamlining processes in AR can be made easier and more efficient. This not only saves time but also limits the cost in terms of resources. Therefore, the impact of AI and generative AI on AR use is demonstrated in the data extract below. This example shows how scripts and voiceovers can be created in various languages by utilising AI technology:

'with AI, what we can do is get that script, put it into an AI voice generator, and we can have it in the software weeks before the actual final script comes through. So we're able to build it with Placeholder footage, placeholder voiceovers, using AI generated content. So even things like this, the art image, it's, yes, it's like an AI generated chat GPT image' (S13).

Another example of utilising machine learning integration is the significant amount of resources it conserves. A software developer highlighted this point, emphasising that harnessing AI technology can greatly benefit small businesses by streamlining operations and reducing the required workforce. This ultimately leads to cost savings and enhanced efficiency:

'We if it wasn't for, like, AI, we would have to have more people, yeah, but yeah, just one person. It's almost equivalent of, like, three or four people probably use different tools' (S13).

An illustrative example of the relationship between machine learning integration and generative AI is presented below. This example highlights the ability to utilise generative AI to assist in developing codes and scripts for AR applications. Moreover, this process can be executed in various programming languages, enabling software developers to engage with clients beyond their home countries and facilitating a broader range of international collaboration:

'we use AI for any code. It's all done by AI, which has changed things dramatically. But even so, I've got in front of me the XXX scripts. So it's being done in English, Spanish' (S12).

This example describes a project manager who uses generative AI for thorough searches and evaluations of written content. Their method emphasises improving the coherence and readability of their work, making sure that the information is not only informative but also flows well. Further details can be found in the data extract below:

'I've been using chat GPT a lot more for chat, GPT, I find is a good alternative to Google when you want to do a comprehensive search on a certain topic, but you don't want to troll through several websites to try and collect information and understand what the common theme is out of all of them, chat, GPT kind of pulls it all together for you. And also it's just a good way to like sense check your written work. So any communications you're sending out, or reports you're writing, if you're unsure of like a paragraph you've written, you can just check in and chat GPT and ask them, ask it if it's if it makes sense. So I've used it for those kinds of work' (E4).

Below is a data extract that illustrates the application of generative AI within the construction industry. In this context, a specific manager has been granted the authority to utilise various AI tools within the organisation, which are actively employed in the AEC environment. This integration improves operational efficiency and encourages innovation in project delivery:

'actually the company has a lot, like some AI tools like ChatGPT, or even the Microsoft Copilot. We can use it actually. But for the other part, like digital engine, two, seems way well for AECs, mainly on the desk before AEC well, like Catia and also the other tools in the manufacturing world, they have also stepped in the AEC industry. So in general, I'm really good at a variety of Camp software and also AEC industry software. Well, for the AEC part,

basically, is all the best, yeah, you know, the whole families. And also for manufacturing, is really those parametric engine like Katia digital project and the early phase, like even co engineers or things like that' (C15).

4.13.3 Automation and 3D environments

AR technology in relation to automation and 3D environments incorporates computer-based modelling, technology automation and 3D virtual environments.

The integration of automation and 3D environments is pivotal for AR use. Automation serves as a fundamental requirement, while the 3D environment is essential to AR technology. Incorporating AI into the functionality of AR is crucial for the successful implementation of various projects. It is imperative to conduct a thorough examination of all factors involved in AR, including automation and 3D environments, to ensure effective integration. The framework diagram in Figure 4.15 illustrates automation and 3D environments within the technology inputs category.

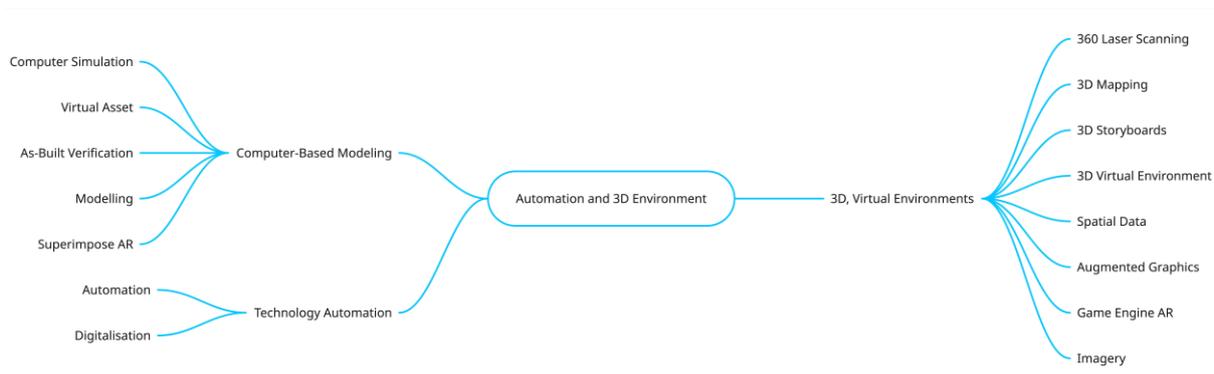


Figure 4.15: Automation and 3D environments

Automation and 3D environments have three relationships: 3D virtual environments, computer-based modelling and technology automation. In this research, the computer-based modelling category includes computer simulation, virtual assets, as-built verification, superimposed AR and modelling, as defined below.

Computer-based modelling:

- Computer simulation: AR technology simulates a real model by modelling one system.
- Virtual asset: This refers to utilising AR technology to virtually see a model.
- As-built verification: This refers to verifying as-built projects by overlaying data on the site.

- Superimposed AR: This refers to confirming the model and overlaying it on the existing data.
- Modelling: This refers to incorporating AR technology to model a system in a 3D environment.

In this research, technology automation includes automation and digitalisation, as outlined below.

Technology automation:

- Automation: This refers to the use of AR technology and automation to enhance 3D modelling.
- Digitalisation: This refers to the use of AR technology and digitalisation to improve 3D modelling.

In the current research, the 3D virtual environments category includes 360-degree laser scanning, 3D mapping, 3D storyboards, 3D virtual environments, spatial data, augmented graphics, game engine AR and imagery, as defined below.

3D virtual environments:

- 360-degree laser scanning: This refers to a 360-degree representation of the immersive environment.
- 3D mapping: This refers to 3D modelling on web-based 3D maps.
- 3D storyboards: This refers to developing a 3D visual that illustrates the project's scope and provides a representation of the project's needs.
- 3D virtual environment: This refers to creating a 3D virtual environment utilising AR technology.
- Spatial data: This refers to utilising AR technology and geographic systems.
- Augmented graphics: This refers to utilising AR technology to generate 3D graphics.
- Game engine AR: This refers to a system used to develop AR technology.
- Imagery: This refers to utilising AR technology to generate 3D imagery.

4.13.3.1 Relationships extracted from automation and 3D environments

Each of the relationships for automation and 3D environments was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for automation and 3D environments is detailed in Table 4.22, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Automation and 3D environments form 15 open codes, 3 axial codes and 1 selective code.

Table 4.22 : Breakdown of automation and 3D environments relationships

Selective code	Axial code	Open code
Automation and 3D environments	Computer-based modelling	Computer simulation
		Virtual asset
		As-built verification
		Superimposed AR
		Modelling
	Technology automation	Automation
		Digitalisation
	3D virtual environments	360-degree laser scanning
		3D mapping
		3D storyboards
		3D virtual environment
		Spatial data
		Augmented graphics
		Game engine AR
		Imagery

Computer-based modelling → Modelling

The relationship between computer-based modelling and modelling is explained in the data extract below. This example emphasises the importance of acquiring project information and visualising it in a 3D environment. Additionally, it illustrates the steps an engineering team would take to develop this information in a 3D setting:

‘But I think based on where we’ve got, where we’ve used them, we’ve now got a whole bunch of examples where I think we’d like to implement them from us. It all stems from the engineering requirements. So we can look at the engineering requirements and say, Okay, this is the information we need to impart, and then we give that to the programming team. So to say, like, usually, where it’s information that we’re printing out on paper visually is sort of where we’ve targeted to implement it. So where we’ve got a visual representation of our engineering that we then print out on paper for the team on the floor, where, like, I printed on

paper when we visually display it for them. Yeah, in rather than 's so that's, I guess, for the most of the applications we've incorporated so far, where the sort of requirements have been communicated. It's like, here is the information in 3d in a model that we'd like to present in 3d in real life' (E3).

Again, the relationship obtained from the data suggests that technical expertise is crucial for developing the modelling and data necessary for AR implementation. This relationship highlights the importance of specialised skills in shaping and optimising AR applications. The expertise in AR modelling significantly impacts the requirement modelling for AR, as indicated by the insights provided by the data extract below:

'So 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 kind of 3d modelling system into a space, and that's a pretty specific skill set to be able to have' (E10).

Computer-based modelling → As-built verification

The relationship between computer-based modelling and as-built verification with AR usage illustrates how AR technology makes it possible to validate the accuracy of 3D modelling and its content. This technology can serve as an overlay that facilitates a thorough check for precision, ensuring that the completed work aligns correctly with the design intent. For instance, consider the data extract provided below, which represents this application in practice:

'The first one is for as built verification, so it's like getting instant, or, you know, progressing review. So we're bringing the model on the phone, or the iPad, and it will bring on site and we overlay with existing the store has in store condition to check is displacing. Or at least it you know, depending on the accuracy of that model, we will at least to see whether the object sits in relatively close location as per the design intent. That's the one thing we do for verification, the other is for a check' (C16).

An illustrative example of the relationship between verification processes and the utilisation of AR technology can be found in the following data extract. This example is relevant to the construction industry, particularly through the lens of BIM. In this scenario, the project manager must prepare data for a tender, necessitating varying degrees of detail depending on the requirements. It is imperative that all information is thoroughly validated to ensure the accuracy and comprehensiveness of the details included in the tender submission:

'Actually, because the contract requirement. Because in our world of the BIM world, the AEC world for digital engineering, we have a requirement for we have LOD, I'm not sure if you aware of the LOD level of details about the model. So we have, like, 100 to 500 where 500 the most extensive one would hire you to have a model that's exactly the same, or, you know, relatively close to the wheel well. So at the end of your construction, you will have in this field model which that you need to verify it, because still, someone has to build a model with a computer. So that's why we need these two to be able to overlay with our model to check you know this, of course, there are many ways to do it, but one way is to do AR VR or MR. So basically more AMR to use it to work, date, the model, accuracy' (C15).

Technology automation → Automation

The relationship between technology automation and automation in AR use is crucial for enhancing the user experience, especially considering the diverse range of software used in various projects. It is evident that effective AR software collaboration significantly influences AR use, as highlighted in the following data extract. The example demonstrates that automation helps streamline processes and deliver projects effectively:

'Yes, we've been, we've got some internal tools that we software's tool that we use, but I suppose automates and streamlines the process. That's our Yeah, we use that to deliver these projects. And eventually, that was, our aim is to make that publicly available. At the moment, it's a tool that we use to deliver projects. So we're sort of each project that we work on, we can add in these features, and different things. So that's really cool that swivel. And that's like our little internal 3d mapping tool that we've got' (S14).

3D visual environments → 360-degree laser scanning

The relationship between 3D virtual environments and 360-degree laser scanning arises from projects needing to depict the surrounding environment. The example below illustrates a wind farm, which requires a representation of both the wind farms and the nearby area to provide users with an immersive experience, as if they were on-site, from their computer:

'We started working with wind farms, right? Yes, yes. And wind farms, we're early. And in fact, I think we've literally, that first wind farm got off who forgot the name that XXX, I think it was. And we did all deals. That was it. We did the first 360, sort of on location. Here, the birds see the frogs in the creek, it was all part of the very early stages of what we're specialising in, which is the feasibility studies due diligence stage, which is the community consultation stage. So what we're focused on is not the high end engineering and millimetre

perfect representation, immersive experiences for engineering and project execution. Were very much focused on the much earlier stages of the marketing and the community consultation phases' (S19).

3D visual environments → 3D mapping

The relationship between 3D visual environments and 3D mapping is illustrated in the data extract below. This example demonstrates how 3D mapping automates and streamlines processes for this specific software developer. Additionally, it emphasises that this is an internal application, not currently available to the public:

'we've got some internal tools that we software's tool that we use, but I suppose automates and streamlines the process. That's our Yeah, we use that to deliver these projects. And eventually, that was, our aim is to make that publicly available. At the moment, it's a tool that we use to deliver projects. So we're sort of each project that we work on, we can add in these features, and different things. So that's really cool that swivel. And that's like our little internal 3d mapping tool that we've got' (S14).

The relationship between the 3D visual environment and 3D mapping highlights the importance of 3D modelling in site development. Incorporating this modelling into web-based 3D maps allows the integration of various levels of data, increasing the overall user experience and functionality. This example is highlighted in the data extract below:

'essentially what they do is capture these 3d models of the site, to we get these 3d models of the site, and then we add these into these web based 3d maps. So that's how we've been able to do that. And then yeah, it's then I suppose, adding on those different levels of data. So one thing that we haven't done is adding in live data, and I think that's going to be that next step is when you start integrating in that level of dialogue, that wind farm example, if you can start adding, yeah, where your contractors, locations are, where vehicle locations are, and sort of takes that to the next level' (S14).

3D visual environments → Augmented graphics

The relationship between 3D visual environments and augmented graphics is essential, as AR technology generates augmented graphics for use. Augmented graphics enable users to integrate AR technology into the real world rather than a virtual setting. This is illustrated in the data example below:

'rather than being an entire virtual space, you can actually see through it into the real world and, and project images, onto surfaces or whatever you choose it to be combination of reality and virtual' (E10).

A further illustration of the relationship between 3D visual environments and augmented graphics is presented in the data extract below. This example highlights how AR technology and augmented graphics can assist in aircraft maintenance. Specifically, it discusses how to familiarise users with incorporating AR technology by utilising augmented graphics to present step-by-step guidelines:

'it needs to be a scenario where you're trying to show somebody what something could look like or invest in the identification of like conveyancing say you're doing maintenance on aircraft or something in your had a setup is familiar with inside the landing gear augmented reality could point a maintenance person to a particular line to say that's what you need to do, and bring up information that actually shows what they need to do step by step' (E10).

Additionally, the following example highlights the application of AR technology and the use of augmented graphics alongside elements like GPS and temperature in our environment:

'So augmented reality in particular. So augmented reality is really about utility. So when you think of augmented reality, like when I think of augmented reality, I think of like looking at the sky and getting a temperature, having the GPS directions, overlaid on my glasses, and maybe looking at a wall and seeing where cables are and things like that, inside the wall that I can't see. So I think it really comes down to you know, it being like augmented reality, it's really a solution for a bunch of problems. So it's about finding that right mix' (S21).

4.13.4 Data privacy and management

AR technology's relationship to data privacy and management includes both data management and data analytics. Integrating data privacy and management is crucial for the effectiveness and successful application of AR technology. It is vital to ensure that all utilised data are properly managed and stored. There have been numerous instances where large organisations have breached personal data, leading to questions about their trustworthiness. Figure 4.16 illustrates the relationship between the use of AR and data privacy, as well as data management.

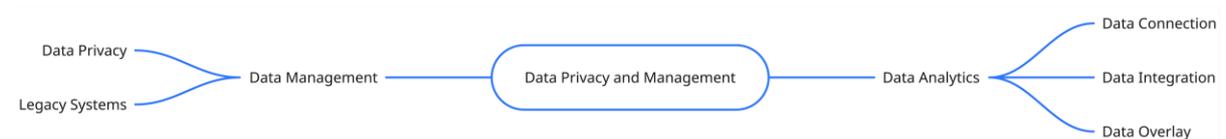


Figure 4.16: Data privacy and management

In this research, data analytics includes data connection, data integration, data overlay and data sets, as defined below.

Data analytics:

- Data connection: This refers to connecting various data types through different systems.
- Data integration: This refers to integrating different data types.
- Data overlay: Different data overlays are arranged to create various layers.

In the current research, the data management category includes data privacy and legacy systems, as defined below.

Data management:

- Data privacy: This refers to the protection of data.
- Legacy systems: These are redundant systems that are no longer in use.

The relationships and supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.13.4.1 Relationships extracted from data privacy and management

Each of the data privacy and management relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for data privacy and management is detailed in Table 4.23, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Data privacy and management form 5 open codes, 2 axial codes and 1 selective code.

Table 4.23 : Breakdown of data privacy and management relationships

Selective code	Axial code	Open code
Data privacy and management	Data analytics	Data connection Data integration

	Data overlay
Data management	Data privacy
	Legacy systems

Data management → Data privacy

The relationship between data management and data privacy is essential when integrating AR technology into projects. Data privacy plays a critical role in utilising AR; first, the information related to AR use in commercial applications must remain confidential, and second, distrust in the system may prevent customers from engaging with AR, necessitating a trustworthy approach. The data extract below provides an example of data privacy, highlighting the reasons that someone might refrain from using AR technology, where security and privacy play a significant role:

‘Barriers might include like, security, privacy, what else the cost, cost of what is going to also learning curve, so people might not know how to use it properly, and it’ll just be It’s all new to them. Security would be a big problem with tech, with any technology’ (C7).

Another example of the relationship between data management and data privacy is outlined below in numerous open-ended survey questionnaire responses, where the participants were asked what barriers would prevent them from using AR technology. Many responses indicated data privacy concerns; these examples are detailed below:

‘Hackers stealing your ideas and saved work, loss of work incase it crashed and never had a backup save’ (SE7).

‘Increased digitisation of workflows has issues regarding regulation and relevant legislation. The leading edge of technology tends to be less heavily regulated, and this can lead to invasions of privacy and other rights. The prevalence of social media now is the posterchild of inadequate regulation, and AR (and pr stunts regarding the “metaverse”) is likely to being a large part of their profit in the future’ (SE10).

‘I have no barriers in the use of new technologies outside of foreign (external to myself) influence over said technologies. Outside of economic factors, the most significant barrier would be data privacy’ (SE12).

‘Difficult to learn how to use. Privacy issues with other companies and personal information’ (SE16).

Data analytics → Data overlay

The relationship between data analytics and the data overlay in relation to integration and AR use is fundamental for the effective utilisation of AR technology. Overlaying various types of data using AR technology enhances the user experience and overall functionality of AR. Therefore, the data overlay significantly impacts AR use, as outlined in the following data extract. This example discusses the different types of data that can be integrated into AR technology:

'So essentially, it's the 3d world where you can then sort of start bringing in different types of data. So at the moment, you can, it's pretty basic, and just adding fairly basic information. But what we're working on at the moment, is being able to bring in, like normal photos and 360 degree photos. And you can see that sort of detailed level will start bringing in some live data. So three using like IoT devices, so you can start to overlay those as well. But yeah, as a way to sort of monitor that progress over time. So then you can overlay drone imagery onto this' (S13).

Data analytics → Data integration

The relationship between data analytics and data integration is essential for developing AR technology. The example in the data extract below illustrates the various types of data and how they can be integrated to create a user-friendly visual model:

'That has been pretty interesting on real time data visualization. So even if it is that more historic type, sort of imagery, but then being able to see over top of that, like IoT data, webcams, foot traffic, and car traffic could be a fairly common thing, especially foot traffic of how people move through an area. So it was interesting, being able to have access to then other data sets. So whether or like the government type of data, environmental data, being able to see that integrated into then what they're sort of visualizing. So if it's like a building or something, then being able to see how, like for councils, they want to see how sort of like rising water would affect that particular area. user friendliness making it easy' (S13).

Another notable example of data integration and the application of AR use is presented in the following data extract. This extract explains the various levels of data integration, specifically focusing on how three-dimensional modelling can be effectively incorporated into 3D mapping solutions and how different levels of data can be added:

'that's essentially what they do is capture these 3d models of the site, to we get these 3d models of the site, and then we add these into these web based 3d maps. So that's how we've been able to do that. And then yeah, it's then I suppose, adding on those different levels of data' (S14).

4.14 Project Output

Project output consists of four key categories: user experience, technology advancements, technology challenges and performance and quality assurance, as detailed below:

1. User experience and AR use: This category encompasses the user experience, acceptance and the adaptability of new technology.
2. Technology advancements: This category details augmented reality benefits.
3. Technology challenges: This category outlines project challenges and technology challenges.
4. Performance and quality assurance: This category outlines performance, quality control, practical solutions, AR technology requirements, quality improvements, performance criteria and project collaboration.

Incorporating these four factors into project outputs establishes a robust framework that portrays the requirements of AR technology in relation to the project outputs, as illustrated in Figure 4.17.



Figure 4.17: Project output

4.14.1 User experience and AR use

The relationship between AR technology and the user experience and AR use incorporates adaptability to new technology and user acceptance. The integration of the user experience with AR use is essential for AR technology; the user experience and the user's thoughts on using AR technology are vital for incorporating this technology. The user needs to understand how to use AR technology with ease after being trained. The lack of a positive user experience could be detrimental for incorporating this type of technology in projects. The framework diagram in Figure 4.18 illustrates the user experience and AR use.

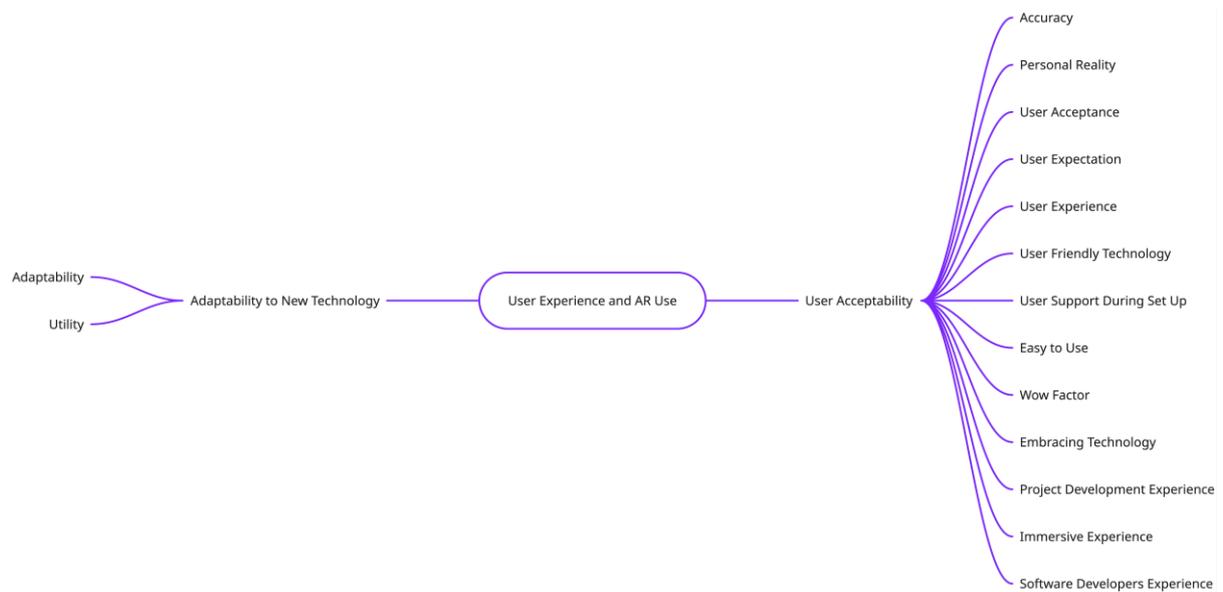


Figure 4.18: User experience and AR use

In this research, the user experience and acceptance of new technology category involves various factors, including the accuracy, personal reality, user acceptance, user expectation, user experience, user-friendly technology, support during set-up, ease of use, wow factor, embracing technology, immersive experience, project development experience and software developers' experience, as defined below.

User acceptability:

- Accuracy: This refers to the accuracy of the modelling using AR technology.
- Personal reality: This refers to the individual's perception of their own use of AR technology.
- User acceptance: The user accepts AR technology.
- User expectation: This refers to the user's expectation in using AR technology.
- User experience: This refers to the user's experience with using AR technology.
- User-friendly technology: This refers to AR technology being user-friendly.
- User support during set-up: There is support from the developer during AR technology set-up.
- Ease of use: The AR technology is easy to use.
- Wow factor: The AR technology experience has a wow factor.
- Embracing technology: The user embraces technology.
- Immersive experience: AR technology provides an immersive experience to the user.
- Project development experience: This refers to the experience with using AR technology during the project development stage.
- Software developers' experience: This refers to the software developers' experience with the user acceptance of AR technology.

In this research, the adaptability to new technology category includes adaptability and utility, as defined below.

Adaptability to new technology:

- Adaptability: This refers to the adaptability of utilising new technology.
- Utility: AR technology functions similarly to a service.

The relationships and supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.14.1.1 Relationships extracted from user experience and AR use

Each of the user experience and AR use relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for the user experience and AR use is detailed in Table 4.24, which outlines the grounded theory approach to forming relationships and developing a theory for this research. The user experience and AR use form 15 open codes, 2 axial codes and 1 selective code.

Table 4.24 : Breakdown of user experience and AR use relationships

Selective code	Axial code	Open code
User experience and AR use	User acceptability	Accuracy Personal reality User acceptance User expectation User experience User-friendly technology User support during set-up Ease of use Wow factor Embracing technology

	Project development experience
	Immersive experience
	Software developers' experience
Adaptability of new technology	Adaptability
	Utility

User acceptability → Accuracy

The user acceptability has been found to impact the accuracy, as illustrated in the data extract below. The accuracy of AR technology is essential for AR technology use. The following example highlights the use of AR technology in construction, showcasing how accuracy and modelling are essential. This example highlights how construction managers utilise AR technology to verify that work done on-site aligns with the intended design:

‘There are two major activities. The first one is for as built verification, so it’s like getting instant, or, you know, progressing review. So we’re bringing the model on the phone, or the iPad, and it will bring on site and we overlay with existing the store has in store condition to check is displacing. Or at least it you know, depending on the accuracy of that model, we will at least to see whether the object sits in relatively close location as per the design intent’ (C16).

This example highlights the use of AR technology, illustrating the accuracy of the modelling and the alignment of the client’s expectations. The quotes below support this relationship, discussing how vital accuracy is for projects and how some clients may have misaligned expectations regarding the accuracy and depiction of the modelling:

‘And there is accuracy, right. So, accuracy of these particular types of products is limited, and it’s limited somewhat in terms of the nature of telco towers, it’s limited by satellite, you know, devices, and the cost associated to bringing all of those things together to create certain levels of accuracy. So that can also be it’s a natural or current limitation of these types of products in in in infrastructure projects is that they may not be accurate enough for some requirements or, or we’ve misaligned the expectations with the client in terms of accuracy. They believe that of course, they see it there, they’re gonna get, that’s millimetre perfect and might not be exact’ (S19).

Another example of user acceptance and its relationship to accuracy is described below. This example emphasises the significance of accurately modelling information and ensuring

that the selected software is appropriate to confirm proper translation for the modelling for the project:

'it's about proving that it works and that there's no errors. So for us, I think it's more about finding the right software that then links and we can confirm that it's the information hasn't passed through multiple software bands to get to the operator that it's, you know, that's only been translated once, and so that we have more confidence it's correct. I guess the perception is, if it the more it travels through various software's, out of our modelling, our engineering modelling, and then into another software, and then into another software, that the data could get corrupted and therefore may not be correct, and maybe then causing quality issues' (E3).

Another instance illustrating user acceptance and its relationship to accuracy is given in the data extract below. This example highlights the application of AR technology in the manufacturing sector, demonstrating how precise overlay data enable workers to drill holes accurately without the need to mark and look at paperwork:

'a good application of it was when we would work on aircraft parts and drilling holes in the right location. So if the if augmented reality helped us overlay like a map of the holes in the right locations, it would give us a good sense check of where to drill them as a practical example. So it would have lots of applications in manufacturing' (E4).

User acceptability → User acceptance

User acceptability has been found to impact the user acceptance of AR technology, and this is demonstrated in the following data extract. When the user perceives AR technology as practical and that this technology aligns with the user's needs, the user is more likely to accept this technology. User accessibility and acceptance are crucial for the effective integration of AR technology. The example below highlights that when there is a general acceptance of new technology within the workflow, integration becomes seamless. Conversely, when there is a prevailing reluctance to adopt new methods and a strong adherence to traditional practices, achieving acceptance becomes challenging:

'general acceptance. And, you know, trying new things, people tend to get set in their ways, in their job, and don't want to try new things, because they perceive it's harder. Or, you know, but I already know how to do this, and, you know, I guess it's, it's just about overcoming that and working through the change and how technology can help. Rather than

just, Hey, there's this new process, we're inflicting it on you. So it's, it's more about cultural change as well' (E3).

Another instance illustrating user acceptability and its connection to user acceptance is presented in the data extract below. This example highlights the significance of user acceptance and the methods used to measure it. Here, user acceptance refers to the speed with which modelling can occur, enhancing the immersive experience and acceptance of AR technology:

'to speak so large groups of the community consultation teams, right so that that acceptance, why speed and ease of use. But speed in which we can realise the sophisticated deployment for them and the deployment being I've got these models, I've got this data and I want you to put it in here. We can do that in a day. It'll enter they'll even get shorter right so that's one of the major things that sort of like the wow factor, and acceptance like we need to do this quickly and make changes quickly. Acceptance Yeah' (S19).

Another instance of user acceptance is the client's familiarity with AR technology. They have seen demonstrations of AR in use, which has contributed to how comfortable they are with utilising AR technology:

'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 written necessarily in a business sense' (E10).

Below is an example of user acceptance. This instance illustrates various reasons for the acceptance of AR technology, which can vary according to the project's scope. It also emphasises the importance of obtaining accurate information from the developer to ensure that the client receives what they require based on the project's specifications:

'The acceptance very, comes down when it's with this to like, different types of diopters with AR. And then like the native app, a native app is got its benefits in terms of it uses the devices, processes, so it's probably can do a bit more with it. But you have to download an app, which could be a barrier with where they are, it's like a QR code, which goes to a web page, which then goes, Can I use your camera and its instance, for like, shorter campaigns with the large amount of eyeballs on it, it's better so you can get more people didn't know about the difference between those two? Didn't actually, we always like when a customer

comes to us and ask for an AR we go well, we ask ourselves, and is it best suited for a native app or where they are? And so for instance, the open call line AR is better for application because there's more depth in it. And it's kind of a bit more involved' (S23).

Another example of user acceptance is highlighted below. This example illustrates that user acceptance stems from how well the technology is integrated into the project and how well this is communicated to the users:

'So the ability to, I guess, 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 there. I think they are the real sort of interest that will drive user acceptance and adopt, get involved with the actual technology' (E10).

An example of user acceptance is highlighted below. This example outlines how new technology is incorporated into a construction project. It shows that the construction manager may overlook the potential benefits of technology in the construction sector; only once these advantages are realised in a manner that positively impacts the project will they contemplate adopting new technology:

'Definitely it is, wherever he is acceptable acceptance, from individual people. Yeah. And I think at this point of time, it's almost like one to nine. One is subset nine is reject, yeah, it's actually a bit difficult to convince them or, you know, to show them what the, what the tech can do, and whether this is really happened to me. And even if they consider this helping them. I think they, they, you know, this is one of like, 9000 things that you could do on site. So they might consider this is not their priority or that important. And either they will miss it, or they will just ignore it. Until, at the very least, so especially a case that they want' (C16).

User acceptability → User expectation

User acceptability has been found to impact the user experience, as demonstrated in the data extract below. It is crucial for users to grasp the capabilities of AR technology and how it compares to their expectations. This example illustrates that acknowledging user expectations and improving their comprehension of AR technology enhances AR integration:

'Especially for us, like, in the experience we have had, like, you get the whole range, you know, like, so we found it's as much, you know, as much as you'd like to build something that's, you know, hands off, and you know, the user can just jump on and do what they need to do and download the app, whatever. There's always that, especially in enterprise, at least,

there's always that benefit of having a consultative process, you know, when setting these things up, you know, our clients with the app and everything that they need, which is, you know, understanding, like XXX said, understanding their expectations and their understanding the base level understanding of what VR AR' (S19).

Below is another example of user accessibility and user expectations. This example highlights that recognising the target audience is essential in developing AR technology, as well as understanding their expectations when they utilise the technology:

'So first, once we know the use case, and what they're going to build, and who is the target audience, which we share about some of the limitations of the AR? That if that expectation is, let's say is if someone is wanting to see how that jacket looks on them? It is not 100%? Like us? Yeah. So then if you understand this thing that sometime because it's all depends on the capability of the device, and mobile, or whatever it is, right, the camera, the camera has to be that these things?' (S18).

User acceptability → User experience

User acceptability significantly influences the user experience, as illustrated by the data extract below. This example demonstrates that a smooth user experience enhances the user acceptance of AR technology. However, when new technology is integrated, it must undergo a robust permission process. Although this process can be tedious, it ultimately benefits users by ensuring a smooth and instantaneous experience:

'So one of the barriers is that some even as we still experiences, that first experience for someone can sometimes be negative because of those complex browser and device and permissions issues that the browser in the technology usually need to connect to things like the camera or the audio and things like that. And you've got to go through a series of sort of permissions on any device to be able to enable that, and especially on mobile, mobile phones, and tablets, and so on. So working from the barrier side, that still, it's still one of the barriers in terms of a seamless, instantaneous augmented reality experience' (S19).

The user experience remains a key factor in the acceptance of AR technology. The data extract example below demonstrates the importance of having clear consultations with clients to ensure that their expectations match those of the developer:

'I mean, yeah, the only thing I would add to that is sort of what we mentioned before, which is, you know, also providing that, you know, close consultation, just to just to narrow down on

their expectations, and also their understanding their needs and what we can do to fit that' (S19).

User acceptability → Ease of use

The relationship between user acceptability and ease of use is crucial for the integration of AR technology. The data extract below highlights that one of the reasons for incorporating this technology into projects is its overall ease of use, not just in terms of the applications but also from the user perspective:

'The facilitators for using this technology is its ease of access and insertion into applications that are readily used by the general population' (E5).

Another example of user acceptability and ease of use regarding the integration of AR technology is its simplicity. This example highlights how easily data can be integrated to create a 3D model of a design:

'And it's a very, very, very easy process with our platform to be able to resubmit an XML or something like that at this stage, and just republish with a new design, you know, that could be a new model, and it could be a new placement of that line, whether it be powerlines, or solar, wind farm, in terms of the placement. So that's the nature of the technology lends itself incredibly well to the nature of the industry, which is at those early stages' (S19).

The example below outlines how easy AR technology is to use and how simple it is to use the apps:

'Pretty good, for the first time, and um, given that it is a new technology and you think it can be hard to use, they made it pretty easy to use with the apps, and just, there isn't much to learn to get it to work, so its pretty good experience' (C9).

Below is another instance illustrating the relationship between user acceptability and the ease of use. This example highlights the straightforward set-up of AR technology, along with the seamless and instant information it provides:

'The ease of use and set-up; being able to not require a dedicated room and particular hardware in a fixed location, but also being able to maximise a collaborative approach to its use, in this day and age of access to immediate information' (SE11).

The relationship between user acceptability and ease of use is demonstrated below; this supporting data extract is from a software developer who is also a director and the company owner. The example below outlines how easy AR technology is to use and the efficiency of interacting with information in the real world:

'The positive side would be if there was like, some sort of machine and you could hold up your phone and go, Well, those buttons are that and press this and stages in training, and kind of some sort of technical manual or if you've got a brochure of a house, and then you can hold up your phone, and it pops up the 3d model. And it's like, you get a feeling for like the plan has suddenly come into 3d. That's the positive sides, when there's some sort of interaction and information displayed in a way that's thoughtful and important to something in the real world' (S21).

The extract below is from an engineering manager who works in a large organisation. This example indicates that AR technology does not require any specialised education to use and describes how easy it is to adopt:

'Quite honestly, 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 is no real restrictions' (E10).

The below supporting data extract is from an engineer who works in the health field. This data extract highlights that this technology is easy to use and is accepted by the younger generation:

'The facilitators for using this technology is its ease of access and insertion into applications that are readily used by the general population' (E5).

User acceptability → Wow factor

The connection between user acceptability and the wow factor derives from how users would like to have an immersive and thrilling experience with AR technology. The data extract below highlights users' enthusiasm for visual effects and their engagement with AR technology:

'It's the interactivity, it's the visual wow factor of augmented reality, and to be able to talk through people through how that infrastructure will sit, be in, in the landscape with those

teams. So that's, I think, you know, sort of lovely, raised that we've sort of coined about the sooner the better, why use augmented reality in these early stages of construction projects' (S19).

Another example of user acceptability and the wow factor is demonstrated in the data extract below. This example illustrates that using AR technology enhances project efficiency. Furthermore, when individuals utilise this technology for the first time, they truly experience an immersive and futuristic encounter:

'So I think, first of all, is cool thing to use it, just personally thinking. The other thing is, we did a requirement, how we can sacrifice the requirement of our projects, and then we will need to think about, you know, which is easier ways to do it. I mean, think about the efficiency... this kind of efficiency gaining, and also the cool, the cooler, I think perspective when people were looking at, you know, doing cool things, I think that that's something we finally use for' (C15).

Again, this example demonstrates that utilising AR technology provides an immersive experience that not only feels futuristic but also captivates users with its immersive nature, enhancing the overall user acceptability and experience:

'How futuristic this is, and that most people and clients and everyone haven't really experienced this, so it's the wow factor for most people' (C9).

Adaptability to new technology → Embracing technology

The relationship between adapting to new technology and embracing technology is demonstrated in the data extracts below. The examples highlight that there are always individuals who embrace technological advancements and those who resist adopting new technologies. Resistance to change is a frequent occurrence; many people prefer to maintain their current practices. However, once individuals begin to learn and adapt to new tools or processes, they frequently find the experience satisfying. An example of embracing technology is outlined below:

'Yeah, of course there is. There is always going to be people that embrace technology and people that see that it's unnecessary. Because a lot of times you get people going, oh, what does this do over just say, you know, a CAD model? So, you know, resistance to change is everywhere' (E10).

Another example illustrating the relationship between adapting to new technology and embracing technology is provided in the data extract below. This example emphasises generational differences that influence whether or not technology is embraced, suggesting that younger individuals tend to adapt to change more readily than their older counterparts:

'Our younger generations are fully embracing new advancements, as they are seeing that this is the way the world is going. AR is both an escape and integration that they're welcoming quite easily' (E5).

Adaptability to new technology → AR adaptability

The connection between adaptability to new technology and AR adaptability highlights that adaptability makes it easier to incorporate AR technology. The data excerpt below indicates that a major factor affecting the use of AR technology is its compatibility with new tools and the positive impact that this has on workflows within the construction sector:

'Other factors would be like, Would it be similar to other technology? Probably what? If it is different, you would probably have to adapt if you're willing to adapt to the new tools, and if it's gonna affect their daily life at work. So for people that use it or make their job a lot easier, possibly' (C8).

An additional example of the connection between adaptability to new technology and AR adaptability is presented below. This example indicates that the construction industry is eager to adopt this technology if it enhances their workflow; therefore, adapting to this technology is a straightforward decision:

'Similar with stuff like that, with that kind of technology, and if you're, if you're willing to adapt to new tools, so and if it, if it pretty much benefits that line of work' (C6).

Adaptability to new technology → Utility

The relationship between adaptability to new technology and utility is clearly outlined in the data extract provided below. This example highlights that utilising AR technology is related to incorporating a new type of service that enables users to engage in an immersive experience:

'So augmented reality in particular. So augmented reality is really about utility. So when you think of augmented reality, like when I think of augmented reality, I think of like looking at the

sky and getting a temperature, having the GPS directions, overlaid on my glasses, and maybe looking at a wall and seeing where cables are and things like that, inside the wall that I can't see' (S21).

4.14.2 Technology advancements

Technology advancements are essential for outlining AR's technological benefits in the workflow. Understanding these benefits is crucial for successful implementation and a great user experience, thus ultimately contributing to the overall success of projects that utilise this technology. The framework illustrated in Figure 4.19 illustrates these technological advantages and their relationship to AR technology use.

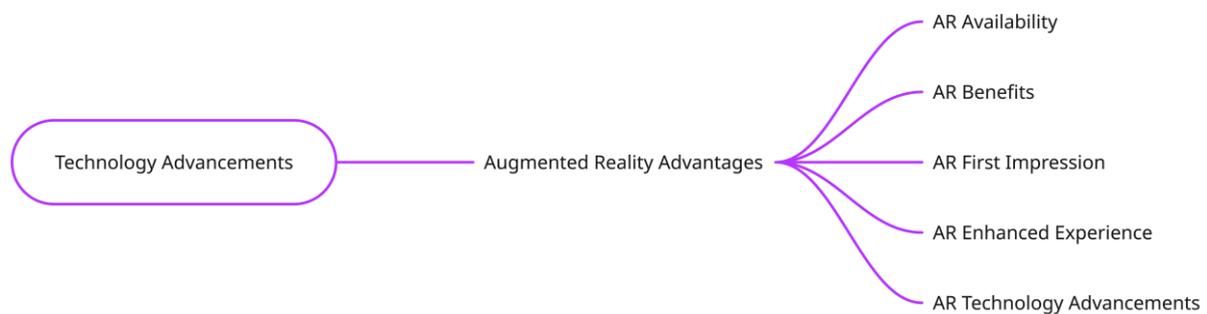


Figure 4.19: Technology advancements

In this research, the augmented reality advancements category includes AR availability, AR benefits, AR first impressions, an AR-enhanced experience and AR technology advancements, as defined below.

Augmented reality advantages:

- AR availability: AR technology is readily available.
- AR benefits: This refers to the benefits of AR technology.
- AR first impression: This refers to the initial immersive experience utilising AR technology.
- AR-enhanced experience: This refers to an enhanced positive experience using AR technology.
- AR technology advancements: This refers to positive advancements in AR technology.

Below, we provide a detailed overview of the relationships and supporting data for each deliverable, including their interactions and the context surrounding their development.

4.14.2.1 Relationships extracted from technology advancements

Each of the relationships for technology advancements was derived from grounded theory. The first step in this approach is to outline the initial concepts through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately leading to the formation of axial code relationships. The data from the axial codes were further analysed to develop core concepts in the selective coding process.

The data analysis for technology advancements is detailed in Table 4.25, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Technology advancements form 5 open codes, 1 axial code and 1 selective code.

Table 4.25 : Breakdown of technology advancements relationships

Selective code	Axial code	Open code
Technology advancements	Augmented reality advantages	AR availability AR benefits AR first impression AR-enhanced experience AR technology advancements

AR advantages → AR availability

The relationship between AR advantages and AR availability indicates that AR is readily available, so it can be easily purchased and used. The availability of AR has been found to have an impact on its usage, and this is supported by the data extract detailed below:

‘One of the really good things about it is that he’s actually readily available technology at the moment. So it’s sort of, you can go out and get the stuff off the shelf. And anybody can use it. So you basically put the headset on and off you go, you don’t need to be an expert, simple configurations and stuff like that it’s already being built in’ (E10).

AR advancements → AR benefits

The relationship between AR advancements, AR benefits and AR usage lies in the fact that AR technology is accessible across various electronic devices, making it widely available to users. The practical benefits of AR have a direct impact on its usage, as the convenience and versatility of the technology encourage increased adoption and integration. This relationship is supported by the data extract below, which highlights the correlation between AR’s practical benefits and its utilisation:

'Yeah, So that's, that's a little bit easier in the sense that everyone has a smartphone or an iPad or whatever. but that also takes away some of the utility of like, of augmented reality glasses. So again, it just comes back to find that balance between use case and practical benefit and ROI for a business. And the technology' (S21).

Another instance illustrating the connection between AR advantages and benefits is the ease of using AR technology for visualising a project at a 1:1 scale. The following example highlights the simplicity and benefits of utilising AR technology, demonstrating how the user can enjoy a 3D modelling experience of the product:

'But from our project planning kind of perspective, it also would enable users to basically walk out to an empty field, put on the headset and say, hey, look, here's your highway, here's your building. He's, he's your refurbished office, right, and really made sure that people and customers understand exactly what it is that they're getting in for, you know, you've seen, I think one of the homes that government has that display that you walk in, they project an image on the floor, so people can understand the size of the house, you know, so all those sorts of things that have a physical aspect, being able to communicate to the customer, in a better way that actually helps them understand the size, scale, shape, all that sort of stuff of a project is really key' (E10).

The following example showcases that one of AR's advantages and benefits is that users can access it from their office or home without needing to travel to a physical site. The following data extract illustrates this example:

'They've pretty much come back and said that they wouldn't be able to run another project without a tool like this. It stopped them having to travel to the sites, I think it's XXX the company. So they are able to log in. And we can see when they do log in as well. So they're logging in almost daily and seeing what's happening' (S14).

Another example demonstrating the connection between AR's advantages and benefits demonstrates that these benefits vary based on the user's needs. Below is an illustration highlighting the different advantages for a construction manager compared to the advantages for an engineer:

'it's really about the benefit that it brings to them? Like you know, like a construction manager would we want to know whether the thing that would be according to design time,

but you know, the engineers we like to know whether the factory has fabricated, the exact piece that they needed so it's really depending on what benefits it's bringing to the user' (C17).

Another example of AR benefits is outlined in the data extract below. This example illustrates how easy it is to interact with AR technology and how 3D modelling can benefit the user. Incorporating AR technology enables a component to be built with AR technology first, allowing one to see all the moving parts prior to constructing the actual component:

'I would see it if, if you have, if you're showing a new member, or a new, a new team member, a rocket then using it would be that wow factor of using augmented reality, so that the graphics of it and how real it seems to them would be a would be one of the beneficiaries in how easy it is for people to interact and to, to move, they can move their components and move their parts and everything how they wanted' (E11).

Another benefit of using AR technology is the decrease in errors. The following example illustrates this. Utilising AR technology relieves operators of cognitive burdens; in this case, a projector guides the operator by outlining the next process step, therefore decreasing errors and benefiting the workflow:

'So that was so they had cameras, tracking the individual items. And then the projector would then just display onto the table. What that next step was, so essentially, it was like wearing the glasses, but it was just projecting it onto the table. So if I had the set of instructions there, it would pretty' (S14).

The correlation between augmented technology advantages and AR benefits reduces scope creep. This is outlined in the data extract below, which describes how scope creep is minimised, as AR technology provides consistency to different stakeholders in various areas of the project. This technology aligns with what needs to be completed:

'So they see that the big benefit as being that consistent from that sales to the delivery. Yes, a big important thing for them. Just to reduce that, I suppose scope, creep and scope where things don't go as planned because someone's doing what they want' (S14).

The correlation between augmented technology advantages and AR benefits relates to the impact that this has on travel and how users can use this technology from anywhere and

therefore reduce the need to travel to the site or to a different place. This is detailed in the data extract below:

'They've pretty much come back and said that they wouldn't be able to run another project without a tool like this. It stopped them having to travel to the sites, I think it's XXX the company. So they are able to log in. And we can see when they do log in as well. So they're logging in almost daily and seeing what's happening' (S14).

AR advantages → AR first impressions

The relationship between the benefits of AR and initial impressions is essential for the integration of AR technology in a commercial application. The data extract below illustrates how initial impressions emphasise the awareness of this technology, and when it is utilised in a commercial context, this awareness will continue for the majority of commercial projects moving forward:

'I think if the first my impression, the first thing we will be triggering is really the awareness of that technology, because people heard about all this technology all the time, and they were using in games and some other stuff, but not directly on their project use, which I think I will be making like a very important role to show them. You know, this tech is all around us and also can be used for what we're working so apart from measuring, are they using it next time or not? I think it is more about let everyone understand what it can do as part of the success that I'm measuring, not just like, say for the next two projects' (C15).

AR advantages → AR-enhanced experience

The relationship between AR advantages and an AR-enhanced experience is vital for the user acceptance of AR technology. The example below illustrates that when designing a tailored experience for a client, one is developing a product that meets their specific needs, ensuring that each experience is uniquely tailored to them; this is an enhanced experience for both the developer and the client:

'So we might do something with XXX or someone when they want a very specific, you know, bespoke or XR type of experience for something that might be training or marketing components or something. But out of that was born, the knowledge, the skill, the capability and sort of our vision from working with these clients, which is, geez, we should really build a product here. Wow. Which we've now done' (S19).

Another illustration of AR benefits and their link to enhanced experiences is provided in the data extract below. This example illustrates that incorporating AR technology into the safety training of a construction project creates a safe working environment in real time, effectively removing potential hazards from the site:

'It would provide new workers with interactive, hands on experiences, enhanced safety by visualizing these, visualizing hazards and providing safety guidelines in real time' (C8).

AR advantages → AR technology advancements

The link between AR advantages and advancements in AR technology lies in the continuous development of technology. Therefore, the advantage of AR technology is that it is also evolving. The data extract below illustrates that the initial applications of AR technology were in the entertainment sector, including music and media. AR has now progressed to more advanced applications in fields such as engineering and construction:

'So essentially, the agency itself, and its skill sets and experience known was the foundation is built on the very first sort of immersive applications in media, entertainment, and music, right. So and the arts and theatre. So, in fact, that's how a lot of companies came about this, because the early stage market, the only people who were paying for these things, were those people in the arts, music, entertainment, who are experimenting with the technology at first. There were, of course, much higher level applications for it for large multinationals and things like that, who started dipping in' (S19).

Another example of AR technology advancements is detailed below. This data extract explains how AR technology will continue to grow in the project management space:

'It's pretty impressive. But once that sort of level of technology moves into the project management space, I think you'll see that it's, it's all about communication, and it'll be so effective that people will be using just as a standard practice' (E1).

4.14.3 Technology and project challenges

AR technology within the environment of technological and project challenges incorporates both technology-related and project-specific challenges. Recognising the challenges associated with the integration of AR technology can clarify potential complications and facilitate a smooth implementation in project settings. Understanding these challenges is crucial to ensuring successful AR integration in projects. This is detailed in Figure 4.20 below.

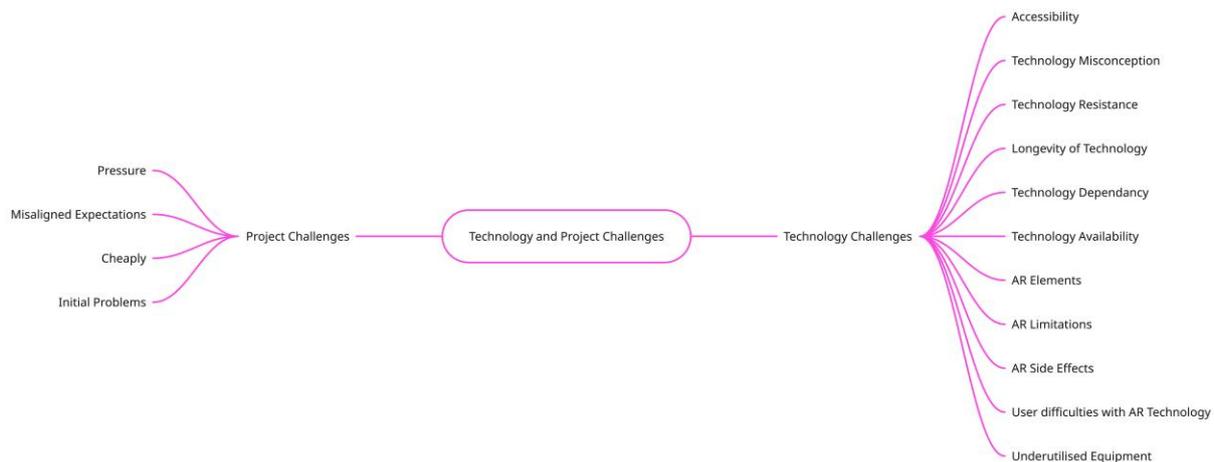


Figure 4.20: Technology and project challenges

In this research, project challenges include pressure, misaligned expectations, cost considerations and initial problems, as defined below.

Project challenges:

- **Pressure:** This refers to pressure constraints on the project.
- **Misaligned expectations:** Expectations are not aligned.
- **Cost considerations:** This refers to cost constraints and expectations for the project.
- **Initial problems:** This refers to issues that may arise at the beginning of the integration of AR.

In the present context of this research, technology issues include accessibility, technology misconceptions, technology resistance, the longevity of technology, technology dependence, technology availability, AR elements, AR limitations, AR side effects, the AR preparation time, user difficulties with AR technology and underutilised equipment, as defined below.

Technology challenges:

- **Accessibility:** This refers to technology accessibility constraints.
- **Technology misconceptions:** This refers to misunderstanding the use of AR technology.
- **Technology resistance:** This refers to the resistance to using AR technology.
- **Longevity of technology:** This refers to the technology's shelf life.
- **Technology dependency:** This refers to the user's dependency on AR technology.
- **Technology availability:** This refers to the availability of AR technology.
- **AR elements:** This refers to the elements and faces used for 3D modelling.
- **AR limitations:** This refers to the limitations experienced in the use of AR technology.
- **AR side effects:** This refers to the side effects experienced while using AR technology.

- User difficulties with AR technology: This refers to the user’s difficulty with understanding and utilising AR effectively.
- Underutilised equipment: This refers to equipment not being used.

The details of the relationships and supporting data for each deliverable, along with their interactions and the context of their development, are explained in detail below.

4.14.3.1 Relationships extracted from technology and project challenges

Each of the relationships related to technology and project challenges was derived from grounded theory. The initial step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to establish relationships among the codes, ultimately forming the axial code relationships. The data from the axial codes were further analysed to develop core concepts during the selective coding process.

The data analysis for technology and project challenges is detailed in Table 4.26, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Technology and project challenges form 15 open codes, 2 axial codes and 1 selective code.

Table 4.26 : Breakdown of technology and project challenges and their relationships

Selective code	Axial code	Open code
Technology and project challenges	Project challenges	Pressure Misaligned expectations Cost considerations Initial problems
	Technology challenges	Accessibility Technology misconceptions Technology resistance Longevity of technology Technology dependence Technology availability AR elements AR limitations AR side effects User difficulties with AR technology

Project challenges → Pressure

The relationship between project challenges and pressure is outlined in the data extract below. This example highlights that there are constraints when working on projects, and when these constraints are present, some individuals do not want to incorporate anything new:

'Particularly when you're under time and pressure constraints, right. So people don't like to force new things when they're under the pump to deliver' (E10).

However, this participant further highlights that, even though there are project constraints, there are advantages to incorporating new technology. Doing this requires the right people to support those needs:

'And it's also an additional unknown in a time perspective as well, right? If you're going into a project going, Hey, we can be innovative and use this new technology, and sort of 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 bit 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' (E10).

Project challenges → Misaligned expectations

The connection between project challenges and misaligned expectations is detailed in the data extract below. This example highlights that there are numerous instances of immersive experiences, and the entertainment applications of AR technology differ from those in sectors such as engineering and construction:

'So that can be misaligned with augmented reality, you know, projects, right, in terms of when and how they come into certain phases. So certainly, that's one, two misaligned expectations. So as I was referring to people seeing things like augmented reality in sport, or Pokémon and things like that, and then seeing an enterprise application for it, those the expectations are somewhat misaligned in terms of like, you know, I have this reference to seeing beautiful, amazing things in TV shows virtual reality in the future for sci fi Pokémon game, which has spent millions and millions and millions developing to a, an amazing application. And then seeing the reality of what's currently available in, in AR for enterprise at the moment, right. So there's that misalignment in terms of expectations, but those

expectations have been created so high in terms of, you know, media marketing efforts, and so on. So that can be a problem' (S19).

Another instance of misaligned expectations can emerge from a modelling perspective. The example below illustrates that certain AR technologies might not meet the expectations for accuracy; however, cost considerations also play a role in integrating these components:

'And there is accuracy, right. So, accuracy of these particular types of products is limited, and it's limited somewhat in terms of the nature of telco towers, it's limited by satellite, you know, devices, and the cost associated to bringing all of those things together to create certain levels of accuracy. So that can also be it's a natural or current limitation of these types of products in in infrastructure projects is that they may not be accurate enough for some requirements or, or we've misaligned the expectations with the client in terms of accuracy. They believe that of course, they see it there, they're gonna go, that's millimetre perfect and might not be exactly' (S19).

Project challenges → Cost considerations

The relationship between project challenges and costs involves the client's expectations regarding expenses and the cost of integrating custom AR applications. In most instances, there is a misconception that these solutions are inexpensive, quick and easy to implement, which is not often the case in these scenarios. The data extract below is an example of this:

'we've worked with solicitors, lawyers, specialists, companies, in terms of the early stages of projects for environmental studies, really everyone who's involved in those early stages, and that sort of common thread of cheaply, easily, quickly' (S19).

Project challenges → Initial problems

The relationship between project challenges and initial problems emerges once AR technology has been integrated. In various scenarios, certain areas still require adjustments. The data extract below indicates that when AR technology was integrated, users encountered problems with the headset, necessitating a review of processes to ensure seamless integration for users:

'But then he found it was hard to look up and down with the glasses on. So because it's a two man operator job, anyway, we had it was about working out the best sort of sequence for the process as well. So we had one operator put the goggles on and tell the other guy what to install wear, so we had one person directing and the other person doing, and that

made it easier, because they weren't trying to do two things at once. So we found, I guess, what I'm trying to say is we found that the initial barriers, a willingness to try, but then working through those sort of teething problems of with them, yeah, what is the new best way to do this job, and sort of working out the new process and what works best. Because the barrier was sometimes you actually want the goggles to not be presenting information, and they get in the way when you're not looking at the job, but you need to pick up tools or what have you. So when we separated that out, we found we had a much better uptake and usage from the operators, because one person would do it and the other one would take the jobs that that were like harder with the goggles on' (E3).

Technology challenges →Technology misconceptions

The relationship between technology challenges and misconceptions arises from various immersive applications, including AR, VR, and MR. Often, confusion exists among these three technologies:

'you know, we go out and demo it all the time, we might be in front of a boardroom table of major infrastructure, people doing that, and you'll get it from a variety of different I've never used VR, is it? I don't know what VR is. Is it VR, AR? What the hell is XR?' (S19).

Another example of technology misconceptions is given below. This example highlights the misunderstanding around AR technology itself:

'I think there is also a lot of misunderstanding around the use of technology such as AR, as with any technological advancements, and these misconceptions can cause concerns' (E5).

Technology challenges →Technology resistance

The connection between technology challenges and technology resistance is illustrated in the data extract below. This example stresses the concerns surrounding the integration of new technology and its potential impact, particularly concerning job displacement for individuals.

'I think that also serves as a barrier as some people can see it as being detrimental to certain job opportunities. With a lot more of the world becoming automated and then adding future AR advancements, this could be seen as taking jobs away from people' (E5).

Another example of how technology challenges relate to resistance is detailed below. This example shows that some individuals resist change and choose not to incorporate new technology, as they prefer to stick with what they know:

'I think a lot of this comes from the simple resistance of change kind of philosophy, where people kind of sit there and go, it's always been done this way' (E10).

This example illustrates that for new technology to be integrated, it must add value to the project, and large companies prefer to rely on familiar solutions:

'resistance to change is everywhere. And, you know, until they're proven otherwise, it tends not to happen, right? So, you know, they try to if that whole value segment, how does this add value? Right? So, if people are looking to these sort of more engaged in moving forward of technology and trying to be innovative, then the acceptance is there, but a lot of people, particularly big companies are very much about, let's stick to the status quo' (E10).

Technology challenges → AR limitations

The relationship between technology challenges and AR limitations is demonstrated in the following data extract. This example emphasises the significant challenges encountered in on-site AR use, particularly when the device requires extensive time investment:

'You talked about loading up, big model a huge model. In your headset, it's impossible to use it on site, not then you have to spend time to really prepare your model before you go, which I think will gradually miss use and significantly reduce, you know, the interest of using this technology. Because we don't want to spend all time the pair before you use it' (C17).

Another example of the relationship between technology challenges and AR limitations in relation to web browsers is depicted below. This data extract outlines that hardware is a significant limiting factor when it comes to integrating AR technology due to the medium of the device:

'the limitation is definitely the hardware at the moment. At least, I think, you know, the hope that we see as with the evolution of the technology is the natural transition from, you know, mobiles and tablets to you know, usable, you know, lightweight, comfortable glasses effectively. Which also takes into consideration how people interact with that that medium, because it's definitely going to be very, very different from your typical flat touchscreen' (S19).

Another example of hardware being the limiting factor is detailed in the data extract below. This example also outlines that the battery life is also a contributing factor:

'it's probably at the moment is that the headsets probably aren't quite up to the standard that they need to be. One of the big ones is battery life. So you can't get a full day of work out of one headset at the most is probably a fairly big barrier. And then they're just that white size of them is. That's what we've, that's the feedback that we get' (S14).

Another limiting factor is how long AR technology takes to load a large model. This is illustrated in the data extract below:

'You talked about loading up, big model a huge model. In your headset, it's impossible to use it on site, not then you have to spend time to really prepare your model before you go, which I think will gradually miss use and significantly reduce, you know, the interest of using this technology. Because we don't want to spend all time the pair before you use it' (C17).

Again, this participant illustrates the limitations related to performance and loading models onto the devices:

'I think is quite expensive, actually. And also, the performance, I think the current problem of you know, all kinds of these devices is really about the objects that you can load in your device. I think with the 4g or 5g either streaming through a back end server you know, all the post processing went through there will certainly help but I don't see any of the device can do this at the moment I mean even cross wirelessly to your PC is not like you know just wirelessly to internet, other supercomputer to do all the processing that comes to the problem of whether the device itself is having in a power performance power to perform, you know the future of AR initiative' (C17).

The relationship between technology challenges and AR limitations is outlined in the data extract below. This example highlights that one limitation of AR technology is the preparation time required to ensure that the 3D modelling is adequate:

'I think it's tech itself, you know, the renders provider in the software itself, is key components. First is really the compatibility of the files, which means you can blow up even types of modal without even doing translation, which is, you know, very back to the model, when you want when I use want to use a model in this project, do I need a lot of preparation

time? Do I need to split up everything, four by four, or I can just go up one model and platform supported to streaming only single details to the phone and still get, you know, comparatively good performance. We don't want to use them if we need our model, but you know, very lacking on site, insight, really efficiency' (C16).

Technology challenges → AR elements

The link between technology challenges and AR elements stems from the required modelling elements. For instance, the number of elements needed to build a structure significantly exceeds the allocated resources. This example also addresses the performance of the model and the difficulties of loading the model onto the device:

'The HoloLens is trying to do something like this, but the performance make it you know, a smaller screen. And also, you know, when you have like a large model, it just like move. It's not, it cannot even load it. They have like the limitation of what 20,000 elements anyway. 20,000 elements for a building is like a joke, you can have, like, for playing, you have like a 1 million pots ready. So or building? Maybe times 10?' (C17).

Technology challenges → AR side effects

The relationship between technology challenges and AR side effects is depicted below. This example illustrates a case from the US defence sector, where the use of this technology was ended in certain areas because users were prone to experiencing illness:

'Well, we can certainly refer to the whole lens, for example, that was one of the primary reasons that the US government stopped food for the programme for the Defence Force. You know, so it's just the yes, some people are more susceptible to sickness than others' (S21).

An additional example of side effects resulting from AR technology is detailed below. This instance highlights that this specific user has found the headsets to be excessively heavy and has experienced headaches due to this technology:

'For me personally? Umm, you know, price, availability, variety, I find the headsets that we currently have quite heavy, and they don't. I haven't tried anything overly light. I've just tried, like, the big, bulky ones in there, they sit pretty heavy on my head, and they can give me a headache sometimes, as cool as they are, but, you know, I don't use them for a very short period of time, so it's not something that I'd be eager to use a lot' (E2).

4.14.4 Performance and quality assurance

The role of AR technology in enhancing performance and quality assurance is vital for its optimisation. This encompasses eight essential components: efficiency, project evaluation, quality control, practical solutions, AR technology, quality improvements, performance criteria and project collaboration. All categories are essential for performance and ensuring quality assurance. The framework illustration in Figure 4.21 reflects the performance and quality assurance of AR technology.

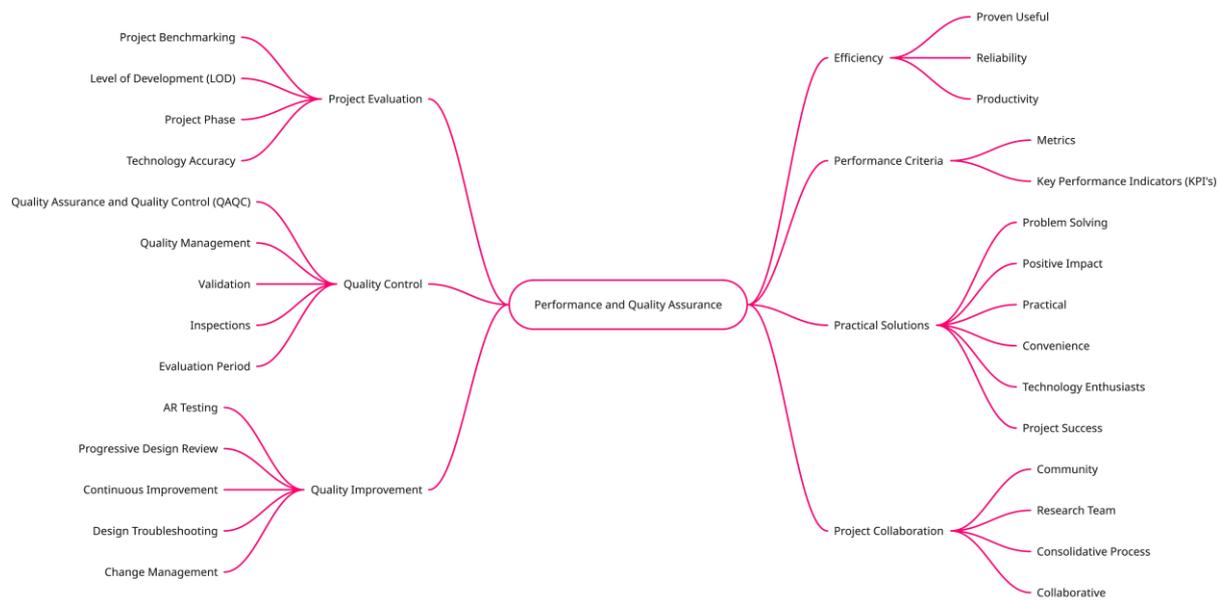


Figure 4.21: Performance and quality assurance

In this study, the efficiency category includes proven usefulness, reliability and productivity, as defined below.

Efficiency:

- Proven usefulness: AR technology has proven to be useful and beneficial.
- Reliability: This refers to the reliability of using AR technology.
- Productivity: This refers to the efficiency of using AR technology.

In the current research, project evaluation includes project benchmarking, the level of development (LOD), the project phase and technology accuracy, as defined below.

Project evaluation:

- Project benchmarking: This refers to evaluating the integration of AR technology.
- Level of development (LOD): This refers to the level of detail of the 3D modelling.
- Project phase: This refers to incorporating AR technology into the project.
- Technology accuracy: This refers to the accuracy of AR technology modelling.

In this research, the quality control category includes quality assurance and quality control (QA/QC), quality management, validation, inspections and the evaluation period, as defined below.

Quality control:

- Quality assurance and quality control (QA/QC): This refers to maintaining quality control.
- Quality management: This refers to managing quality control.
- Validation: This refers to validation through AR technology.
- Inspections: This refers to inspection designs using AR technology.
- Evaluation period: This refers to utilising AR technology to assess and evaluate the design.

In the current research, the practical solutions category includes problem-solving, positive impact, practicality, convenience, technology enthusiasts and project success, as defined below.

Practical solutions:

- Problem-solving: This refers to utilising AR to solve problems.
- Positive impact: This refers to AR technology having an impact.
- Practicality: This refers to the practicality of AR technology.
- Convenience: This refers to the convenience of AR technology.
- Technology enthusiasts: This refers to people who enjoy using new technology.
- Project success: This refers to the integration of AR technology.

In this study, the quality improvement category includes progress, design review, continuous improvement, design troubleshooting and change management, as defined below.

Quality improvement:

- AR testing: This refers to AR technology testing for design intent.
- Progressive design review: This refers to the review of construction design modelling and verification.
- Continuous improvement: This refers to continuously enhancing the quality of AR technology output.
- Design troubleshooting: This refers to design consultations and amendments.
- Change management: This refers to adapting to change.

In the current research, the performance criteria category includes metrics and key performance indicators (KPIs), as defined below.

Performance criteria:

- Metrics: This refers to whether AR technology has measured up in terms of performance.
- Key performance indicators (KPIs): This refers to how AR technology has been measured against project objectives.

In this research, the project collaboration category includes the community, research development team, consolidative process and collaboration, as defined below.

Project collaboration:

- Community: This refers to consultation with stakeholders regarding the integration of AR technology.
- Research development team: AR technology is being researched by the development team.
- Consolidative process: This refers to simplifying an extensive process.
- Collaboration: AR technology is integrated through a collaborative approach.

The relationships and supporting data for each of these deliverables, including their interactions and the context behind their development, are detailed thoroughly below.

4.14.4.1 Relationships extracted from performance and quality assurance

Each of the performance and quality assurance relationships was developed using grounded theory. The process begins with open coding to outline the initial concept. These open codes were then analysed and grouped to form relationships, leading to the formation of axial code relationships. The axial code data were further analysed to identify core concepts during the selective coding process.

The data analysis for performance and quality assurance is detailed in Table 4.27, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Performance and quality assurance form 29 open codes, 7 axial codes and 1 selective code.

Table 4.27 : Breakdown of performance and quality assurance relationships

Selective code	Axial code	Open code
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Performance and quality assurance	Efficiency	Proven usefulness Reliability Productivity
	Project evaluation	Project benchmarking Level of development (LOD) Project phase Technology accuracy
	Quality control	Quality assurance and quality control (QA/QC) Quality management Validation Inspections Evaluation period
	Practical solutions	Problem-solving Positive impact Practicality Convenience Technology enthusiasts Project success
	Quality improvement	AR testing Progressive design review Continuous improvement Design troubleshooting Change management
	Performance criteria	Metrics KPIs
	Project collaboration	Community Research team Consolidative process Collaboration

Efficiency → Proven usefulness

The connection between efficiency and proven usefulness is essential for incorporating AR technology. The following example illustrates that showing how AR technology can be useful

is vital for the integration of new technology. It is important to provide reasons for clients to adopt this technology, highlighting its potential benefits:

‘So from a sales perspective, and things like that. So if you have that kind of element where you’re showcasing what you plan to happen, then it pays itself off in fold. Right? It’s a good system, so very much depend on the projects. And if I was at a point where I was projecting something to a customer of what would it look like it would probably not be that hard decision to be able to convince the powers that be that this would be a step in the right direction’ (E10).

Efficiency → Productivity

The relationship between efficiency and productivity is outlined in the data extract below. This example illustrates that AR technology was successfully introduced in a manufacturing environment, resulting in increased productivity, job satisfaction and overall contentment:

‘speaking to the people who do the job and seeing their satisfaction with it. So yeah, if you’re getting those quantifiable money savings, generally, you also see that the an increase in productivity and general satisfaction of the operator doing the job as well. So you generally see a bit of a morale boost as well, because their job is easier, they’re enjoying it more, yeah, so on and so forth. So I guess there’s the quantifiable and the qualitative yeah side of things as well, but they generally go hand in hand’ (E3).

Another instance illustrating the connection between efficiency and productivity is detailed below. This example demonstrates that utilising AR technology enhances efficiency, which in turn boosts productivity. By employing AR technology to overlay a model, we can achieve more effective use of AR and improve construction processes:

‘we solve or if it meets the objective that we want to apply the end of the session, like what I’m talking about those challenges, and difficulties we have for QA QC. If it to feel that part, like improve our efficiency, we don’t need to call surveyor to check those information. We just use the AR device and overlay and see it was like perfect match, then I think this kind of benefits could call in as the success of integration. But at the same time I think that’s it. I mean, maybe if we solve the problem we have in our workflow and improve our efficiencies that does it. Sometimes even if it costs a lot, it’s still key. Because we will have more certainty, certainly on our work on a project’ (C17).

This participant also expresses how AR technology improves efficiency and productivity:

'the benefits, definitely, the workflow it brings will improve our efficiency in in, you know, in the way that we're working on a project' (C17).

The relationship between efficiency and productivity leads to improved workflow and project execution. Therefore, AR use impacts project efficiency by making projects more efficient, resulting in time, scheduling and resource savings. This is outlined in the data extract below:

'probably just the same as before, just improved efficiency, yeah, yeah. Just solutions that that meet our needs' (C6).

Project evaluation → Project benchmarking

Project evaluation is found to impact project benchmarking, as when it comes to performance and quality assurance, project evaluation plays an important role; evaluating AR technology and benchmarking the results are essential for the successful integration of AR technology. An example of this is detailed below. This example highlights that internal processes take place when it comes to evaluating products, and benchmarking needs to occur to ensure quality:

'So before we release to the final production, we do a lot of checks with the user. So we give them the latest release the test by themselves. Once a satisfied with everything, then we have our own QA team to understand the performance, the benchmarking we have. And then we once everything is work according to what it should mean, then we will, we will just release the product once the client says, Yes, we are very happy with everything just released to the production. So we involve the user who is going to actually use the application' (S18).

Project evaluation → Level of development (LOD)

Project evaluation is found to impact the LOD because a certain level of quality is essential in the construction industry. This requirement stems from the accuracy needed in modelling, as the field model must serve as the verification for the final installation of a product:

'Actually, because the contract requirement. Because in our world of the BIM world, the AEC world for digital engineering, we have a requirement for we have LOD, I'm not sure if you aware of the LOD level of details about the model. So we have, like, 100 to 500 where 500 the most extensive one would hire you to have a model that's exactly the same, or, you know, relatively close to the wheel well. So at the end of your construction, you will have in

this field model which that you need to verify it, because still, someone has to build a model with a computer' (C15).

Project evaluation → Project phase

Project evaluation influences project phases because evaluation processes take place within these phases. The example below illustrates that evaluating the design occurs throughout the entire process of using AR technology. The design modelling process requires continuous evaluation to ensure that the project stays on track:

'I think it would be similar to what say, like bringing the virtual world integrate with the build world, so that your, for us in the AEC industry, that your design intent will be able to inspect it and also validate, you know, on the whole process, no matter this design phase or construction phase, you bring your things or before it is built, you can, you know, superimpose with the environment, so that you will have a sense of what the project will be' (C15).

Another example of project evaluation and the influence of project phases is detailed below. This example outlines that a software developer is invested in the early stages of construction projects:

'This five or seven stages of major infrastructure or construction projects, and we're really in those early phases, right? So we're somewhere in feasibility scoping studies, the first two or three phases is what we're solving to at the moment, doesn't mean it can't be used in later phases' (S19).

Quality control → QA/QC

The relationship between quality control and QA/QC processes is crucial for improving certainty and efficiency within a project. AR technology enables model visualisation and model overlay, allowing accurate assessments. This is supported by the following data extract:

'purchase? First of all really does justice technology brings benefits to our current workflow. I mean, if it included the if it's not necessary to save the cost, but at least it brings in, you know, we will improve our certainty of the project or certainty and also the efficiency by for example, we, we use it for to do this our Quality assurance and Quality Control (QA QC). Without it, you know, you have to do a lot of measurement, even some type of measurements to work via whether it fits or it was built according to the design 10. With this

technology, we can quickly visualise it, overlay your model with the environment. And I think it's much faster than the other way...' (C19).

Quality control → Quality management

The link between quality control and quality management plays a vital role in integrating AR technology in manufacturing. The product must undergo a rigorous quality process to ensure that its output meets standards. The example below demonstrates that utilising AR technology to enhance quality effectively addresses both quality and human factor challenges:

'So I think that for from my role in manufacturing, we would like to use it to improve quality, because the operator, rather than have to rely on work instructions or visual cues that are on a computer fire away. They're getting the point of use information while they do the job. So that's definitely going to help them make sure they get it right, because they're not having to go back and forth or forget anything is you're not relying on the person's memory, because it's all overlaid right in front of them, and they've got that point of use information it's also really good because often we have a lot of information that needs to be given on a large scale product, and so we scale that down to make it palatable in paper based forms' (E3).

Another instance highlighting the connection between quality control and quality management is presented below. This case illustrates the quality management process that occurs before the final product is released:

'So before we release to the final production, we do a lot of checks with the user. So we give them the latest release the test by themselves. Once satisfied with everything, then we have our own QA team to understand the performance, the benchmarking we have. And then we once everything is work according to what it should mean, then we will, we will just release the product once the client says, Yes' (S18).

Quality control → Validation

Quality control influences validation, as ensuring that the product or item being constructed meets performance and quality assurance standards is essential. The example below illustrates how the validation process is applied on a construction site, with AR technology used to overlay the project design, verifying the accuracy of the product:

'think it would be similar to what say, like bringing the virtual world integrate with the build world, so that your, for us in the AEC industry, that your design intent will be able to inspect it

and also validate, you know, on the whole process, no matter this design phase or construction phase, you bring your things or before it is built, you can, you know, superimpose with the environment, so that you will have a sense of what the project will be' (C15).

Practical solutions → Problem-solving

Practical solutions influence problem-solving, as each issue requires its own resolution. The data extract below illustrates that, depending on the project, the problems addressed can vary significantly across different domains and user cases:

'depends what success looks like for the client. If they've engaged us to create something to solve a problem, then it's about getting metrics as to where that essentially ameliorated that problem or not. So it could be anything from productivity metrics, other KPIs, or, you know, it could be like, a P value for something been statistically significant or not. It really just depends, like every, we do so many different things. But every use case is different' (S21).

This participant also points out that when incorporating AR technology, this technology serves as a solution for a wide range of issues, depending on the user case and the specific problem being solved:

'So augmented reality in particular. So augmented reality is really about utility. So when you think of augmented reality, like when I think of augmented reality, I think of like looking at the sky and getting a temperature, having the GPS directions, overlaid on my glasses, and maybe looking at a wall and seeing where cables are and things like that, inside the wall that I can't see. So I think it really comes down to you know, it being like augmented reality, it's really a solution for a bunch of problems. So it's about finding that right mix' (S21).

Practical solutions → Positive impact

Practical solutions create a positive impact. Incorporating AR technology serves as a solution for many issues, and utilising AR technology can benefit the project. The example below demonstrates that using AR technology is straightforward. When a product is developed using AR technology first, this can help determine how everything will fit together and what is needed before the product is built. This approach positively influences the project, as this modelling will assist in the construction of the product:

'I would see it if, if you have, if you're showing a new member, or a new, a new team member, a rocket then using it would be that wow factor of using augmented reality, so that

the graphics of it and how real it seems to them would be a would be one of the beneficiaries in how easy it is for people to interact and to, to move, they can move their components and move their parts and everything how they wanted' (E11).

Below is another example illustrating the connection between practical solutions and positive outcomes. In an engineering context, the application of AR technology shows promise in minimising defects and improving safety. Depending on the metrics applied or the specific requirements of a project, AR technology serves as an effective solution for enhancing safety or reducing defects:

'in a work situation, if what we're trying to achieve is reduced defects or greater safety, we just count those metrics to see how much improvement there has been in safety and defect count' (E4).

Practical solutions → Project success

Practical solutions influence project success, as evidenced by the data extract below. This example illustrates that software developers value success when the client utilises the technology. Additionally, a meeting will be organised to gather feedback:

'we normally do a follow up after. So this project actually, we're going to do it a little bit differently and do a retrospective. But normally we do some type of just informal sort of meeting after, like after they've used it, but we're going to start doing a little bit more of a formal sort of debrief once they've used it to get some feedback' (S12).

Another example regarding the relationship between practical solutions and project success is demonstrated in the data example below. This example illustrates that the success of incorporating AR technology varies depending on the project needs:

'In regards to what success look like, it varies from customer to customer, like, with VR stuff, the breakdown, which is similar to our AR stuff. At some of the metrics that we've had is like, speed. Like, for example, we did a project with mushroom harvesting, where we looked at speed before and after the training of mushroom pickers' (S21).

The relationship between practical solutions and project success is demonstrated in the extract below. This data extract came from a software developer and states that if the client is happy and the technology is implemented and being used, this indicates success:

'At the moment is usually they're happy about it. And if they're happy about it, then it'll get implemented' (S21).

Quality improvements → AR testing

The relationship between quality improvements and AR testing is crucial for ensuring that the developed AR technology aligns with the design intent. An example of AR testing is outlined in the data extract below. This example indicates that the product must undergo evaluation before its release:

'So before we release to the final production, we do a lot of checks with the user. So we give them the latest release the test by themselves. Once a satisfied with everything, then we have our own QA team to understand the performance, the benchmarking we have. And then we once everything is work according to what it should mean, then we will, we will just release the product once the client says, Yes' (S18).

Below is another example of quality improvements and testing. This illustrates the importance of having a designated space where design and testing can occur without restrictions:

'Yeah, very typical example is really making prototype room. We, we need to commit the consultant using freely all the times they design freely. They also have VR, I think it's, it's more important for something our team can be using it internally, not just to, not just for succession. Of course, with succession is, you know, one major thing that they needed. But it is more about, like, test environment' (C15).

Quality improvements → Progressive design review

Quality improvements impact progressive design reviews as part of ensuring that the product being developed aligns with the design intent. There needs to be a progressive design review to keep the project on track. The example below highlights that in the construction industry, using AR technology, progressive design reviews are employed to ensure that the design of the product corresponds with the design intent:

'There are two major activities. The first one is for as built verification, so it's like getting instant, or, you know, progressing review. So we're bringing the model on the phone, or the iPad, and it will bring on site and we overlay with existing the store has in store condition to check is displacing. Or at least it you know, depending on the accuracy of that model, we will

at least to see whether the object sits in relatively close location as per the design intent' (C16).

Quality improvements → Change management

The link between quality improvements and change management is evident, as change leads to improvements. The example below illustrates how change can be difficult to incorporate; however, once it is investigated and shown to produce positive outcomes, the focus shifts to demonstrating to the user how this will make things easier and how to adapt to the change:

'I guess that technology insertion in our company is hard. So for us, it's about proving that it works and that there's no errors. So for us, I think it's more about finding the right software that then links and we can confirm that it's the information hasn't passed through multiple software bands to get to the operator that it's, you know, that's only been translated once, and so that we have more confidence it's correct. I guess the perception is, if it the more it travels through various software's, out of our modelling, our engineering modelling, and then into another software, and then into another software, that the data could get corrupted and therefore may not be correct, and maybe then causing quality issues. I think the other barrier is just general acceptance. And, you know, trying new things, people tend to get set in their ways, in their job, and don't want to try new things, because they perceive it's harder. Or, you know, but I already know how to do this, and, you know, I guess it's, it's just about overcoming that and working through the change and how technology can help. Rather than just, Hey, there's this new process, we're inflicting it on you. So it's, it's more about cultural change as well' (E3).

The example below highlights that when things have always been done a certain way, there may be resistance to change that needs to be worked through:

'I think a lot of this comes from the simple resistance of change kind of philosophy, where people kind of sit there and go, it's always been done this way' (E10).

Another example of the relationship between quality improvements and change management is detailed below. This example demonstrates that adopting new technology often hinges on the individual's prior exposure to technology, and individuals who are more familiar with such technology tend to support the change more readily. In contrast, those with less familiarity struggle to accept it. Nonetheless, it is important to recognise that imposing

new technology can be counterproductive. Once individuals comprehend the reasons for the change and the benefits it offers, they are generally more willing to embrace the technology:

'we obviously have a range of, you know, operators who are in their 20s all the way through to operators in their 60s. Yeah, I have, I find, generally, the more a person has exposed to technology at a younger age, the more willing they are to uptake it. But it's the same, I would say it's the same with, you know, the changes that have been made in technology through, you know, just normal cell phones, through the smartphones. And it just takes people who are less familiar with technology in general that little bit longer to jump on board that. Said, I am really generalising. We've had some of our older members are like, this is awesome because, you know, it's something quite different and exciting for them, so all across the spectrum. But I think with any change, you have some people who are more keen to get on board based on lived experience. So if they've been doing this job for 10 years and they hate it, and, you know, it takes forever, and we're telling you, hey, that was suddenly, you're going to get to do it in half the time, they're probably more likely to get on board than, say, someone else in another area who's never had to deal with it. Yeah, you know the time wasting and things like that. So yeah, there's a few ways to look at that, but generally, I've noticed the more you let people try and ask questions on their own time. So come to the technology on their own, rather than having a foisted on them, you get a much better result' (E3).

Performance criteria → Metrics

Performance criteria are found to impact metrics, which represent a form of measured performance. In the example below, AR integration is deemed successful when the project requirements are fulfilled. The data extract below outlines that the metrics for these project requirements are evaluated based on speed:

'In regards to what success look like, it varies from customer to customer, like, with VR stuff, the breakdown, which is similar to our AR stuff. At some of the metrics that we've had is like, speed. Like, for example, we did a project with mushroom harvesting, where we looked at speed before and after the training of mushroom pickers' (S21).

Furthermore, the connection between performance criteria and metrics is evident. The metrics outlined below function as measurements, with examples including reduced defects and enhanced safety:

'in a work situation, if what we're trying to achieve is reduced defects or greater safety, we just count those metrics to see how much improvement there has been in safety and defect count' (E4).

Performance criteria → Key performance indicators (KPIs)

Performance criteria are found to influence KPIs, which represent a type of performance measurement. The data example below indicates that when AR technology is incorporated, KPIs can vary based on specific project requirements and are also focused on addressing the project needs:

'depends what success looks like for the client. If they've engaged us to create something to solve a problem, then it's about getting metrics as to where that essentially ameliorated that problem or not. So it could be anything from productivity metrics, other KPI's, or, you know, it could be like, a P value for something been statistically significant or not. It really just depends, like every, we do so many different things. But every use case is different' (S21).

Project collaboration → Research team

The relationship between project collaboration and the research team is evident, as the research team focuses on investigating new technology. The data extract below illustrates that this company's research team examines new technology and its potential benefits for the manufacturing environment, and if AR technology was proposed, this team would explore its possibilities:

'Well, I guess, in our company, we have a research development team. Actually, we have a couple. So if we were, if we were in getting into that space, we have people already playing with augmented reality, and we would be engaging them to say, Hey, this is our requirements' (E10).

Project collaboration → Consolidative process

The relationship between project collaboration and the consolidative process examines a holistic approach to integrating AR technology. The example below outlines the high-level approach from start to handover and the considerations that need to be taken into account when introducing AR technology:

'it's very much a consultative process. So because my background has, when I was in engineering was in consultancy, you know, we did planning and scheduling, and a lot of like project management services. So, you know, I'm very familiar with, I guess, client facing

consultative processes, and in particular, with, I guess, you know, training them to use AR apps, it's very much you have to sort of hold their hand, because depending, again, you have to assess their level of understanding of AR but also just hardware and devices, you know, someone, one, one person might have very different level of tech literacy, compared to the other person, and that could just be, you know, handling an iPad, or, you know, using their Apple ID or something like that. So, you know, we found that, that having a, you know, in person, you know, whether it's, you know, on teams, or whether it's physically in person, having that availability to sort of guide them through the actual use, whether it's usually, the first time use is immensely helpful' (S19).

Project collaboration → Collaboration

Participating in project collaboration encourages collaboration as the use of AR technology focuses on meeting project requirements and addressing challenges. This is illustrated in the data extract below. This example shows that when considering the integration of AR technology, various factors must be taken into account. It requires a collaborative effort to ensure that resources are fully considered and that the design intent is effectively communicated:

'I asked them about what they're going to build with the targeted audience, and what they expect it to be. And then I scope it out. So I prepared a scope, I made sure that we covered everything, what needs to be done. And then I will tell them the resource requirement, how many people will be required, what kind of skill sets were required. And then I will tell them the costing less dimensions, like milestones and timeframes and everything. So we communicate, we take as much as information we can. And then we formulate all these requirements into a scope of work. And then we share with the client and say, this is exactly what you want. Please confirm and then you can start. So yeah. brainstorming sessions will be there. Yes. Yeah, of course understand the vision' (S18).

Another example of collaboration is outlined below. This example highlights the collaboration between a software developer and a construction manager. It focuses on fostering engagement and ensuring that the design intent is deliverable:

'if I wanted to develop this type of software with it, with a developer for like lines, I'd go speak to them and get possibly collaborate with them to bring it together and also get their advice as well. Yeah, so just making that all work together would be doable, but just have to work out a good way to make it all work and come together' (C7).

4.14.5 Communication

To effectively integrate AR technology, clear communication is essential throughout the project lifecycle. Communication and, knowledge and lessons learnt form a continuous flywheel. This continuous flywheel of communication is vital to the integration of new technology. This is further illustrated in Figure 4.22.

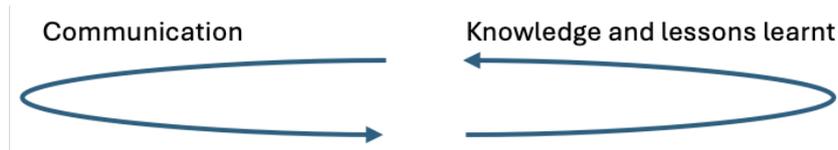


Figure 4.22: Communication flywheel framework

Communication is crucial throughout the project lifecycle. It directly relates to both communication management and stakeholder management. Stakeholder communication primarily focuses on aligning stakeholders and ensuring their satisfaction with the use of AR technology. In contrast, communication management relates to how the AR technology itself conveys project requirements and the effectiveness of that communication. This is illustrated below in Figure 4.23.

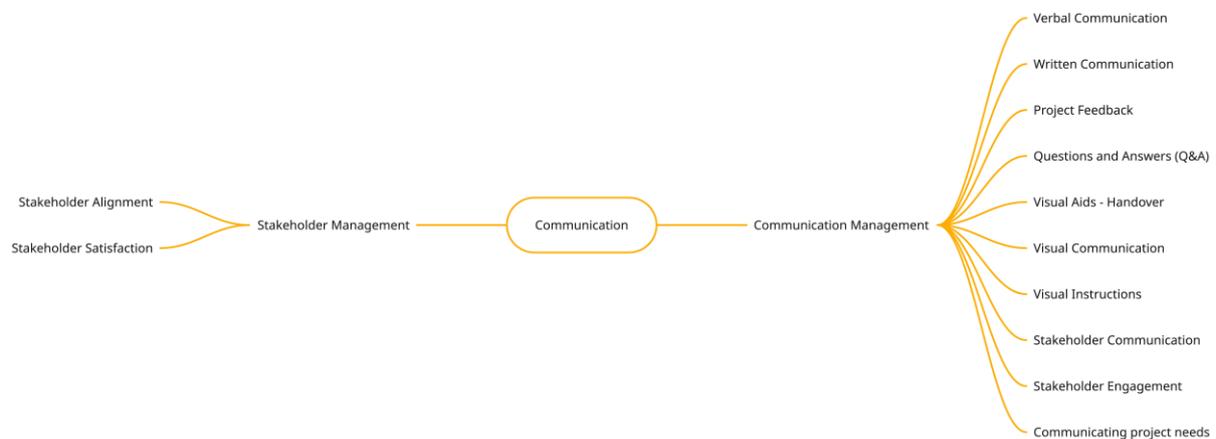


Figure 4.23: Communication

In this research, the communication management category includes communication projects, verbal communication, written communication, project feedback, questions and answers, visual aids, visual communication, visual instructions, stakeholder communication, stakeholder engagement, technology feedback and communicating project needs, as defined below.

Communication management:

- Verbal communication: This refers to communicating verbally.

- Written communication: This refers to communicating in writing.
- Project feedback: This refers to obtaining feedback on the AR technology that was developed and integrated for the project.
- Questions and answers (Q&A): This refers to questions and answers during the feedback for AR integration.
- Visual aids – handover: During handover, visual aids are recorded and screenshots are taken for training purposes.
- Visual communication: This refers to communicating visually.
- Visual instructions: This refers to visual instructions to help the user to use AR technology.
- Stakeholder communication: This refers to communication between the software developer and the client.
- Stakeholder engagement: This refers to stakeholder engagement during the design process.
- Communicating project needs: This refers to communicating the project needs.

In the current research, the stakeholder management category includes stakeholder alignment and stakeholder satisfaction, as defined below.

Stakeholder management:

- Stakeholder alignment: This refers to ensuring that all stakeholders are aligned in all phases of the project and design.
- Stakeholder satisfaction: This refers to ensuring the satisfaction of all stakeholders throughout the project and design.

Below, comprehensive details about the relationships and supporting data for each of these deliverables are presented, including their interactions and the context surrounding their development.

4.14.5.1 Relationships extracted from communication

Each of the communication relationships was developed using grounded theory. The first step in this method is to outline the initial concept through open coding. The open codes were analysed and grouped to establish relationships among the codes, ultimately forming the axial code relationships. The data from the axial codes were further analysed to develop core concepts in the selective coding process.

The data analysis for communication is detailed in Table 4.28, which outlines the grounded theory approach to forming relationships and developing a theory for this research.

Communication forms 12 open codes, 2 axial codes and 1 selective code.

Table 4.28 : Breakdown of communication relationships

Selective code	Axial code	Open code	
Communication	Communication management	Verbal communication	
		Written communication	
		Project feedback	
		Questions and answers (Q&A)	
		Visual aids – handover	
		Visual communication	
		Visual instructions	
		Stakeholder communication	
		Stakeholder engagement	
		Communicating project needs	
	Stakeholder management	Stakeholder alignment	Stakeholder alignment
			Stakeholder satisfaction

Stakeholder management → Stakeholder alignment

The relationship between stakeholder management and stakeholder alignment is essential for incorporating AR technology in engineering and construction projects. Below is a data extract describing stakeholder alignment on AR technology and developing a product that meets the clients’ needs:

‘I do have that good technical understanding of what can be achieved and what can’t be, I think some people have been burnt before by getting over promised. And then there. So it is, again, that’s that expectations, I think, yeah, having a good technical understanding of what can and can’t be achieved is fairly important’ (S12).

Another example of the relationship between stakeholder management and stakeholder alignment is outlined below. This data extract outlines that effective communication is crucial for achieving stakeholder alignment, as everyone perceives things differently; it is necessary to ensure that the integration of AR technology meets the project’s requirements. Therefore, it is important for everyone to be in alignment when it comes to the project needs:

'And it would even go so far as to getting funding and stuff for bigger projects, right down to actually when you're executing and have ensure all the contractors, you're bringing in, you can go around and show them where things need to be and what it needs to look like. So it kind of sets a really, you know, make sure everybody facing the same direction, because a lot of the times everybody's picturing things in their head. But it's not necessarily the same thing' (E10).

Stakeholder management → Stakeholder satisfaction

It is crucial to closely monitor the relationship between stakeholder management and stakeholder satisfaction. Stakeholder satisfaction must be maintained throughout the project lifecycle but is especially vital during the implementation of technology. It is necessary to ensure that the stakeholders are satisfied with the functions of the AR technology. If the stakeholders are happy, the software developers are happy, and the project is successful:

'At the moment is usually they're happy about it. And if they're happy about it, then it'll get implemented. I don't think the timelines and the project have been, like long enough, and the amount of projects haven't happened to get big amounts of data citizens, whether people are experienced with good or average of that. Yeah, if there's not much feedback at the moment, as far as that we're happy. And then after that, it's probably going to be okay' (S23).

Another example of stakeholder management and the connection to stakeholder satisfaction is detailed below. This data extract outlines that the software developer maintains ongoing communication with the client, guaranteeing that the AR technology is integrated according to the intended specifications. Thus, when the client utilises the technology, stakeholder satisfaction is achieved:

'keeping in those regular contact. But then through that handover phases will I suppose it's making sure that things are integrated or working as needed. And then so like that example, I showed you the water tanks, we can look at it on your phone, so we have analytics on it. So I suppose from the analytics, we can know that people are using it and if people are using it must be working. So yeah, it's probably the data that we can track from not saying that people are using it' (S14).

Communication management → Communicating project needs

The relationship between communication management and communicating the project needs is vital for seamless AR technology integration. Communicating the project needs is essential throughout the project cycle, and this is depicted in the data extract below. This

example highlights the process of how the project needs are communicated in an engineering project:

'So we can look at the engineering requirements and say, Okay, this is the information we need to impart, and then we give that to the programming team. So to say, like, usually, where it's information that we're printing out on paper visually is sort of where we've targeted to implement it. So where we've got a visual representation of our engineering that we then print out on paper for the for the team on the floor, where, like, I printed on paper when we visually display it for them. Yeah, in rather than 's so that's, I guess, for the most of the applications we've incorporated so far, where the sort of requirements have been communicated. It's like, here is the information in 3d in a model that we'd like to present in 3d in real life' (E3).

Another example highlighting communication is provided below. This data extract emphasises the significance of communication and the project needs to ensure a successful project:

'So project management is all about communication, like very heavily communication, like 90%. So having another communication tool, whether it be for stakeholders, or subcontractors, or end users is really quite valuable' (E10).

This participant also states that the primary driver of user acceptance is communication, which has a clear relationship to the project's communication requirements:

'So the ability to, I guess, 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 there. I think they are the real sort of interest that will drive user acceptance and adopt, get involved with the actual technology' (E10).

Communication management → Verbal communication

The connection between communication management and verbal communication is evident, as illustrated in the data extract below. Effective communication is crucial for any project, and this example emphasises the importance of holding meetings and discussing the required project outcomes:

'I'll probably start off with what we're what we're doing. But then go down and talk about more about how we design it. And how we've designed it in the past and how we want how,

how we want to move forward in changing the design process. And ways in which we can utilise AR to make it work better' (E11).

Communication management → Project feedback

The connection between communication management and project feedback is essential to ensure that the integration of AR technology meets the project's requirements and delivers the desired outcomes. The example below illustrates how software developers would touch base with the client for feedback and receive an update on the technology's progress:

'we normally do a follow up after. So this project actually, we're going to do it a little bit differently and do a retrospective. But normally we do some type of just informal sort of meeting after, like after they've used it, but we're going to start doing a little bit more of a formal sort of debrief once they've used it to get some feedback' (S12).

Another example of the relationship between communication management and project feedback is detailed in the data extract below. This example details how the software company will send a survey to provide feedback on how the project went and what improvements are needed:

'Most communication what is required from us to the technology developer company to improved on the technology or program is through survey and provide feedback what can be improved' (E1).

Another example of feedback is detailed below. This data extract highlights the importance of communication and obtaining information through feedback, and how this can be integrated into other projects:

'I mean, in terms of the, the hard the hard requirements of functionality, I guess the other way we can assess it, as you know, based on feedback, so one thing, customers already covered the consultation stuff, the other one being client feedback, and how, but also how they're inspired by what's been made already. So you know, using, you know, the apps and seeing AR work, kind of a thoughts, giving them ideas of how to further the applications, or like, what else can we do, you know, with it in, you know, not just going to be for this project' (S19).

Communication management → Visual communication

The relationship between communication management and visual communication is essential for integrating AR technology. AR technology serves as a visual communication tool used to project an immersive 3D experience. The data extract below highlights the importance of the visual display in communicating the project needs:

'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 like conveyancing say you're doing maintenance on aircraft or something in your had a setup is familiar with inside the landing gear augmented reality could point a maintenance person to a particular line to say that's what you need to do, and bring up information that actually shows what they need to do step by step' (E10).

Another example of visual communication is illustrated in the data extract below. This example emphasises the significance of visualisation when integrating AR technology and when utilising AR technology. Being able to see the displays while still using one's hands is truly revolutionary:

'Being able to just to see that, whether it's that menu of what you need to be doing or even the remote telecommunication. So you can put that camera on and someone else would be looking at what you're doing, but you still get access to your two hands. So not having to hold a device. So that's a big one. That's probably one of the biggest ones. Some of the projects that we've worked on and visualisation. visualisation of what is what is needed to be done on what's going to look like' (S14).

Communication management → Visual instructions

Communication management is found to impact visual instructions, as outlined in the example below. This data extract highlights that AR technology used in the engineering and manufacturing sector can overlay information visually for the intended personnel, minimising any errors that may occur and helping the project become more efficient:

'So I think that for from my role in manufacturing, we would like to use it to improve quality, because the operator, rather them have to rely on work instructions or visual cues that are on a computer fire away. They're getting the point of use information while they do the job. So that's definitely going to help them make sure they get it right, because they're not having to go back and forth or forget anything is you're not relying on the person's memory, because it's all overlaid right in front of them, and they've got that point of use information it's

also really good because often we have a lot of information that needs to be given on a large scale product, and so we scale that down to make it palatable in paper based forms' (E3).

Communication management → Stakeholder communication

The relationship between communication management and stakeholder communication is crucial when looking into integrating AR technology. The data example below details communicating with the client as they go through the project brief. In this scenario, the developer is communicating about what the infrastructure and landscape would look like using AR technology:

'So we're essentially started our process with answering to a client brief, which was how can we use augmented reality handheld devices commonly available devices, to be able to communicate to the stakeholders and the community themselves how that infrastructure is going to look in the landscape at a future point, right. So that's largely really where our total focus is' (S19).

The following example is yet another instance of stakeholder communication, illustrating how AR technology can improve interactions. This example emphasises the importance of visual feedback through AR and how AR technology contributes to project success:

'For example, an invitation from the council to discuss the current layout/process in place for obtaining permits. The developer provided a mock-up of the tool and wanted to see if the user can figure out if the layout was friendly user with an implemented of AR into the layout. I picked up a function that the developers were surprised, as they did not know the function exist or worked. I provide some feedback and how it can be improved to make it friendly user' (SE24).

4.14.6 Knowledge and lessons learnt

Integrating AR technology effectively requires knowledge and lessons learnt throughout the project lifecycle. This continuous exchange of insights, paired with communication, acts as a dynamic flywheel. This flywheel of knowledge and lessons learnt is crucial for the successful integration of new technology, as illustrated in Figure 4.24.

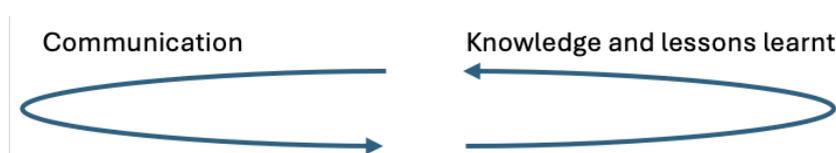


Figure 4.24: Knowledge and lessons learnt flywheel

Knowledge and lessons learnt are crucial throughout the project lifecycle. They directly relate to the educational, training and learning environments. The educational environment focuses on the general understanding of and education on AR technology. The training environment concentrates on how to set up and provide training with AR technology, while the learning environment centres on what has been learnt using the technology. This is illustrated in Figure 4.25.



Figure 4.25: Knowledge and lessons learnt

In this research, the training environment category includes for this (ad-hoc) training, self-training, the set-up of the technology, training, the project champion and the support team or representative of AR, as defined below.

Training environment:

- Ad-hoc training: This refers to training that was provided without any arrangement.
- Self-training: This refers to self-training through online tutorials.
- Set-up of the technology: This refers to training provided during the initial set-up of the technology.
- Training: This refers to general scheduled training.
- Project champion: This refers to an individual who is chosen to be trained to train others.
- Support team or representative for AR: This refers to a support team or representative from the software company who is available when needed.

In the current research, the learning environment category includes lessons learnt and learning, as defined below.

Learning environment:

- Lessons learned: This refers to information learnt from using AR technology; this information acts as feedback for the project.
- Learning: This refers to learning to use AR technology.

In this research, the education environment category includes education, the understanding of AR, the instruction sheet and a general overview of AR, as defined below.

Education environment:

- Education: This refers to being formally educated in AR technology.
- Understanding of AR: This refers to the knowledge of AR technology obtained through education.
- Instruction sheet: This refers to having a formal instruction sheet on how to use AR technology.
- General overview: This refers to a general overview of AR technology.

The relationships and the supporting data for each of these deliverables, including how they interact with one another and the context behind their development, are thoroughly detailed below.

4.14.6.1 Relationships extracted from knowledge and lessons learnt

Each of the knowledge and lessons learnt relationships was derived from grounded theory. The first step in this approach is to outline the initial concept through open coding. The open codes were analysed and grouped to form relationships among the codes, ultimately forming the axial code relationships. The axial code data were further analysed to form core concepts in the selective coding process.

The data analysis for knowledge and lessons learnt is detailed in Table 4.29, which outlines the grounded theory approach to forming relationships and developing a theory for this research. Knowledge and lessons learnt form 10 open codes, 3 axial codes and 1 selective code.

Table 4.29 Breakdown of knowledge and lessons learnt relationships

Selective code	Axial code	Open code
Knowledge and lessons learnt	Training environment	Ad-hoc training Self-training Set-up of technology Training Project champion AR support representative
	Learning environment	Education

	Understanding of AR
Education environment	Education
	Understanding of AR
	Instruction sheet
	General overview of AR

Training environment → Ad-hoc training

The excerpt below illustrates the connection between the training environment and ad-hoc training. It features an example from the engineering sector, where one individual initially inquired about the use of AR technology. This person expressed that it was easy to learn how to use this technology and that they could be trained on how to use it quickly:

‘No, so my experience with it is obviously just being on the floor and grabbing the goggles from the people who’d set it up so our robotics Mechatronics guys and helping the operators use them. So my role, I guess, was more facilitating the implementation of them onto the floor, yeah. But that said, I found them equally quite easy to sort of learn how to use and I found it quite easy to pick the technology up’ (E3).

Training environment → Self-training

The training environment influences self-training; this is highlighted in the example below. The data extract below illustrates how an individual in the construction sector self-trained with AR technology and subsequently recommended the implementation of AR to the construction company:

‘Within my trades as someone you know, I think mostly, especially with this kind of new tech, mostly self learning and either talk to these tech company, get some trial licences. A lot of video footage in YouTube, maybe in their work and then if I got a licences, you know, quickly pick up something either using you know, commercial software or maybe just to test my theory. And normally I will use this to propose it back to our team. So there’s I don’t think I have attend any class I mean, if you not considering you know, some of the tutorials in YouTube is declassified sometimes follow those tutorial to make something’ (C17).

Another example of self-training is highlighted in the data extract below. This example demonstrates that this individual was interested in utilising AR technology, so they self-trained through online tutorials and received professional training through work:

'on online tutorials, even like direct training from that person that's showing you how to use it like, I think I've covered most of that for that one. Actually, the training I experienced with the goggles, the AR stuff, wasn't bad, like the guy that was showing me, like, teaching me how to deal with the hand gestures and the clicking of the fingers, the pinching to zoom in, zoom out, just showing me what to do' (C8).

Training environment → Set-up of the technology

The connection between the training environment and the set-up of the technology is evident in the data extract below. This example highlights the need for someone to set up the AR technology and train others who are not familiar with the system. This scenario concerns this technology being used by someone who does not necessarily use it all the time:

'So the biggest restriction is having the people that are able to actually do the augmented reality setup to be able to be used by people that aren't familiar with the systems' (E10).

Another example of the relationship between the training environment and the set-up of the technology is detailed below. This example demonstrates that there are many factors to consider when utilising AR technology, and one of these factors is setting up the technology and integrating it into the project:

'Well, I think it's really part of the selection that we were making, because we I think it's, it's equivalent to, you know, the selection criteria. When we were considering whether these tickets, it's good or not, like the compatibility and also the setup time preparation time, and also the deploying workflow, these kind of three major key items that will consider' (C16).

Training environment → Training

The extract below is derived from a manager in the construction industry who works at a large construction company. This example outlines that AR training is essential for AR use; this required the workplace to understand the technology being used and how it can be useful and then to implement this type of technology:

'The first question is even training myself, the second is training, what really, if it is only for training others what we normally do for us in your whole team, that the team in house, then will review the target, and we will create a workflow and we identifying what the problem was to tackle. And we will have a separate presentation that showing you know, to the project, you know, we can implement this to resolve this issue or to enhance a capability or efficiency, you know, this issue. And then if the team buys in it, and then we will do on site

training, including you know, helping them to select the type of software hardware, and then we will coach them to start' (C15).

Another example illustrating the connection between the training environment and the training is detailed below. This data extract highlights that the software developer will provide training and that this training will relate to the product that is being used:

'We go to the client side, we show them how to work with the handheld device that they have right with their products. And with the claims they can move forward, they can move backward, they can turn around 360. So depending on the device so we can provide them the training' (S18).

Training environment → Project champions

An example of the relationship between the training environment and project champions is detailed in the data extract below. This example highlights the vital role of appointing a 'project champion' or lead within the team. This individual not only receives individual training but also actively promotes the integration of AR technology within their organisation:

'Yeah. So definitely, those innovators, those early adopters. We always sort of call them that, like Project champion, having that one person that from so like, for example, XXX, having people in that team who are the ones who are pushing the technology helps a lot, because then they're the one who I suppose..., rather than us having to do the convincing there that they've already convinced the people internally that using AR, VR, or some type of the tech is the way to go' (S12).

The relationship between the training environment and project champions is detailed in the data extract below. This example emphasises the importance of having project champions within the project team. These champions can facilitate the implementation of AR technology and help others better understand the value of using AR technology:

'those innovators, those early adopters. We always sort of call them that, like Project champion, having that one person that from so like, for example, ... , having people in that team who are the ones who are pushing the technology helps a lot, because then they're the one who I suppose, I suppose, rather than us having to do the convincing there that they've already convinced the people internally that using AR, VR, or some type of the tech is the way to go. So definitely, having that like internal champion is very important, and identifying who that is early is good, because it does make it a lot easier, and then keeping them on

board and keeping them up to date, of like, what you're what, what, what is happening in that development process is definitely really important. Rather than having to convince someone of the technology, and then getting all the project done can become complicated' (S13).

Training environment → AR support representative

The relationship between the training environment and the AR support representative is detailed in the data extract below. This example highlights the importance of having someone who can provide assistance with any questions or issues that may arise:

'So with an enterprise use case, you need to have an ROI there, whether that ROI is a financial ROI, or where Okay, right, it's taken us you know, when we send someone on site. If we have, if they're wearing a whole lens, we can have a technician that's in another state that can see what they're seeing and help them through it' (S21).

Learning environment → Lessons learnt

The relationship between the learning environment and lessons learnt is outlined in the example below. This data extract highlights the importance of understanding lessons learnt, and it discusses how rapidly designs can change and how to mitigate this in the design process:

'But also, as we learned, one of the really important things that's, you know, become a feature of our product is the design has changed so rapidly, which we didn't understand. We were going through crazy iterative processes with the client, about design changes that were either influenced by politics, or by community, or by budget, or by whatever it is, right' (S19).

Learning environment → Learning

The relationship between the learning environment and learning how to use AR technology is illustrated in the data extract below. This example highlights that utilising AR technology can be beneficial in the engineering sector and describes how this can benefit training:

'For being able to instruct people on what to do, how to learn in a physical environment, how to maybe look out for certain pieces of equipment when working in a very physical environment. So you know, a trade or manufacturing or something like that, that it would, yeah, I could definitely see the benefits, particularly in training' (E2).

Another example of the relationship between the learning environment and learning AR technology is outlined below. This example discusses all the different ways to learn about AR technology:

'Within my trades as someone you know, I think mostly, especially with this kind of new tech, mostly self learning and either talk to these tech company, get some trial licences. A lot of video footage in YouTube, maybe in their work and then if I got a licences, you know, quickly pick up something either using you know, commercial software or maybe just to test my theory' (C17).

Education environment → Education

The following relationship provides insights into the correlation between the education environment and education on AR technology. This outlines the significance of educational initiatives in normalising the commercial use of AR technology:

'I think education around AR technology will be the driving factor for its use and growth moving forward. So far, it's openly marketed to a younger generation and clientele for making life more fun, interesting and "user friendly" - the generations who prefer to limit in person interactions where possible. I think education and normalisation of AR in more industrial and farming fields will see further acceptance from a larger audience' (E5).

The data extract below illustrates the connection between the educational environment and AR technology. This example highlights the advantages of teaching AR users how to integrate AR technology, as well as how the construction sector is leveraging this integration:

'So yeah, so a lot of AR is in the construction zone things that that sort of thing where it's educational or it's sort of educational to the public in terms of the airport and showing this is what the layout of the airport is going to be in terms of actually working for construction companies them a lot of stuff we have done there is more of the VR side of things where we visualised like buildings before they have been built' (S22).

Education environment → Instruction sheet

The relationship between the education environment and the instruction sheet is detailed below. This example highlights that an instruction sheet can be used to educate the user on how to use AR technology. This is provided during the handover stage of the project design and is essential for educating the user on how to use this technology:

'We always do, like a project handover sort of document, and that will have, normally one set for, like the internal to people, and then like an external sort of instruction sheet. So one of these feel fairly detailed, and go through of, like, everything that's needed, but then we'll have a more basic version, which is the people who are actually using it, and that will be, we always put, like, an illegal disclaimer on there, and then some basic instructions, and then, normally, a screenshot of what they will see. So that helps a lot. Yeah, so normally, two sets of instructions that will be created' (C15).

4.15 Taxonomy for AR Technology Integration

The research question we are exploring is the following: What are the dynamics of the user acceptance of AR technology in engineering and construction projects? To thoroughly address this question, it is essential to analyse and interpret the various relationships involved in the integration of AR technology, which have been highlighted throughout this chapter.

As depicted in Figure 4.26, there are a total of 18 distinct relationships that form the foundation for successfully integrating AR technology into the engineering and construction sectors. Each of these relationships has been discussed in detail earlier in the chapter to provide a comprehensive understanding of how they interact and influence user acceptance.

The figure provides a visual representation of these relationships as part of a holistic approach, offering a clearer visual understanding of the relationships and dynamics. The illustration in Figure 4.25 outlines the concept in three layers, providing a more comprehensive approach.

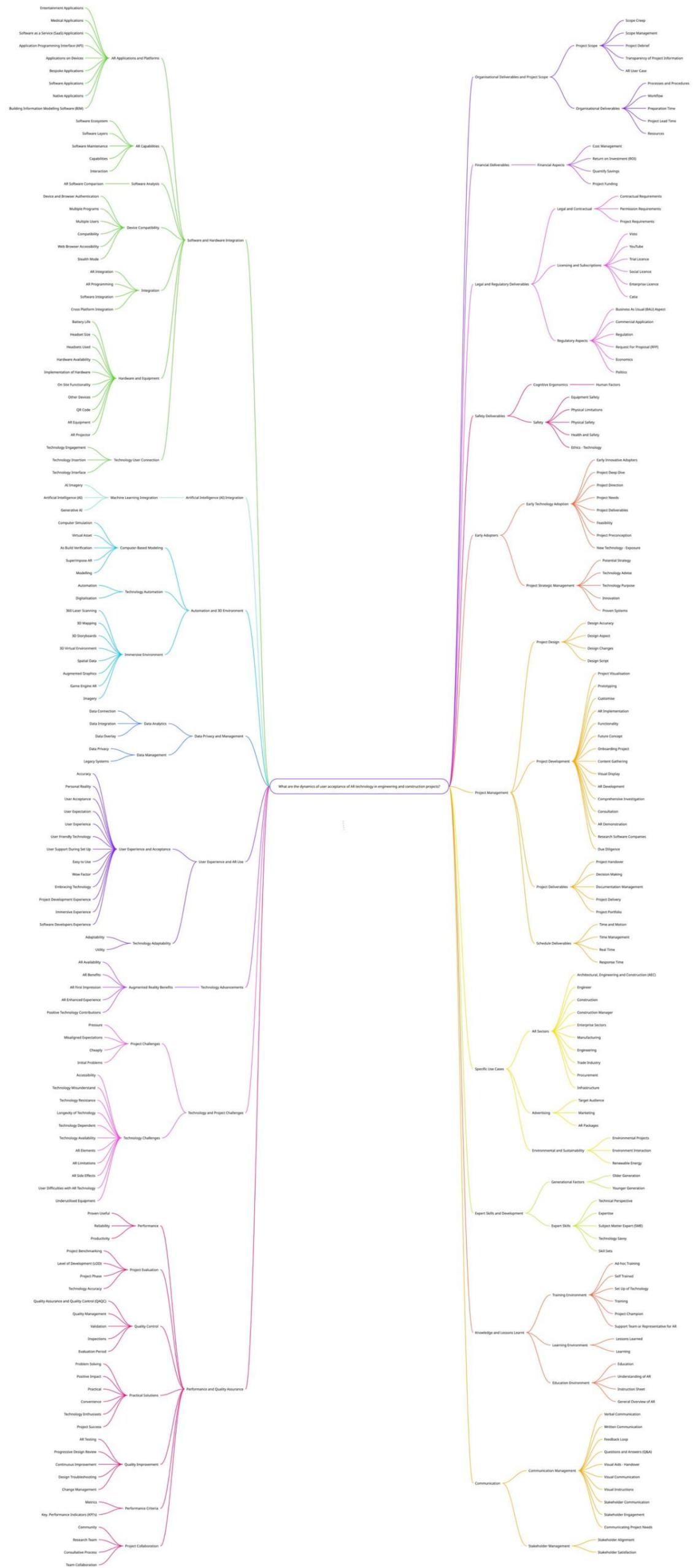


Figure 4.26: Taxonomy for AR integration

4.16 Framework for AR Technology Integration

The image of the overall framework is described in detail below, and it is further explained throughout this chapter. The relationships and theory derived from grounded theory include four key categories: organisational deliverables, project input, technology input and project output. Communication, knowledge and lessons learnt are integrated throughout this framework and serve as a flywheel that represents the constant communication and knowledge sharing required to ensure that technology integration is successful.

The organisational deliverables category includes the following categories:

1. Project scope;
2. Financial deliverables;
3. Legal and regulatory deliverables;
4. Safety deliverables.

The project input category includes the following categories:

1. Early adopters;
2. Project management;
3. Specific use cases;
4. Expert skills and development.

The technology input category includes the following categories:

1. Software and hardware integration;
2. Artificial intelligence (AI) integration;
3. Automation and 3D environments;
4. Data privacy and management.

The project output category includes the following categories:

1. User experience and AR use;
2. Technology advancements;
3. Technology and project challenges;
4. Performance and quality assurance.

In this theoretical framework, organisational deliverables flow into project and technology inputs, which then lead to project outputs. Communication, knowledge and lessons learnt are conceptualised as a flywheel, illustrating a continuous cycle from organisational deliverables to outputs, thus flowing through each category. This is illustrated in Figure 4.27.

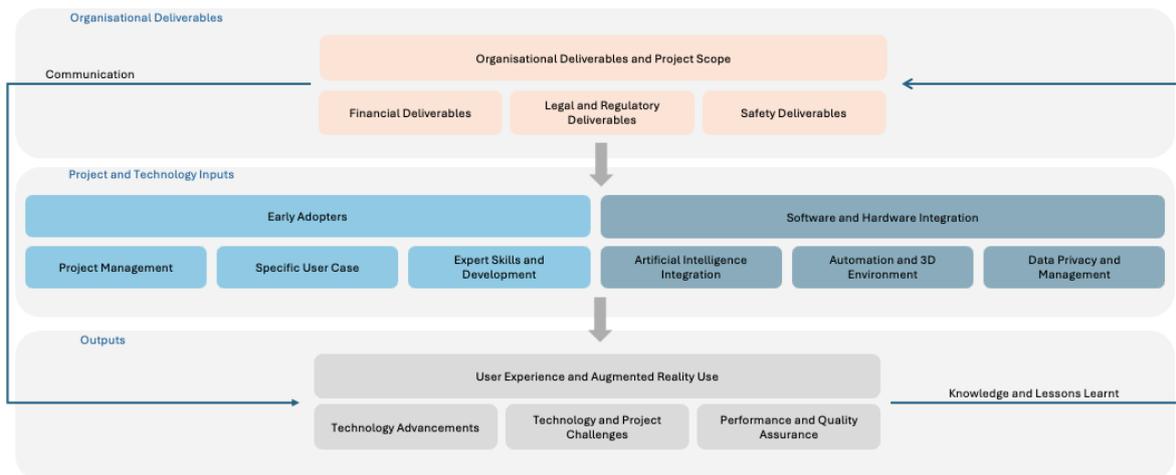


Figure 4.27: AR technology framework

4.17 Relationship Chains

The relationship chains outlined in this research were developed using a grounded theory approach. This grounded theory approach employed a methodology that allowed patterns and connections to emerge from the qualitative data.

Overall, 11 relationship chains are identified in the study. These chains were built by analysing the taxonomy relationships and data gathered during the research, and they include the following:

1. Early adoption and success chain;
2. Knowledge and stakeholder satisfaction chain;
3. User experience and acceptance chain;
4. Performance and quality assurance chain;
5. Stakeholder and project success chain;
6. Organisational deliverables and success chain;
7. Technology challenge and user acceptance chain;
8. Data management and success chain;
9. Expert skills and knowledge chain;
10. Project management and success chain;
11. Technology advancements and user acceptance chain.

Each relationship chain represents interconnected relationships that transpired. For example, for the first relationship chain, 'early adoption and success chain', this study outlines each connecting relationship. These relationships include the following:

- Early Technology Adoption → Early Innovative Adopters: This focuses on the early adopters for the use of AR technology and integrating it into projects.
- Early Innovative Adopters → Project Deliverables: This identifies the deliverables and drivers for AR integration.
- Project Deliverables → Decision-making: This involves deciding on whether to use AR technology.
- Decision-making → User Acceptance: This refers to the process of adopting AR technology.
- User Acceptance → Stakeholder Satisfaction: Stakeholders recognise and appreciate the benefits of AR.
- Stakeholder Satisfaction → Stakeholder Alignment: This refers to ensuring that all stakeholders are satisfied with the use of AR.
- Stakeholder Alignment → Stakeholder Management: This refers to ensuring that all stakeholders are aligned.
- Stakeholder Management → Stakeholder Engagement: This refers to ensuring that all stakeholders are engaged.
- Stakeholder Engagement → Stakeholder Communication: When AR is aligned, communication is improved through AR technology.
- Stakeholder Communication → Communicating Project Needs: This refers to the clear communication of project needs and understanding among stakeholders.
- Communicating Project Needs → Project Collaboration: This refers to sharing project needs and progressing towards common goals.
- Project Collaboration → Team Collaboration: The project and team work together to implement AR technology.
- Team Collaboration → Project Success: This refers to a successful implementation of AR that meets the project needs.

4.17.1 Early adoption and success chain

The relationship chain for early adoption success is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for early adoption and success is given below:

Early Technology Adoption → Early Innovative Adopters → Project Deliverables → Decision-making → User Acceptance → Stakeholder Satisfaction → Stakeholder Alignment → Stakeholder Management → Stakeholder Engagement → Stakeholder Communication →

Communicating Project Needs → Project Collaboration → Team Collaboration → Project Success.

The relationship between early adoption and success is clear from the data analysed and outlined in Figure 4.28. It is important to emphasise the role of innovations and adopting new technology early in projects to facilitate a smooth transition and achieve project success. Engaging in new technology implementation early supports project development. Early adopters of AR technology implement the technology early on and identify the project deliverables. Once the project deliverables are identified, a decision must be made about adopting AR technology, which signifies the acceptance of the technology. After acceptance, this information is shared with the relevant stakeholders, and alignment is established to ensure that the technology is suitable for the project. All stakeholders are engaged and informed about the project needs. After the project requirements are communicated, they are reviewed through team collaboration to ensure that all parameters are met for the project's success. This is reflected in the following data extracts:

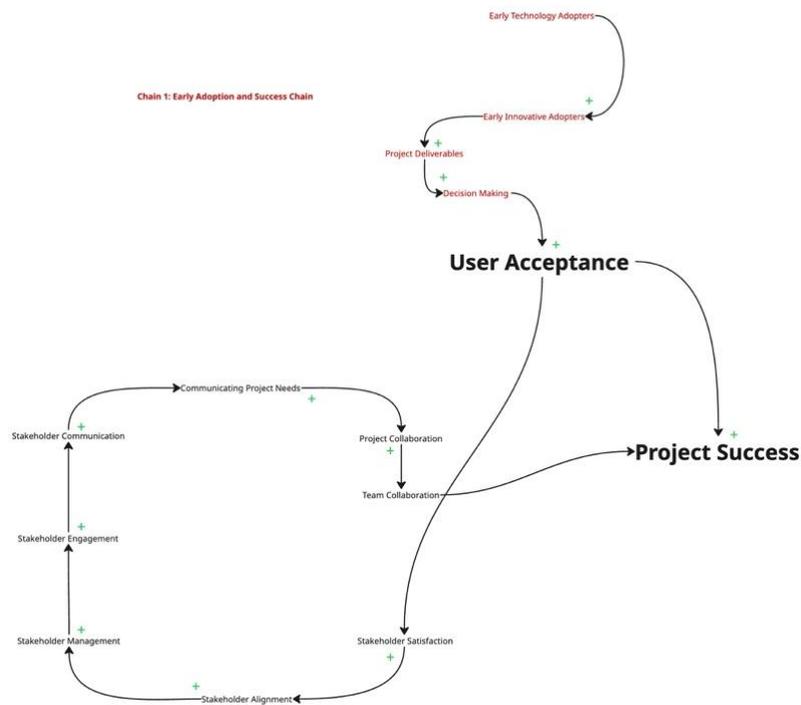


Figure 4.28: Early adoption and success chain

Early adoption:

'there is no set way that they do things that this sort of technology can kind of stand up. And it won't be until that's more common place that more people get on board. So finding those early adopters is going to be a sort of real key' (E10).

Project success:

'depends what success looks like for the client. If they've engaged us to create something to solve a problem, then it's about getting metrics as to where that essentially ameliorated that problem or not. So it could be anything from productivity metrics, other KPIs, or, you know, it could be like, a P value for something been statistically significant or not. It really just depends, like every, we do so many different things. But every use case is different' (S21).

4.17.2 Knowledge and stakeholder satisfaction chain

The relationship chain for knowledge and stakeholder satisfaction is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The knowledge and stakeholder satisfaction chain is given below:

Learning Environment → Lessons Learnt → Learning → Education Environment → Understanding of AR → User Experience and Acceptance → Practical Solutions → Communication Management → Communicating Project Needs → Stakeholder Communication → Stakeholder Engagement → Stakeholder Management → Stakeholder Alignment → Stakeholder Satisfaction.

The relationship between knowledge and stakeholder satisfaction is clear from the data analysis and is described in Figure 4.29. This chain shows that stakeholder satisfaction depends on knowledge concerning AR technology and how it will be implemented. It is noted that stakeholders are satisfied when they receive all the necessary information. This relationship highlights the importance of the learning environment and lessons learnt, which are essential for developing successful projects. After lessons are identified and learnt, they can be used to provide education and a better understanding of how to integrate AR technology in engineering and construction projects. Once there is an understanding of AR technology, stakeholders' user experience and acceptance improve, especially when they are trained and educated effectively, providing practical solutions to project needs. This understanding is then communicated to all stakeholders. Engaging and satisfying stakeholders is crucial for the successful integration of AR technology in the engineering and construction sectors. This is reflected in the following data extracts:

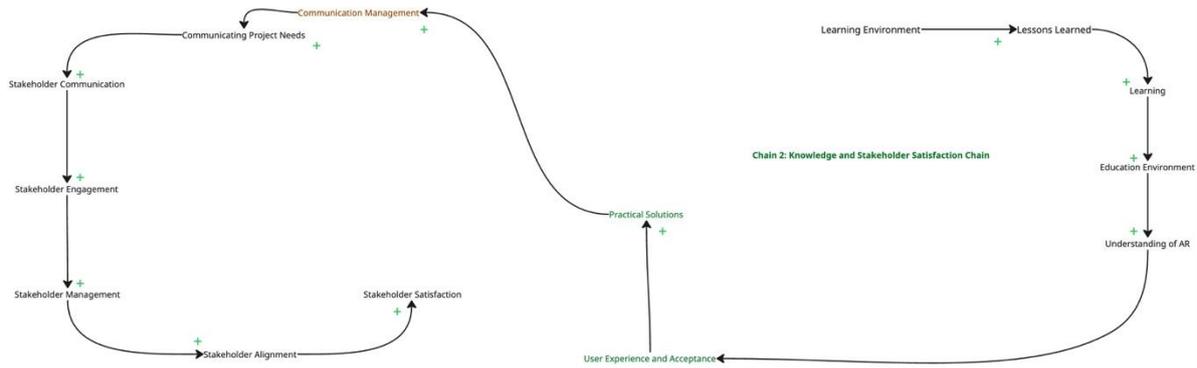


Figure 4.29: Knowledge and stakeholder satisfaction chain

Knowledge:

'But also, as we learned, one of the really important things that's, you know, become a feature of our product is the design has changed so rapidly, which we didn't understand. We were going through crazy iterative processes with the client, about design changes that were either influenced by politics, or by community, or by budget, or by whatever it is, right. But that became essentially a feature of the product, right, is that with the simple submission, I think you'd get the nature of our product, you've got a model, and you've got a data set lat long and altitude. And it's a very, very, very easy process with our platform to be able to resubmit an XML or something like that at this stage, and just republish with a new design, you know, that could be a new model, and it could be a new placement of that line, whether it be powerlines, or solar, wind farm, in terms of the placement. So that's the nature of the technology lends itself incredibly well to the nature of the industry, which is at those early stages, the designs change so rapidly' (S19).

'For being able to instruct people on what to do, how to learn in a physical environment, how to maybe look out for certain pieces of equipment when working in a very physical environment. So you know, a trade or manufacturing or something like that, that it would, yeah, I could definitely see the benefits, particularly in training' (E2).

4.17.3 User experience and acceptance chain

The relationship chain for user experience and acceptance is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The user experience and acceptance chain is given below:

User Experience and AR Use → User Experience and Acceptance → User-Friendly Technology → Ease of Use → Wow Factor → User Acceptance.

The relationship chain for user experience and acceptance is clear in the data analysis, and it is shown in Figure 4.30. This chain indicates that a positive user experience leads to AR technology user acceptance. It is noted that more user experience with AR technology leads to more positive user experiences and user acceptance, which requires the technology to be user-friendly. When AR technology delivers immersive visual information, a certain level of 'wow factor' is necessary for it to be accepted by users. This is reflected in the following data excerpts:

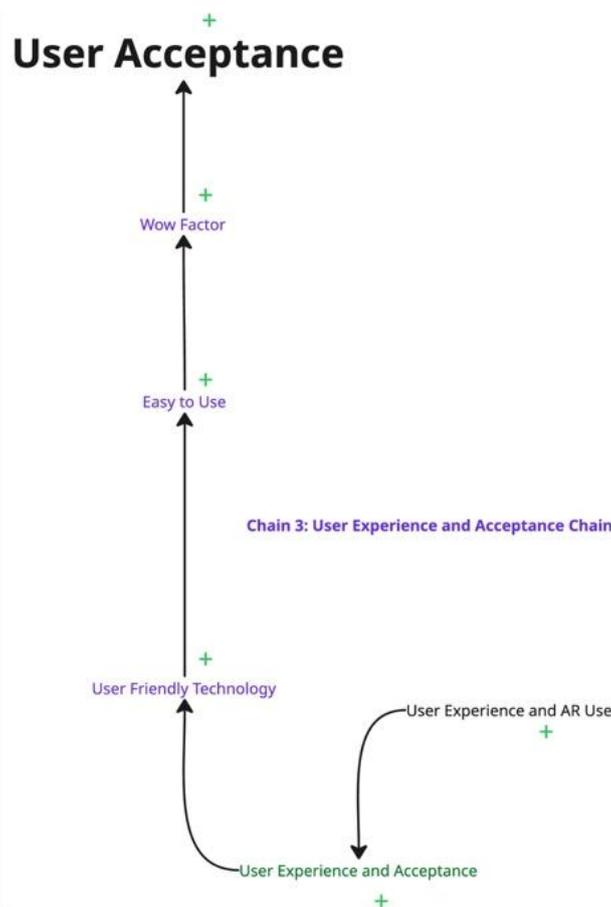


Figure 4.30: User experience and acceptance chain

User experience:

'I mean, yeah, the only thing I would add to that is sort of what we mentioned before, which is, you know, also providing that, you know, close consultation, just to just to narrow down on their expectations, and also their understanding their needs and what we can do to fit that' (S19).

‘So the ability to, I guess, 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 there. I think they are the real sort of interest that will drive user acceptance and adopt, get involved with the actual technology’ (E10).

4.17.4 Performance and quality assurance chain

The relationship chain for performance and quality assurance is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The performance and quality assurance chain is given below:

Performance and Quality Assurance → Quality Control → Quality Assurance and Quality Control (QA/QC) → Quality Management → Continuous Improvement → Project Success.

The relationship chain for performance and quality assurance is clear in the data analysis, and it is shown in Figure 4.31. This chain indicates that quality assurance leads to improved performance. The data reflect a connection between performance and quality assurance. Therefore, performance and quality assurance are linked to quality control, as having a QA/QC process highlights potential issues that may arise. Managing this QA/QC process is essential, as it continuously enhances quality improvement and therefore project success. This is reflected in the following data extract:

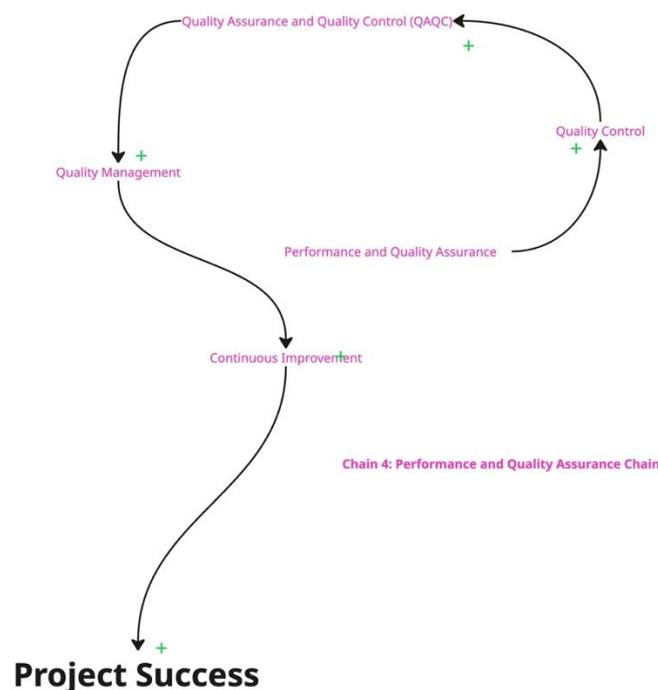


Figure 4.31: Performance and quality assurance chain

Performance and quality assurance:

‘So I think in our work related experience is really about like, we have a 3d model about, you know, the building, somewhat spent a long time to design it and, you know, company constructed. I think it’s really about the you know, we want to work by or even find some issue before, you know, we, I mean, it’s about the quality not only in the 3d model, it looks perfect, but in case you know, if there’s something happened when you build it, we want to work fine if it is built according to the design intent. So this kind of like QA QC process’ (C17).

4.17.5 Stakeholder and project success chain

The relationship chain for stakeholder and project success is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for stakeholder and project success is given below:

Stakeholder Communication → Stakeholder Engagement → Stakeholder Management → Stakeholder Alignment → Stakeholder Satisfaction → Team Collaboration → Project Collaboration → Communicating Project Needs → Communication Management → Practical Solutions → Project Success.

The relationship chain between stakeholder and project success is evident in the data analysis, and it is outlined in Figure 4.32. This chain shows that project success relies on stakeholder management. It indicates that effective stakeholder communication and engagement ensure that stakeholders are managed well, and with communication and engagement, stakeholder alignment is achieved, as everyone is on the same page. This alignment leads to stakeholder satisfaction and improved team collaboration. Project deliverables and needs must be managed effectively to ensure that the project’s solutions are delivered and success is achieved. This is demonstrated in the following data extract:

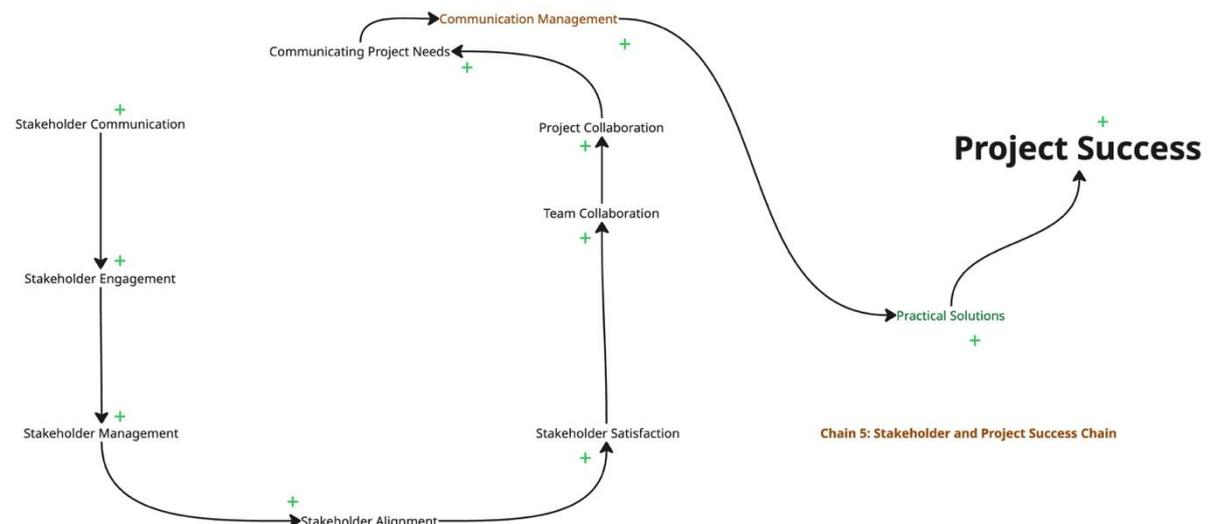


Figure 4.32: Stakeholder and project success chain

Stakeholder communication:

‘So two things on which work together, which is one being the communication tool. And for people to understand what they can expect to see in their local landscape, or, you know, like, in the story of, you know, taking it to community consultations, and letting stakeholders see, you know, what, for especially large infrastructure projects, how, yeah, you know, adding an element of transparency, but also, you know, enhancing the level of communication between private or public companies, with interested stakeholders, compared to having to do lengthy processes, often in photogrammetry, which is your traditional way of doing Photoshop on a strict viewpoint, you know, using augmented reality really takes that level of communication, transparency’ (S19).

4.17.6 Organisational deliverables and success chain

The relationship chain for organisational deliverables and success is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for organisational deliverables and success is given below:

Organisational Deliverables → Processes and Procedures → Workflow → Preparation Time → Project Lead Time → Resources → Financial Deliverables → Financial Aspects → Return on Investment (ROI) → Decision-making → User Acceptance → Project Success.

The relationship chain between organisational deliverables and success is clear in the data analysis, and it is shown in Figure 4.33. This chain indicates that project success depends

on effectively managing organisational deliverables. It is evident that organisational deliverables are controlled through processes and procedures to ensure that the staff do the right thing; these are implemented within the project workflow. When AR is integrated into the project workflow, there must be adequate preparation time, with clear project lead times and proper resource allocation. This also involves financial considerations to ensure an ROI for AR technology adoption in the engineering and construction sectors. The following data extract reflects this:

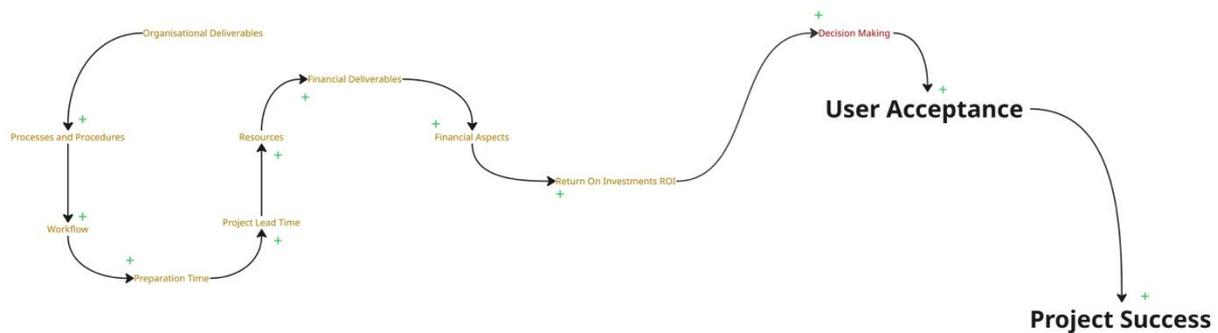


Figure 4.33: Organisational deliverables and project success chain

Organisational deliverables:

'Personally, myself, I like to get involved in these things kind of as early as possible. But as you're sitting in most businesses, these days, there's a lot of pressure to deliver, and a lot of lack of resources, and all those sorts of things. And that kind of prevents people from exploring and investing in new ways of doing things. So it's only an environment that really, there is no set way that they do things that this sort of technology can kind of stand up. And it won't be until that's more common place that more people get on board. So finding those early adopters is going to be a sort of real key. Because people don't really know as much as they talk about innovation and things like that. It's hard to be the first people easier use like, particularly in aerospace, like you want to use proven systems and technologies rather than being trailblazers' (E10).

4.17.7 Technology challenges and user acceptance chain

The relationship chain for technology challenges and user acceptance is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for technology challenges and user acceptance is given below:

Technology and Project Challenges → Project Challenges → Technology Misunderstanding → User Difficulties with AR Technology → Technology Resistance → Underutilised Equipment → Learning Environment → Lessons Learnt → Learning → Education Environment → Understanding of AR → User Experience and Acceptance → User-Friendly Technology → Ease of Use → Wow Factor → User Acceptance.

The relationship chain for technology challenges and user acceptance is clear in the data analysis, and it is shown in Figure 4.34. This chain indicates that user acceptance occurs when the technology functions as expected and there are no issues. If challenges arise, they must be addressed through targeted training and education. According to the data, technology and project challenges often stem from misunderstandings about how to use the new technology or resistance from users who prefer the current methods. The underutilisation of equipment can also be a factor. Once a challenge is identified, it is important to learn why it occurred and to educate users on how to operate and understand the technology. When users gain a clear understanding, the system becomes user-friendly and easier to operate. Using AR technology offers an immersive experience that can enhance user acceptance. This is reflected in the following data extracts:

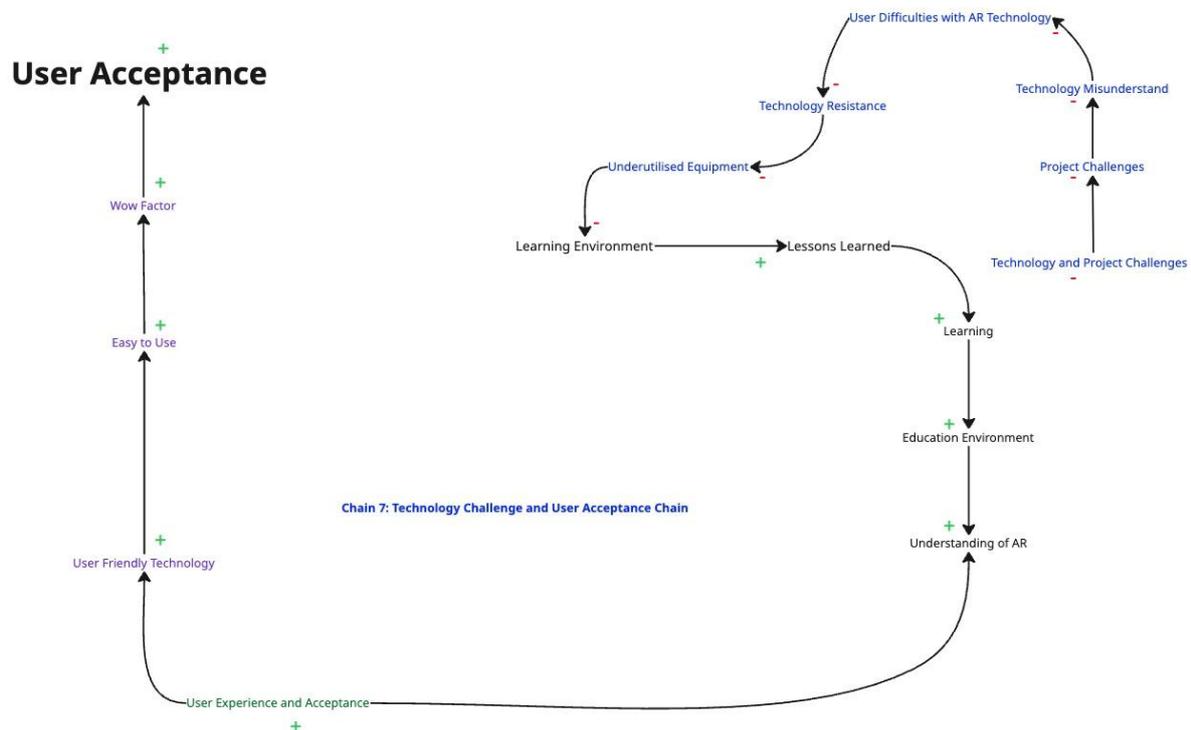


Figure 4.34: Technology challenge and user acceptance chain

Technology and project challenges:

'you know, we go out and demo it all the time, we might be in front of a boardroom table of major infrastructure, people doing that, and you'll get it from a variety of different I've never used VR, is it? I don't know what VR is. Is it VR/AR? What the hell is XR?' (S19).

'I think there is also a lot of misunderstanding around the use of technology such as AR, as with any technological advancements, and these misconceptions can cause concerns' (E1).

'Yeah, of course there is. There is always going to be people that embrace technology and people that see that it's unnecessary. Because a lot of times you get people going, oh, what does this do over just say, you know, a CAD model? So, you know, resistance to change is everywhere. And, you know, until they're proven otherwise, it tends not to happen, right? So, you know, they try to if that whole value segment, how does this add value? Right? So, if people are looking to these sort of more engaged in moving forward of technology and trying to be innovative, then the acceptance is there, but a lot of people, particularly big companies are very much about, let's stick to the status quo' (E10).

4.17.8 Data management and success chain

The relationship chain for data management and success is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for data management and success is given below:

Data Privacy and Management → Data Analytics → Data Connection → Data Integration → Data Overlay → Data Management → Data Privacy → Stakeholder Satisfaction → Team Collaboration → Project Success.

The relationship chain for data management and success is clear in the data analysis, and it is shown in Figure 4.35. This chain shows that success relies on proper data management. Data privacy and management involve protecting data and how they are handled. First, data analytics and data connection are vital for data integration. Integrating data in AR technology requires data overlays. Once the data are outlined, they must be managed properly, and data privacy requirements must be met. When the data are managed well, stakeholders are satisfied, and team collaboration can occur using AR technology, leading to project success. This is shown in the following data extract:

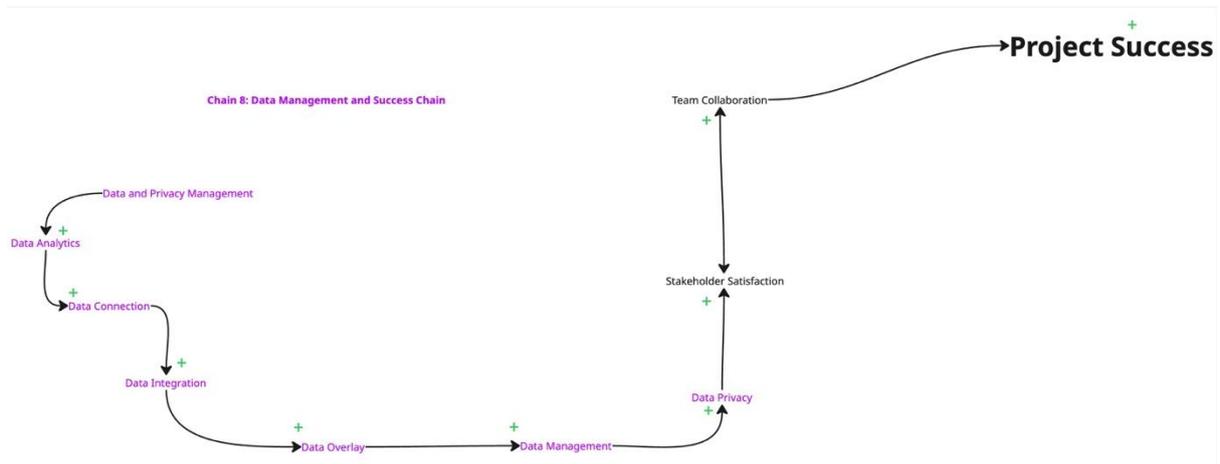


Figure 4.35: Data management and success chain

Data privacy and management:

'That has been pretty interesting on real time data visualization. So even if it is that more historic type, sort of imagery, but then being able to see over top of that, like IoT data, webcams, foot traffic, and car traffic could be a fairly common thing, especially foot traffic of how people move through an area. So it was interesting, being able to have access to then other data sets. So whether or like the government type of data, environmental data, being able to see that integrated into then what they're sort of visualizing. So if it's like a building or something, then being able to see how, like for councils, they want to see how sort of like rising water would affect that particular area. user friendliness making it easy' (S13).

4.17.9 Expert skills and knowledge chain

The relationship chain for expert skills and knowledge is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for expert skills and knowledge is given below:

Expert Skills and Development → Expert Skills → Technical Perspective → Expertise → Technology Savvy → Training → Training Environment → Understanding of AR → Educational Environment → Learning → Lessons Learnt → Learning Environment → Project Success.

The relationship between expert skills and knowledge is clear in the data analysis, and it is shown in Figure 4.36. This relationship indicates that knowledge and expert skills are crucial

for integrating new technology. When adopting new technology, there needs to be a technical perspective and expert advice, which requires experts who are technically savvy. This involves training to ensure that each individual understands AR technology within an educational environment that combines learning and lessons learnt. Once the expert technology users have trained and educated others on how to use AR technology, it contributes to the success of the project. This is reflected in the following data extracts:

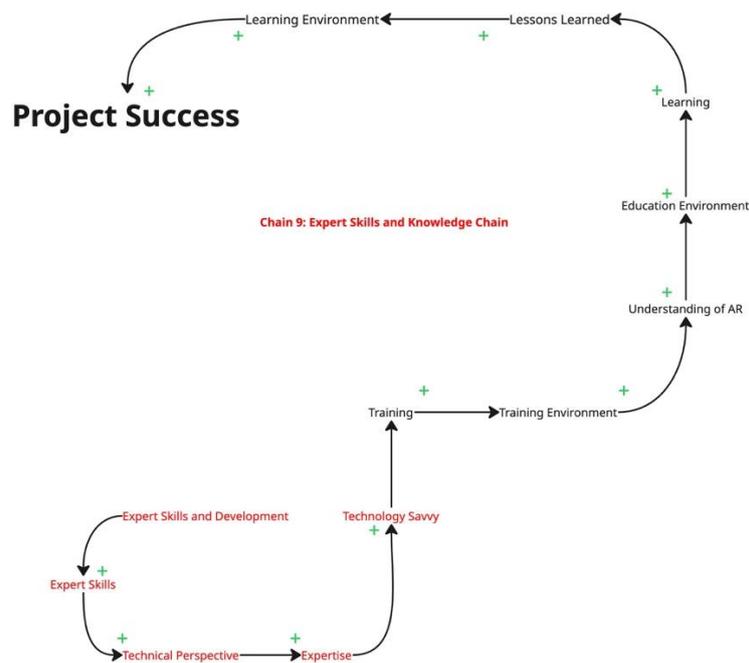


Figure 4.36: Expert skills and knowledge chain

Expert skills:

'when we're scoping out a project, we scope it out in regards to what we need to do on a technical perspective. And we also really get clarity from the client as to the nuts and bolts of what they need us to develop. And then we work very closely with them because we're creating something bespoke for their use case' (S21).

'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 kind of 3d modelling system into a space, and that's a pretty specific skill set to be able to have' (E10).

4.17.10 Project management and success chain

The relationship chain for project management and success is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for project management and success is given below:

Project Management → Project Design → Design Accuracy → Design Aspect → Design Changes → Project Development → Prototyping → Customisation → AR Implementation → Accuracy → Performance and Quality Assurance → User Experience and Acceptance → Practical Solutions → Project Success.

The relationship chain for project management and success is clear in the data analysis, and it is shown in Figure 4.37. This chain shows that success depends on effective project management. When introducing AR technology in engineering and construction, expert skills and a technical perspective are essential. This also requires proper training, education and knowledge of AR technology. Once this knowledge is transferred, it helps achieve project success. This is demonstrated in the following data extract:

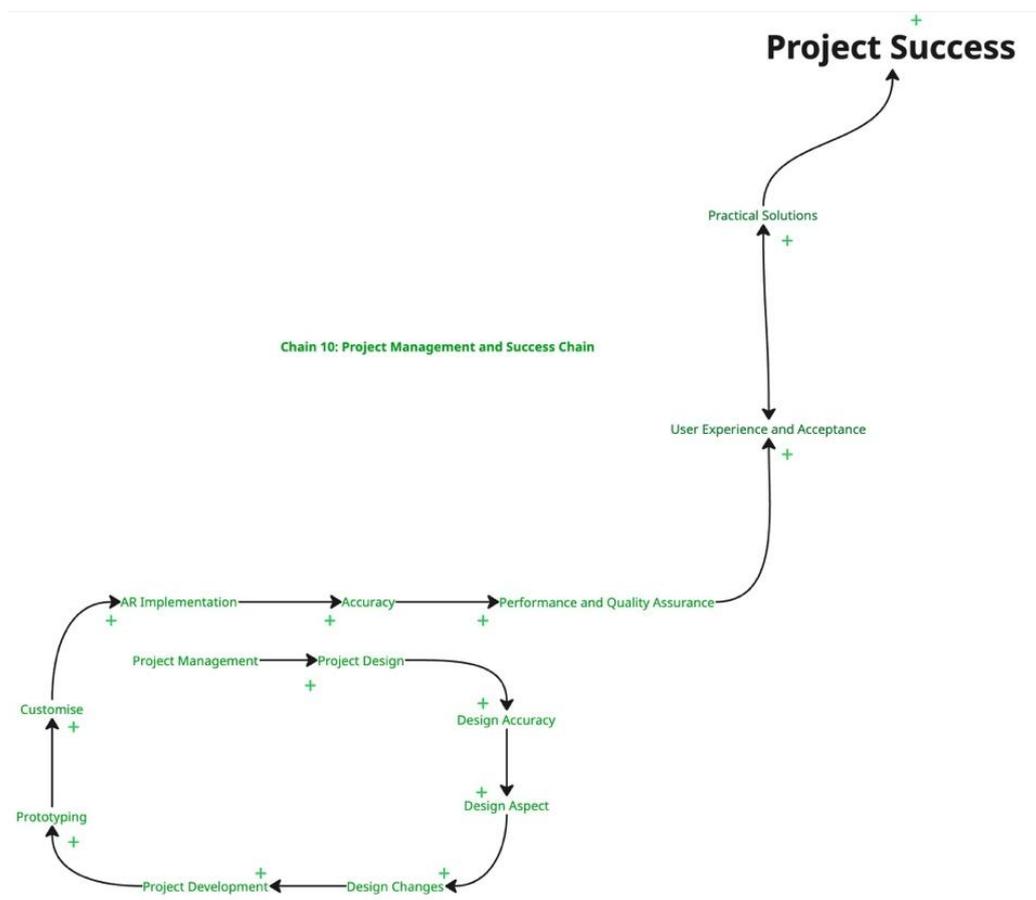


Figure 4.37: Project management and success chain

Project management:

'The first one is for as built verification, so it's like getting instant, or, you know, progressing review. So we're bringing the model on the phone, or the iPad, and it will bring on site and we overlay with existing the store has in store condition to check is displacing. Or at least it you know, depending on the accuracy of that model, we will at least to see whether the object sits in relatively close location as per the design intent. That's the one thing we do for verification, the other is for a check. So like the one case that we're using the project is there. They are going to install a very complicated steel structure on the roof. And they want to see and check and inspect whether the fixing items and details were there and they're in the accurate position. So we will bring the steel structural model including all these particular details, fitting details, and then we will position the AR model using QR code to get more accuracy into the overlay and check whether these positions are correct or not. At this same time, the team can use it to see what's coming up in the next few weeks, because they can see the whole model whereas not just one For or, you know, where it's not just 2d drawings on paper' (C16).

4.17.11 Technology advancements, user acceptance and success chain

The relationship chain for technology advancements and user acceptance is outlined in detail below. This includes the data extracts that support the relationship chain, providing a clear understanding of how the relationships are interconnected.

The relationship chain for technology advancements, user acceptance and success is given below:

Technology Advancements → AR Benefits → Early Adopters → Early Technology Adoption → Early Innovative Adopters → New Technology → Exposure → Project Deep Dive → Project Deliverables → Immersive Experience → User Acceptance → Wow Factor → Ease of Use → User-Friendly Technology → User Experience and Acceptance → Practical Solutions → Project Success.

The relationship between technology advancements, user acceptance and success is clear in the data analysis, and it is shown in Figure 4.38. This relationship indicates that success depends on the user acceptance of AR technology. When integrating AR into engineering and construction projects, it should provide benefits to these projects, and adopting new

technology early in the process can help ensure a smooth transition and foster innovation. At the start of a project, a thorough review is necessary to confirm that deliverables are on track and that there is an engaging visual experience. Once users accept the visual communication, it creates a wow factor that enhances their experience and acceptance, resulting in beneficial development for stakeholders and practical solutions, ultimately leading to project success. This is reflected in the following data extract:

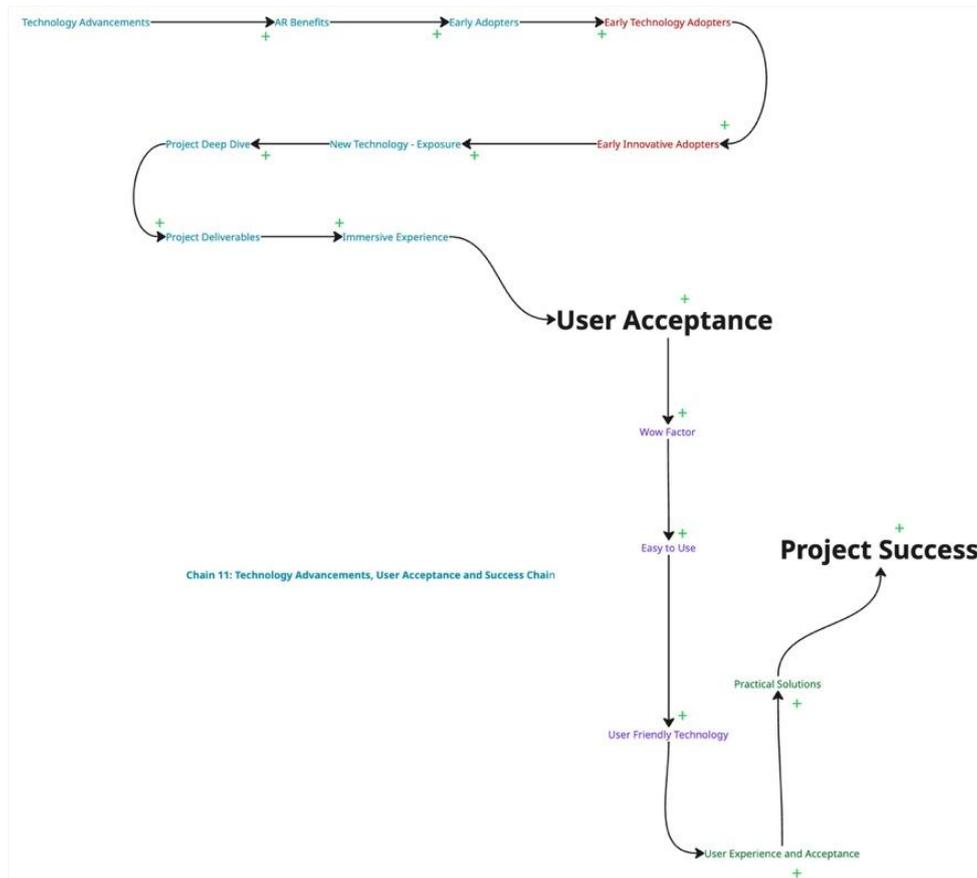


Figure 4.38: Technology advancements, user acceptance and success chain

Technology advancements:

'it's really about the benefit that it brings to them? Like you know, like a construction manager would we want to know whether the thing that would be according to design time, but you know, the engineers we like to know whether the factory has fabricated, the exact piece that they needed so it's really depending on what benefits it's bringing to the user. The construction manager does not care about, the specific piece because overall speaking when everything is correct, it should build up something that when they used the device it over lays that correctly similarly saying he's not really down to the detail details of the parts but the trays engineers or you know, maybe our engineers when we you know, want to know whether, you know, this piece that shipped from the factory is it built according to the

specification and requirements needed so it's different people have different grow even benefits' (C17).

4.18 Feedback Loop

The feedback outlined in this research was developed using grounded theory. This grounded theory approach employed a systematic methodology that allows patterns and connections to emerge from the qualitative data.

In total, two feedback loops were identified within the study. These loops were established by analysing the relationships detailed in the taxonomy and the data collected during the research; they are listed as follows:

1. Communication feedback loop;
2. Knowledge and lessons learnt feedback loop.

Each feedback loop represents an interconnected relationship chain that occurred and formed a loop. For example, for the first feedback loop, 'communication feedback loop', each of the connecting stages is outlined as follows:

- Stakeholder Communication → Communicating Project Needs: The stakeholder has been told about and understands the AR technology integration.
- Communicating Project Needs → Project Collaboration: The project needs have been communicated.
- Project Collaboration → Team Collaboration: The project needs are communicated, and teamwork is involved in the integration of AR technology.
- Team Collaboration → Stakeholder Satisfaction: The stakeholder is satisfied with the AR technology.
- Stakeholder Satisfaction → Stakeholder Alignment: With stakeholder satisfaction, the stakeholders all need to align their expectations.
- Stakeholder Alignment → Stakeholder Management: The stakeholders have aligned their expectations.
- Stakeholder Management → Stakeholder Engagement: All stakeholders are engaged with the expectations of AR technology integration.
- Stakeholder Engagement → Stakeholder Communication: The stakeholders are communicated with, and the feedback loop begins again to ensure that there is communication across the whole project phase.

4.18.1 Communication feedback loop

The feedback loop for communication is outlined in detail below. This includes the data extracts that support the feedback loop, providing a clear understanding of how the feedback loop is structured.

The feedback loop for communication is given below:

Stakeholder Communication → Communicating Project Needs → Project Collaboration → Team Collaboration → Stakeholder Satisfaction → Stakeholder Alignment → Stakeholder Engagement → Stakeholder Communication.

The communication feedback loop explains how different types of communication connect; it acts like a rotating flywheel moving in all directions. This is shown in Figure 4.39. Examples of this are given in the data extracts below:

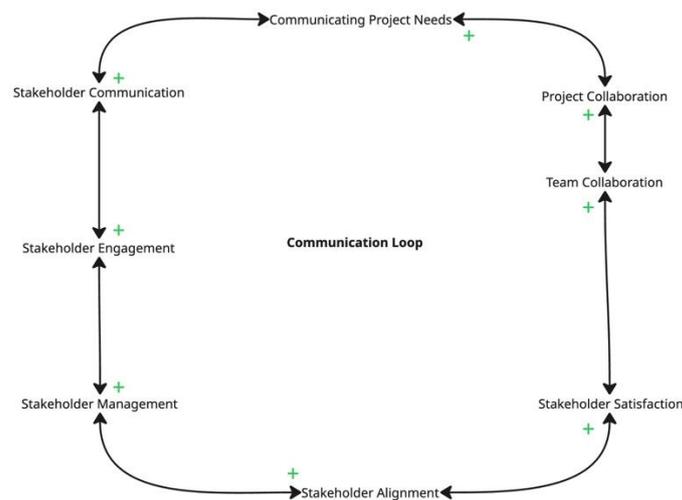


Figure 4.39: Communication feedback loop

Communication:

‘So two things on which work together, which is one being the communication tool. And for people to understand what they can expect to see in their local landscape, or, you know, like, in the story of, you know, taking it to community consultations, and letting stakeholders see, you know, what, for especially large infrastructure projects, how, yeah, you know, adding an element of transparency, but also, you know, enhancing the level of communication between private or public companies, with interested stakeholders, compared to having to do lengthy processes, often in photogrammetry, which is your traditional way of doing Photoshop on a strict viewpoint, you know, using augmented reality really takes that level of communication, transparency’ (S19).

'And it would even go so far as to getting funding and stuff for bigger projects, right down to actually when you're executing and have ensure all the contractors, you're bringing in, you can go around and show them where things need to be and what it needs to look like. So it kind of sets a really, you know, make sure everybody facing the same direction, because a lot of the times everybody's picturing things in their head. But it's not necessarily the same thing. And you know, through my experience, I've learned that some people don't have the ability to picture things in their head. Right? So in that sense that actually this is absolutely invaluable' (E10).

4.18.2 Knowledge and lessons learnt feedback loop

The feedback loop for knowledge and lessons learnt is outlined in detail below. This includes the data extracts that support the feedback loop, providing a clear understanding of how the feedback loop is structured.

The feedback loop for knowledge and lessons learnt is given below:

Learning Environment → Lessons Learnt → Learning → Education Environment → Understanding of AR → Training Environment → Project Champion → User Experience and AR Use → Project Development Experience → Project Success → Learning Environment.

The knowledge and lessons learnt feedback loop explains the link between education, learning and training, and how these different types of knowledge are interconnected. It acts like a rotating flywheel that spins in two directions. This is shown in detail in Figure 4.40. An example of this can be seen in the following data extract:

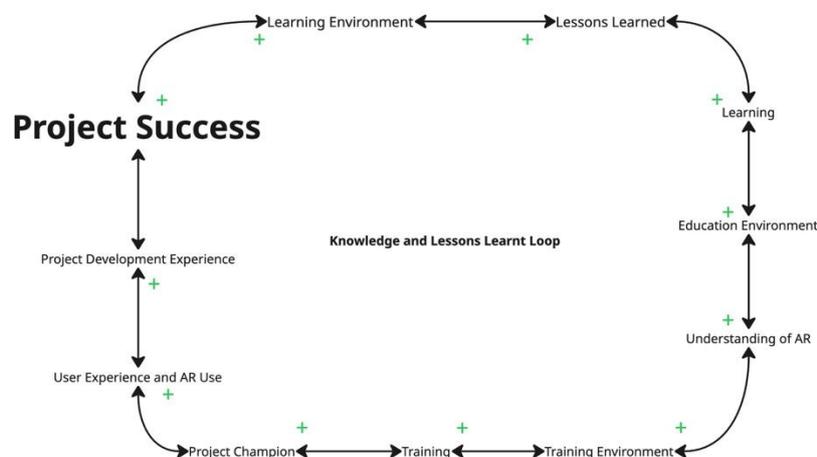


Figure 4.40: Knowledge and lessons learnt feedback loop

Knowledge:

'But also, as we learned, one of the really important things that's, you know, become a feature of our product is the design has changed so rapidly, which we didn't understand. We were going through crazy iterative processes with the client, about design changes that were either influenced by politics, or by community, or by budget, or by whatever it is, right. But that became essentially a feature of the product, right, is that with the simple submission, I think you'd get the nature of our product, you've got a model, and you've got a data set lat long and altitude. And it's a very, very, very easy process with our platform to be able to resubmit an XML or something like that at this stage, and just republish with a new design, you know, that could be a new model, and it could be a new placement of that line, whether it be powerlines, or solar, wind farm, in terms of the placement. So that's the nature of the technology lends itself incredibly well to the nature of the industry, which is at those early stages, the designs change so rapidly' (S19).

The relationship chains and feedback loops are detailed in the causal loop diagram, which provides a visual representation of the relationships and feedback loops in relation to AR user acceptance and its dynamics in the engineering and construction sector. This diagram was generated through grounded theory data analysis. The data analysis identified 11 relationship chains formed from the data. Additionally, the diagram includes two feedback loops. This is detailed in Figure 4.41.

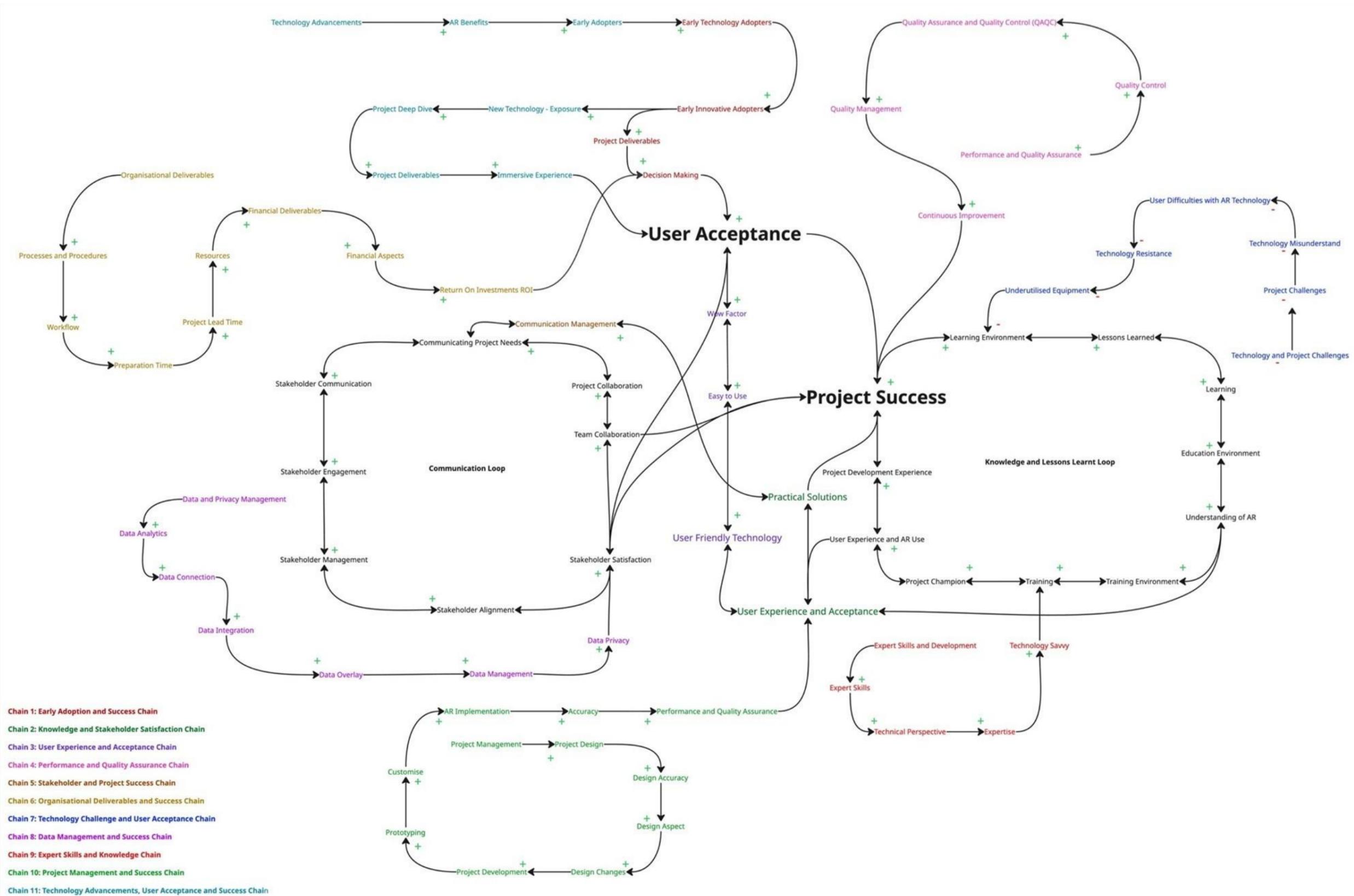


Figure 4.41: Relationship chain and feedback loop causal loop diagram

4.19 Conclusion

The data analysis demonstrates how grounded theory was used to incorporate the primary sets of data into open coding, axial coding, and selective coding. This comprehensive data analysis outlines the user adoption of AR technology in engineering and construction projects. The data originated from raw primary data collected through interviews, focus groups, and open-ended questionnaire surveys. Grounded theory was used throughout the data analysis; this led to the development of a framework and a causal loop diagram to visually map the relationships involved in AR technology integration.

The taxonomy for AR technology integration depicts the open codes as the first layer of data analysis, the axial codes as the second layer, and the selective codes as the third layer, as shown in Figure 4.26. This taxonomy captures the complexity of relationships and AR-driven change. Each code functions as a node within a larger system, reflecting the nature of AR technology integration.

Building from the taxonomy, the data established a framework that outlines the flow of a project. First, organisational deliverables feed into the project and technology inputs, which then produce the project output for AR technology integration. The framework demonstrates how AR technology integration is influenced by the project cycle. It shows that AR integration is not a linear process; it includes feedback loops. This framework is illustrated in Figure 4.27 and offers an evidence-based model for AR technology integration in projects.

The causal loop diagram is a visual display of the relationships and interdependencies outlined in the data analysis. The relationships and feedback loops illustrate how AR technology integration emerges from the technology, people, processes and procedures, and organisational learning; this is shown in Figure 4.41.

Together, the taxonomy, the framework, and the causal loop diagram provide AR technology integration in construction and engineering projects, offering technology adoption and practical guidance for AR technology. This is further discussed in Chapter 5.

The data analysis chapter is the fourth chapter of this study; it explains how the data analysis was conducted. It follows Chapter 1, the introduction, Chapter 2, the literature review, and Chapter 3, the research methodology. Chapter 5 presents the discussion and lastly, the conclusion, which summarises the research contributions.

Chapter 5: Discussion

This chapter presents an analysis of the findings from the previous data analysis, interpreting the results within the theoretical framework. It addresses the research question by discussing the taxonomy, the relationships within AR technology, and the proposed framework developed from the data analysis. Additionally, this chapter highlights gaps in the existing research, emphasising skill development, innovation, and collaboration.

5.1 Overview

This chapter presents a comprehensive analysis of the data findings discussed in Chapter 4. Its purpose is to interpret these results and explore their implications, providing insights into the significance of the data within the overall research context. By analysing the various components of the findings, this chapter clarifies their relevance to the research questions, specifically examining the role of augmented reality in advancing technology within construction and engineering projects. During this research, 8 applications have been used. This includes:

1. Qualtrics: Assist with the open-ended survey questionnaires and to record the participants acceptance.
2. Microsoft Teams: Assist with recording the interviews.
3. Zoom: Assist with recording the interviews.
4. Google Meet: Assist with recording the interviews.
5. Otter: Assist with transcribing the interviews.
6. NVivo: Assist with the analyse of the data.
7. Miro: Assist with the development of the diagrams.
8. Grammarly: Assist with the grammar of the thesis.

The aim of this research is to explore the dynamics of the user acceptance of AR technology in the engineering and construction sectors, utilising qualitative data through grounded theory, along with DeLone and McLean's IS success model approach (DeLone & McLean, 1992; DeLone & McLean, 2003). Through this research, academic knowledge can be enhanced, and practitioners can gain an in-depth understanding of digital transformation and how to integrate this into their current workflows.

It has been noted that the gap identified in the literature review highlights a lack of real-world settings where AR technology is integrated into complex construction and engineering projects (Hajirasouli et al., 2022). There are also immature standardised systems for AR integration (Delgado, Oyedele, Beach, et al., 2020). Additionally, there is a lack of a

comprehensive framework and guidelines for integrating AR technology, as well as insufficient training with the appropriate set of skills, which highlights the need for further research (Ghorbani et al., 2024; Han & Clevenger, 2025).

Due to its inability to embrace digitalisation, there have been limited digital technology advancements in the construction and engineering sector (Alkan & Basaga, 2023). Additionally, there are minimal studies on the benefits and issues of integrating AR technology within organisations (Delgado, Oyedele, Demian, et al., 2020). Therefore, AR technology requires more research since it is still developing, and a complete system and framework have yet to be fully established (Delgado, Oyedele, Demian, et al., 2020; Kolaei et al., 2022; Sangiorgio et al., 2020).

The relevance of this research lies in the identification of the research question – ‘what are the dynamics of the user acceptance of technology in engineering and construction projects’ – and articulating this in both theory and practice. Therefore, understanding the user acceptance of AR technology is essential for the digital transformation in engineering and construction projects, and it aligns with DeLone and McLean’s (2003) call for research into system use, user satisfaction and net benefits, alongside the grounded theory approach, which incorporated primary data from participants who use AR technology or work within organisations that utilise AR technology.

5.2 Addressing the Research Question

In this thesis, a qualitative approach was used through grounded theory. During the study, interviews took place via online platforms with participants in the construction and engineering sectors who currently work with AR technology or for companies where AR technology is used in the workplace. Additionally, interviews were conducted online with software developers who develop AR technology. Furthermore, the same questions were uploaded to Qualtrics and used as an open-ended survey questionnaire for individuals who preferred not to be interviewed and answered the questions in their own time. The questions aimed to support answering the research question and outlining the user acceptance of AR technology in the construction and engineering sectors. This qualitative research resulted in a taxonomy of the developed open, axial and selective codes. These were further developed into a framework and a causal loop diagram. This research question is as follows.

RQ: What are the dynamics of the user acceptance of technology in engineering and construction projects?

The aim of this qualitative study was to explore the factors influencing the user acceptance of AR technology. This research investigated the research question and examined the dynamics of the user acceptance of technology within the construction and engineering sectors. The findings included a taxonomy, a framework and a causal loop diagram related to the user acceptance of AR technology. The research utilised grounded theory, along with the DeLone and McLean IS success model approach (DeLone & McLean, 1992; DeLone & McLean, 2003), to establish the foundations and understanding of user acceptance and satisfaction. For this research, the DeLone and McLean IS success model was not utilised as the framework of the data; however, it served as a theoretical lens that aided in guiding potential relationships without limiting new codes and relationships. By utilising the DeLone and McLean IS success model, the approach aligns with grounded theory, allowing new theories to emerge.

When the qualitative data were coded using grounded theory, several categories aligned with the DeLone and McLean IS success model, including user satisfaction, quality, and benefits. This is influenced by technology reliability and quality. However, grounded theory allows the data analysis to go beyond the DeLone and McLean IS success model, deriving insights from the data on topics such as education, organisational deliverables, and stakeholder alignment. It is noted that grounded theory enables a more holistic approach to AR technology, whereas the DeLone and McLean IS success model is more technology-based.

Therefore, the theoretical lens for AR technology integration is derived from grounded theory and expands on the DeLone and McLean IS success model by validating new categories through coding and outlining that AR technology integration derives from not only technology but also organisational deliverables, project and technology inputs, and project outputs. This is further detailed below.

From the qualitative study using grounded theory, 248 open codes were identified, along with 49 axial codes and 18 selective codes. The 18 selective codes reveal the dynamics of the user acceptance of AR technology. In addition to these 18 areas, relationships have been identified, highlighting how these interconnections relate to the user adoption of AR technology. The factors that influence the user acceptance of AR technology are detailed below. The descriptions were generated from grounded theory. This highlights how each category and relationship is essential for AR technology adoption.

5.2.1 Taxonomy and framework for AR technology integration

AR technology in the engineering and construction sector is driven by its immersive real-time data applications, enabling stakeholders to communicate and collaborate easily. The dynamics of the user acceptance of AR technology are illustrated through a qualitative study using grounded theory. The findings, derived from primary data and recent literature, cover several critical categories. These categories were identified through open, axial and selective coding, helping to elucidate the user acceptance of AR technology. The results led to the development of a taxonomy and framework that highlight categories that might seem minor individually but are crucial when viewed together. The taxonomy is illustrated in Figure 5.1. More details on these categories are provided below.

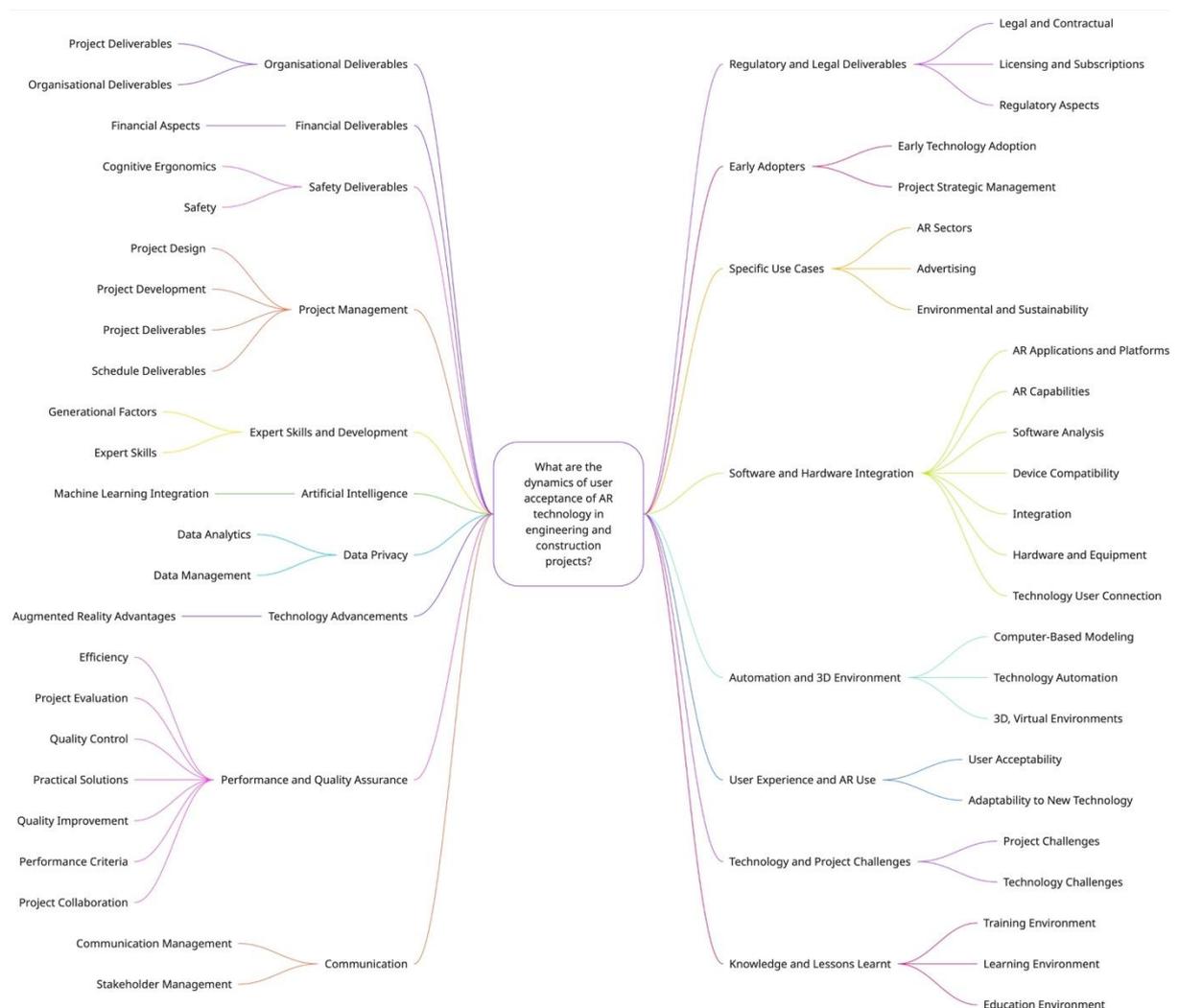


Figure 5.1: Taxonomy of AR user acceptance

5.2.1.1 Organisational deliverables and project scope

Organisational deliverables and the project scope are essential for the user adoption of AR technology. The project scope includes high-level project information, such as scope management and the transparency of project information. It also outlines organisational deliverables such as resources and the lead time. Essentially, this category identifies the high-level data needed to initiate digital technologies like AR in projects from an elementary perspective.

An important implication for AR technology is its ability to help align organisational deliverables and the project scope by making complex designs more visible and easier to understand. Understanding the end product before starting the project supports a better understanding of the project scope and deliverables and ensures that stakeholders are aligned (Delgado, Oyedele, Demian, et al., 2020). By reducing misconceptions about the design and enabling stakeholders to understand the deliverables and scope, AR contributes to better decision-making and reduces errors.

5.2.1.2 Financial deliverables

This category highlights the financial aspects related to the use of AR technology, such as cost management, the ROI, project funding, and how these relate to a quantifiable benefit in the long run. Financial deliverables for projects are essential for cost control, and integrating digital technologies like AR has been shown to help reduce costs (Hajirasouli et al., 2022). Many benefits from AR technology have been recognised, including the ability to identify delays and save time, which supports cost reduction (Hajirasouli et al., 2022).

The benefits of cost savings when integrating AR technology are beneficial for user acceptance and integration, and they can enhance the ROIs on projects, making this a feasible option for digital technology.

5.2.1.3 Legal and regulatory deliverables

The legal and regulatory deliverables for AR integration outline the legal and contractual deliverables, such as project and contractual requirements. This section also addresses regulatory considerations like economic and political requirements. Furthermore, it covers licencing and subscription needs for AR integration, such as licencing for platforms and software use.

To ensure that AR user acceptance and integration align with organisational needs, there must be a proper understanding of legal and regulatory deliverables, and organisations must comply with standards when integrating digital technologies. It is highlighted that compliance and sustainability are essential for AR technology (Elmousalami et al., 2025), thus supporting organisational needs to address legal and regulatory items early on. Ensuring that organisational deliverables incorporate compliance will mitigate any issues and lead to better integration of AR technology and user acceptance.

5.2.1.4 Safety deliverables

Safety deliverables outline the ergonomic requirements and safety aspects of AR integration and use. There are considerations that need to be addressed in areas such as equipment safety and human factors. AR technology, when integrated into projects in the construction and engineering sectors, can enhance workplace safety. AR technology is the ideal digital technology to enable workers to visually identify hazards in a safe environment (Delgado, Oyedele, Demian, et al., 2020). Utilising AR technology enables bespoke real-world scenarios to be identified and allows workers to better understand the hazards surrounding them.

5.2.1.5 Early adopters

The early adopters category is an essential category that highlights early technology adoption and strategic project management. Early technology adoption focuses on areas such as project needs and directions, exposure to new technology and early innovative adopters. It involves identifying digital technology and integrating it into the project early. Strategic project management emphasises strategy and outlining proven systems to support new innovation.

Early adopters are a crucial element in AR user integration and acceptance, and they play a vital role in innovation within organisations. A strong motivator for AR technology is the desire to stay connected and not be left out of the advancements of digital technology, which leads to time being spent researching and experimenting with different types of digital technology and integrating innovation as these technologies change.

5.2.1.6 Project management

Project management is a broad category that is essential for any project. This category includes project design, project development, project deliverables and schedule deliverables. Project design outlines all the design elements needed to integrate AR technology. Project development includes many important areas, such as prototyping, customisation and content

gathering, that are necessary during the development phase. Project deliverables specify the designs required to deliver AR technology, such as documentation, portfolios, project delivery and handover requirements. Finally, schedule deliverables emphasise the schedule and time requirements for AR technology integration and use.

Integrating AR technology can improve efficiency in areas such as project design and deliverables in the construction and engineering sectors. AR technology contributes to improved collaboration and communication with internal and external stakeholders. In addition, it improves productivity and enhances the overall project understanding (Delgado, Oyedele, Beach, et al., 2020). These deliverables concerning AR integration and user acceptance outline that AR technology enhances project management and highlights a shift towards a more visual approach in project delivery.

5.2.1.7 Specific use cases

The specific use cases category details AR use in various sectors such as engineering and construction, including AEC, manufacturing, trade and infrastructure. This category also covers environmental and sustainability aspects, such as environmental projects and renewable energy. Additionally, it includes advertising, which considers target audiences and marketing requirements.

In engineering use cases, AR technology enhances accuracy and efficiency for tasks such as inspections and design changes. In these tasks, AR technology creates digital overlays to support these activities. AR technology offers real-time data overlays, facilitating improved decision-making aligned with the design intent and the specific use case for enhanced accuracy (Schmitt et al., 2025).

5.2.1.8 Expert skills and development

The expert skills and development category details generational factors that influence AR use and expert skills such as technical perspectives. This includes SMEs and skill sets related to AR integration and user acceptance.

One of the main gaps in the literature and findings is the lack of skill set and organisational development for digital technology such as AR (Hajirasouli et al., 2022). For AR integration and user acceptance, expert skills must be used, and upskilling the workforce is necessary to ensure that AR technology is being used according to the design intent (Delgado, Oyedele, Demian, et al., 2020). Ensuring that expert skills are used in integrating AR

technology can ensure that digital transformation is effectively implemented in projects and that the user acceptance of AR technology is achieved.

5.2.1.9 Software and hardware integration

Software and hardware integration is a large category that is essential for user acceptance and AR integration. This section outlines the applications and platforms necessary for AR technology, such as SaaS or APIs. It highlights AR functionalities, software analysis, device capabilities, hardware and equipment, user connectivity and AR integration requirements like cross-platform integration and programming.

There are many areas of software and hardware integration. In the construction sector, combining AR technology with BIM is crucial, as it allows the use of accurate real-time data to detect defects (Liao & Luo, 2025). Therefore, in the construction sector, user acceptance largely depends on software and hardware integration with aspects such as BIM.

5.2.1.10 AI integration

The AI category is important because it includes machine learning that incorporates AI imagery and generative AI to assist in project development, such as writing codes and scripts. It is noted that AI integration is a vital part of digital technology today, as it is gradually being accepted in organisations.

AR technology is evolving from digital overlays to data-enabled environments. AR technology and AI use are essential in the engineering and construction sectors, as intelligent digital twins (IDTs) are being utilised to digitalise inspections and processes (Yin et al., 2023). Integrating AR technology and AI enables manual tasks to be predicted by AI analytics and transforms optimisation and capabilities.

5.2.1.11 Automation and 3D environments

The automation and 3D environments category details areas such as computer-based modelling, technology automation and immersive environments. This is essential for AR integration and user acceptance, as real-time immersive visual data are an important aspect of AR technology.

AR technology and 3D environments are essential for AR technology adoption and user acceptance. One of the main benefits of using AR technology in the construction and

engineering sector is its 3D modelling and visualisation capabilities (Bórquez et al., 2025). 3D modelling improves visual communication and design capabilities.

5.2.1.12 Data privacy and management

Data privacy and management are essential for AR technology adoption and user acceptance. This includes data analytics and data management, ensuring that all data are properly managed and integrated into AR technology for the intended purpose.

There has been an increase in data management requirements, as many data breaches have occurred in Australia within large organisations, leading to information leaks. Regarding AR technology, organisations and end users need to be managed accordingly, and AR must be integrated according to the design intent. It is highlighted that data security and ownership are essential factors when using AR technology (Delgado, Oyedele, Demian, et al., 2020), and organisations must ensure that proper systems are in place to ensure that sensitive data are managed accordingly.

5.2.1.13 User experience and AR use

The user experience and AR use are crucial; they include user acceptance, which involves accuracy, user expectations, the ease of use and variables such as the wow factor. Technology adaptability is also important, detailing how AR technology is adapted to projects and how it is used.

The user acceptance of AR technology depends on the perception and use of AR technology. Hajirasouli et al. (2022) highlight that AR technology is effective during the design review phase, especially regarding the user experience and user acceptance, when it is used for visual presentations. This highlights that user adoption and acceptance are facilitated through virtual representation.

5.2.1.14 Technology advancements

Advancements in technology highlight the benefits of using AR technology. AR is introduced to projects mostly to gain a certain level of advantage or benefit. Additionally, it aims to provide users with an improved immersive experience through positive technology contributions.

AR technology was developed some time ago; however, advances in AR technology have restored interest and increased user adoption in the construction and engineering sectors.

Delgado et al. (2020) highlight that recent advancements in AR and VR technology have revived interest in AR due to the development of more efficient devices, therefore creating digital transformation in the construction and engineering sectors.

5.2.1.15 Technology and project challenges

With all technology, there are challenges, and highlighting what these challenges may be is essential for the smooth integration of AR technology and user adoption. This includes technology and project challenges, such as pressure and cost problems, technology resistance and underutilised equipment.

Despite the many advancements in AR technology, there are always challenges when integrating new technology. Some limitations of AR include the battery life, low resolution and uncomfortable HMDs (Delgado, Oyedele, Beach, et al., 2020). These limitations can reduce the reliance on AR technology. However, clearly outlining these limitations to begin with and identifying the most suitable AR device for the project can minimise challenges and improve AR usage with the correct device and information.

5.2.1.16 Performance and quality assurance

Performance and quality assurance captures a large range of factors that influence AR adoption and user acceptance, including items such as quality control, quality improvement, performance criteria and the performance of AR technology.

Integrating AR technology in the construction and engineering sectors provides a powerful tool for performance and quality assurance. Utilising AR technology for detecting real-time defects enables instantaneous feedback, enhancing efficiency and quality (Liao & Luo, 2025). Real-time feedback on defects improves the quality, project delivery and overall success. Therefore, using AR technology for performance and quality assurance enhances the user acceptance of AR technology.

5.2.1.17 Communication

Communication is vital for any project, and when AR technology is integrated, it connects to all categories. This includes communication management, which includes stakeholder, written and verbal communication. This also involves stakeholder management, as communication plays a significant role for stakeholders; this includes stakeholder alignment and ensuring stakeholder satisfaction.

AR technology is an immersive virtual communication tool that enables complex data to be easily visualised, and AR technology excels at transforming data into an immersive experience. AR technology can be used to create realistic representations of designs, resulting in more appropriate feedback when it is integrated into construction and engineering projects (Delgado, Oyedele, Demian, et al., 2020). Therefore, user adoption and acceptance are essential to AR technology and how it enables better communication and collaboration for organisations and end users.

5.2.1.18 Knowledge and lessons learnt

Knowledge and lessons learnt are essential for any project, and when integrating AR technology, they are connected to all categories. The areas of expertise and lessons learnt include training, learning and the education environment.

Knowledge and lessons learnt are essential for AR adoption and user acceptance, as they influence all stages of the project. It is recognised that AR technology provides an immersive environment that supports knowledge and learning in complex environments (Sangiorgio et al., 2020). This highlights not only the value that AR technology has as a tool but also its value in an educational environment. Therefore, it is clear that knowledge and lessons learnt support AR technology acceptance and user adoption.

5.2.2 Relationships for AR technology integration

The main findings from the data analysis used qualitative data derived from grounded theory to develop emerging themes. Additionally, principles from DeLone and McLean's IS success model aligned with themes like quality and user acceptance, aiding in identifying concepts related to AR technology. By combining grounded theory with principles from DeLone and McLean's IS success model, this research captured not only the IS success but also organisational deliverables, communication, and learning. Utilising the grounded theory approach of coding and then categorising and finding relationships formed the relationship chains and feedback loops outlining the complex dynamics of the user acceptance of AR technology in the engineering and construction sectors. Each relationship chain has interconnected pathways that collectively illustrate the successful integration of AR. Using the causal loop diagram to outline the relationship chains and feedback loops, this analysis identifies that the user acceptance of AR technology is not just one item but the interconnection between technology, organisational processes and internal and external stakeholders. A detailed review of the relationship chains and feedback loops is provided

below, supported by the literature, primary data collected through the grounded theory approach and principles from DeLone and McLean's IS success model.

5.2.2.1 Early adoption and success chain

The relationship chain for early adoption and success is illustrated in Figure 5.2.



Figure 5.2: Relationship chain 1: Early adoption and success

The early adoption and success relationship chain for the construction and engineering sectors illustrates that the main areas for this relationship chain include early adoption, project management and deliverables, stakeholders, communication and collaboration. This relationship chain acts as a catalyst for the successful integration of AR technology. It is highlighted that *'there is no set way that they do things that this sort of technology can kind of stand up. And it won't be until that's more common place that more people get on board. So finding those early adopters is going to be a sort of real key'* (E10). This data extract highlights the need to find early adopters and set a standard for new technology integration. It is also noted that organisations that effectively encourage early innovative adopters set a positive precedent for the acceptance of AR technology and increase expert skills.

The early adopters and success relationship chain is derived from this research in relation to the engineering and construction sectors, demonstrating that the early adoption of AR technology has many benefits. This is consistent with the literature, as Han and Clevenger (2025) highlight that AR technology is mature enough to bring benefits to construction projects, and according to Rohil and Ashok (2022) and Yunus et al. (2025), it is vital for organisations and stakeholders to accept innovation through the use of new technology and trends. Furthermore, Arowoiyaa et al. (2021) highlight that there are crucial success factors for AR technology use, and one of the factors includes the need for innovativeness in project execution. DeLone and McLean's IS success model (DeLone & McLean, 2003) aligns with these findings, as it details how users and systems correlate to net benefits.

The relationship chain identifies an early adoption approach for the user acceptance of AR technology. This chain begins with early technology adoption and outlines the need for an organisational approach to digital transformation in real-world projects. However, there is

often apprehension and resistance to change (Kolaei et al., 2022). The successful integration of AR technology relies on organisations being open to innovation and identifying early adopters (Arowoija et al., 2021). Therefore, it is demonstrated that early adopters provide benefits that accelerate digital transformation within organisations.

5.2.2.2 Knowledge and stakeholder satisfaction chain

The relationship chain for knowledge and stakeholder satisfaction is illustrated in Figure 5.3.

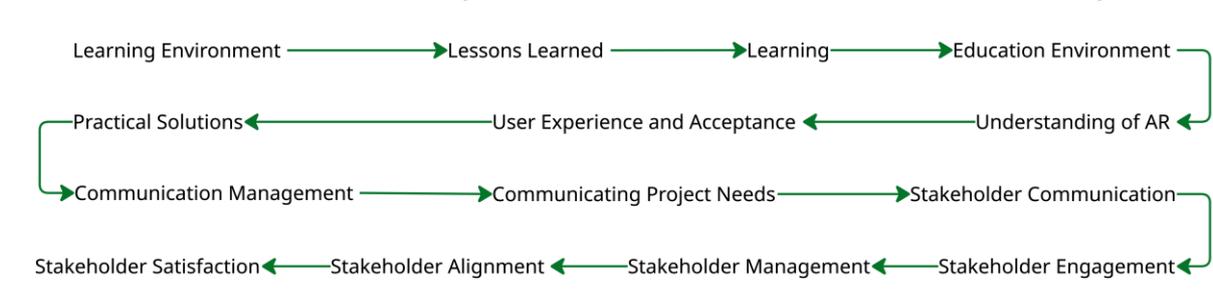


Figure 5.3: Relationship chain 2: Knowledge and stakeholder satisfaction

The knowledge and stakeholder satisfaction relationship chain for the construction and engineering sectors illustrates that the main areas of focus for this relationship chain include lessons learnt, understanding AR, communication and stakeholder requirements. The successful integration of AR technology is driven by the organisational environment for learning and education and by achieving stakeholder satisfaction through digital transformation. The data analysis highlighted the need for lessons learnt and to continuously educate the workforce.

The knowledge and stakeholder satisfaction relationship chain outlines that the learning environment, with lessons learnt, and the education environment, with understanding AR technology, are related to the user experience and user acceptance. It is identified that using AR technology for training is viable (Söbke et al., 2025) and that having professionally trained instructors is essential to using AR technology (Yunus et al., 2025). The following is noted in the data analysis: *'I think education around AR technology will be the driving factor for its use and growth moving forward'* (E5). Additionally, participant E2 stated the following: *'For being able to instruct people on what to do, how to learn in a physical environment, how to maybe look out for certain pieces of equipment when working in a very physical environment. So you know, a trade or manufacturing or something like that, that it would, yeah, I could definitely see the benefits, particularly in training.'* This indicates that showing users how to use this product is beneficial to project success. This relationship chain enables organisations and users to successfully implement AR technology and aligns with

DeLone and McLean’s IS success model, which highlights information quality and service quality as drivers for net benefits (DeLone & McLean, 2003) and hence user satisfaction.

As stakeholders’ satisfaction is crucial in this relationship chain and linked to knowledge, it is highlighted that stakeholder engagement is a critical enabler (Delgado, Oyedele, Beach, et al., 2020). In addition, an awareness of AR technology is essential for the full integration of AR technology with organisations (Arowoia et al., 2021). Therefore, it is necessary to ensure that the AR technology-related context is effectively communicated to stakeholders to facilitate smooth project delivery and stakeholder satisfaction.

5.2.2.3 User experience and acceptance chain

The relationship chain for user experience and acceptance is illustrated in Figure 5.4.

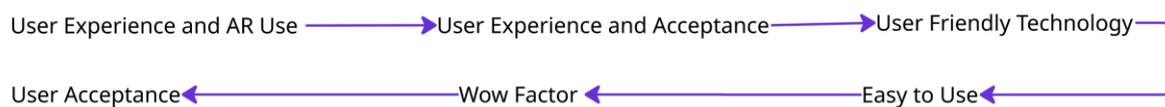


Figure 5.4: Relationship chain 3: User experience and acceptance

The user experience and acceptance chain for the construction and engineering sectors illustrates that the main areas of focus for this relationship chain include an immersive experience, user acceptance and easy-to-use, user-friendly technology. The data analysis has illustrated that AR technology is driven by the quality of the user’s experience and the usability of the system. When utilising AR technology in the construction and engineering sectors, there need to be tangible benefits, and users are likely to accept AR when the technology is supported.

One of the main factors identified from the data analysis that influences user acceptance is the experience the user has; additionally, this is supported by Rohil and Ashok (2022), who state that stakeholders have a better experience through AR technology. Furthermore, Hajirasouli et al. (2022) state that user acceptance and the user experience for AR technology are more effective in the early design stages. Again, user acceptance is about the technology being useful, engaging and easy to understand (Alkan & Basaga, 2023). This is further supported by participant S19, who discussed how user acceptance is related to ease of use: *‘to speak so large groups of the community consultation teams, right so that that acceptance, why speed and ease of use. But speed in which we can realise the sophisticated deployment for them and the deployment being I’ve got these models, I’ve got this data and I want you to put it in here. We can do that in a day. It’ll enter they’ll even get shorter right so that’s one of the major things that sort of like the wow factor, and acceptance*

like we need to do this quickly and make changes quickly. Acceptance Yeah.’ This is further supported by DeLone and McLean’s IS success model, which includes the system quality and user satisfaction (DeLone & McLean, 2003).

User acceptance is evolving and is identified through the user experience. However, user experiences can vary greatly, and organisations that implement AR technology early on can improve this. It is shown that it is important for stakeholders to be prepared to accept innovation through digital transformation and the identification of new technology trends (Arowoia et al., 2021), thus underscoring that user acceptance and the user experience depend on innovation and an immersive experience.

5.2.2.4 Performance and quality assurance chain

The relationship chain for performance and quality assurance is illustrated in Figure 5.5.



Figure 5.5: Relationship chain 4: Performance and quality assurance

The performance and quality assurance chain for the construction and engineering sectors highlights that the main focus areas include performance, quality assurance, quality control and continuous improvement. When utilised in construction and engineering projects, AR technology requires quality assurance and ongoing improvement through performance, quality assurance and project management processes. AR technology allows organisations to transition from traditional reactive quality control to innovative digital transformation via proactive detection systems and real-time feedback data systems.

Integrating AR technology reduces human error and enhances data reliability in the workflow by identifying key limitations (Bórquez et al., 2025). Additionally, AR technology enables hazards to be removed without any human interaction (Rohil & Ashok, 2022), and the early detection of any defects prevents additional labour and rework costs and saves time (Hajirasouli et al., 2022); in addition, issues can be identified before they happen. It is also illustrated that AR technology can facilitate the detection of defects and address them in real time (Liao & Luo, 2025). Participant C17 outlined that when using AR technology in construction, they want to know about issues beforehand during the design phase: *‘So I think in our work related experience is really about like, we have a 3d model about, you know, the building, somewhat spent a long time to design it and, you know, company*

constructed. I think it's really about the you know, we want to work by or even find some issue before, you know, we, I mean, it's about the quality not only in the 3d model, it looks perfect, but in case you know, if there's something happened when you build it, we want to work fine if it is built according to the design intent. So this kind of like QA QC process.' Therefore, AR technology plays a vital role in addressing quality management.

Grounded theory outlines that the AR technology performance and quality assurance process is an evolving process, and DeLone and McLean's IS success model provides a theoretical lens through which to view the chain, considering the system quality, information quality and user satisfaction with net benefits (DeLone & McLean, 2003). Utilising AR technology and understanding performance and quality assurance ensures that quality standards are integrated, and there is an expectation that this will constantly evolve through continuous improvements, aligning with Han and Clevenger (2025), who highlight that AR technology provides productivity and quality improvements. Furthermore, AR technology has been demonstrated to result in improved efficiency, precision and user satisfaction (Bórquez et al., 2025).

It is evident that the performance and quality assurance chain transforms quality management into a proactive, real-time process. Utilising grounded theory and DeLone and McLean's IS success model highlights that AR technology enables defects to be detected immediately and contributes to project success by reducing costs, labour and defects while improving time efficiency (DeLone & McLean, 2003).

5.2.2.5 Stakeholder and project success chain

The relationship chain for stakeholder and project success is illustrated in Figure 5.6.



Figure 5.6: Relationship chain 5: Stakeholder and project success

The stakeholder and project success chain for the construction and engineering sectors highlights that the main focus areas include stakeholder and communication management for project success. Stakeholder engagement for AR technology addresses the stakeholders' needs and expectations concerning digital transformation and innovation.

It is clearly articulated by participant S19 that communication and stakeholder engagement are essential for project success: *'So two things on which work together, which is one being the communication tool. And for people to understand what they can expect to see in their local landscape, or, you know, like, in the story of, you know, taking it to community consultations, and letting stakeholders see, you know, what, for especially large infrastructure projects, how, yeah, you know, adding an element of transparency, but also, you know, enhancing the level of communication between private or public companies, with interested stakeholders, compared to having to do lengthy processes, often in photogrammetry, which is your traditional way of doing Photoshop on a strict viewpoint, you know, using augmented reality really takes that level of communication, transparency.'*

Dalgado et al. (2020) outline that integrating AR technology relies on stakeholders having a clear understanding of the end product, thus leading to stakeholder alignment and facilitating clear communication between stakeholders and strong alignment. Hajirasouli et al. (2022) state that AR technology helps align objectives, while Delgado et al. (2020) emphasise that stakeholder engagement is a vital enabler of communication and alignment, highlighting the importance of AR technology success in stakeholder and communication management.

The relationship chain for stakeholder and project success emerged from the grounded theory approach, which involved the open coding of interviews and open-ended question survey questionnaires. This analysis highlighted that stakeholder satisfaction is correlated with effective communication and project success. It is also noted that DeLone and McLean's IS success model is applicable to net benefits, and when AR technology delivers benefits with tangible results, it enhances project success and innovation (DeLone & McLean, 2003). This is further outlined by Han and Clevenger (2025), who state that there is strong confidence in AR technology expectations and benefits, thus further supporting the stakeholder and project success chain.

The stakeholder and project success chain contributes to successful AR integration in the construction and engineering sectors. The use of grounded theory has contributed to this research through data analysis, resulting in one of eleven chains.

5.2.2.6 Organisational deliverables and success chain

The relationship chain for organisational deliverables and success is illustrated in Figure 5.7.

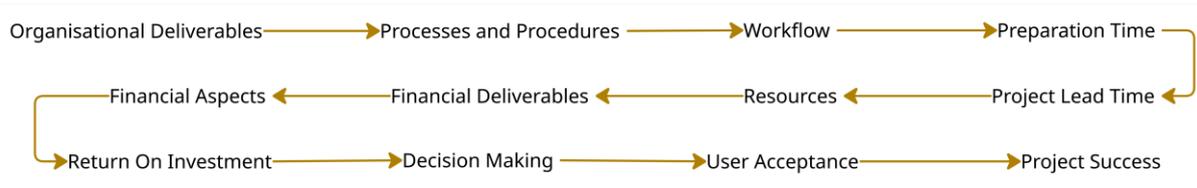


Figure 5.7: Relationship chain 6: Organisational deliverables and success

The organisational deliverables and success chain for the construction and engineering sectors highlights that the main focus areas include organisational processes, resources and decision-making for project success. Implementing AR technology relies on resources, clear processes and procedures, and decision-making.

It is highlighted that not clearly embracing digital technology effectively is the primary reason that AR technology is not fully adopted (Alkan & Basaga, 2023), and a critical enabler of this is organisational factors. It is also noted that budget constraints can hinder AR technology adoption as well (Yunus et al., 2025). This is also evident from participant E10, who outlined how organisational deliverables like resources and processes can hinder innovation in projects: *'Personally, myself, I like to get involved in these things kind of as early as possible. But as you're sitting in most businesses, these days, there's a lot of pressure to deliver, and a lot of lack of resources, and all those sorts of things. And that kind of prevents people from exploring and investing in new ways of doing things. So it's only an environment that really, there is no set way that they do things that this sort of technology can kind of stand up. And it won't be until that's more common place that more people get on board. So finding those early adopters is going to be a sort of real key. Because people don't really know as much as they talk about innovation and things like that. It's hard to be the first people easier use like, particularly in aerospace, like you want to use proven systems and technologies rather than being trailblazers.'*

By integrating grounded theory, open codes were used to code interviews and open-ended survey questionnaires. Common themes include processes and procedures, resources, the ROI, user acceptance and project success. The data have demonstrated that success relies on many different aspects of AR integration, and for the organisational deliverables and success chain, resources and processes are important. DeLone and McLean's IS success model supports these data through the service quality, system quality and information quality (DeLone & McLean, 2003). It has been found that AR technology is a cost-effective approach that can be integrated into projects of various sizes to contribute to digital technology advancements (Bórquez et al., 2025).

For this particular relationship chain, for the successful project implementation of AR technology, the data analysis indicated that user acceptance, resources, processes, procedures and decision-making are vital. In addition, barriers include implementation costs, limited benefits (Bórquez et al., 2025) and incorrect decision-making due to poor information being provided (Harikrishnan et al., 2021).

Therefore, organisational deliverables and success contribute to successful AR integration in the construction and engineering sectors through improved decision-making, adequate resources, effective processes and procedures that result in user acceptance. The use of grounded theory has supported this research through data analysis, resulting in one of eleven chains.

5.2.2.7 Technology challenges and user acceptance chain

The relationship chain for technology challenges and user acceptance is illustrated in Figure 5.8.

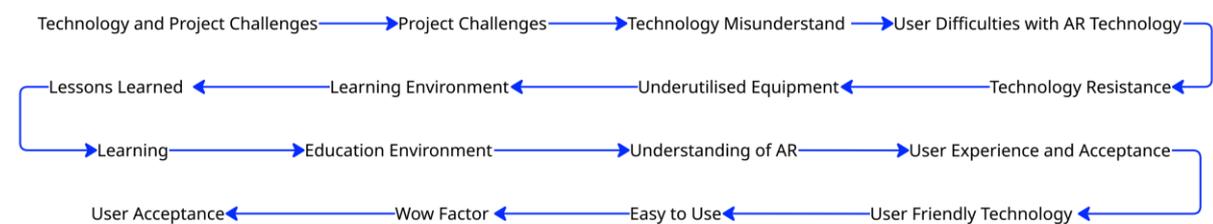


Figure 5.8: Relationship chain 7: Technology challenges and user acceptance

The technology challenges and user acceptance chain for the construction and engineering sectors highlights that the main focus areas include project challenges, technology challenges, learning and the educational environment, and user-friendly technology that is easy to use. The main inhibitors include a lack of accuracy and the lack of a comprehensive AR system.

The chain highlights that technical limitations impact user acceptance, and this is evident in accuracy limitations. Participant S19 highlighted that technology limitations, such as accuracy limitations, can affect user acceptance: *'and there is accuracy, right? So, accuracy of these particular types of products is limited, and it's limited somewhat in terms of the nature of telco towers, it's limited by satellite, you know, devices, and the cost associated to bringing all of those things together to create certain levels of accuracy. So that can also be it's a natural or current limitation of these types of products in in in infrastructure projects is*

that they may not be accurate enough for some requirements or, or we've misaligned the expectations with the client in terms of accuracy. They believe that of course, they see it there, they're gonna go, that's millimetre perfect and might not be exactly.' Rohil and Ashok (2022) outline that capturing accurate results is critical and that inaccuracies can hinder user adoption. Additionally, limitations in the 3D modelling positions and sensors for AR technology can reflect inaccurate data and modelling (Bórquez et al., 2025). Furthermore, software immaturity can complicate user acceptance (Schmitt et al., 2025) and integrating real-time data is challenging with data accuracy and reliability (Contini et al., 2025).

There are many factors that influence technological limitations, and having the right education can prevent user misunderstandings. This is made evident by participant S29, who outlined that there are many different types of digital transformation, and this often becomes confusing: *'you know, we go out and demo it all the time, we might be in front of a boardroom table of major infrastructure, people doing that, and you'll get it from a variety of different I've never used VR, is it? I don't know what VR is. Is it VR/AR? What the hell is XR?'*

Using grounded theory, limitations when using AR technology were identified, including hardware limitations, as outlined by participant S14: *'I think it's huge opportunities for VR headsets and AR headsets. But there's a few limiting factors at the moment, which makes it a little bit difficult. And as you mentioned before the glasses need to get smaller and a bit more accessible.'* Additionally, limitations include the preparation time, as detailed by participant C17: *'And the prep time, the preparation time, it's very long. I'm not talking about like, one day, I mean, even if you need me to just prepare a model using an hour, I still really hesitate, because, you know, I just want to use it straight away.'* It is noted that DeLone and McLean's IS success model highlights that system quality is needed for user satisfaction and net benefits (DeLone & McLean, 2003).

Delgado et al. (2020) outline that the construction workforce lacks trained staff, and upskilling is required. It is also noted that the lack of skilled staff is the main reason companies face challenges (Han & Clevenger, 2025). Therefore, user acceptance is reliant on adequate training and education to ensure that these challenges are mitigated, as detailed by participant E5: *'I think education around AR technology will be the driving factor for its use and growth moving forward.'*

The technology challenges and user acceptance chain outlines that technical and project challenges need to be identified, alongside proper educational and learning environments.

Organisations also need to recognise that any new digital technology integration comes with initial teething problems, which can be overcome with the right learning and educational environments.

5.2.2.8 Data management and success chain

The relationship chain for data management and success is illustrated in Figure 5.9.

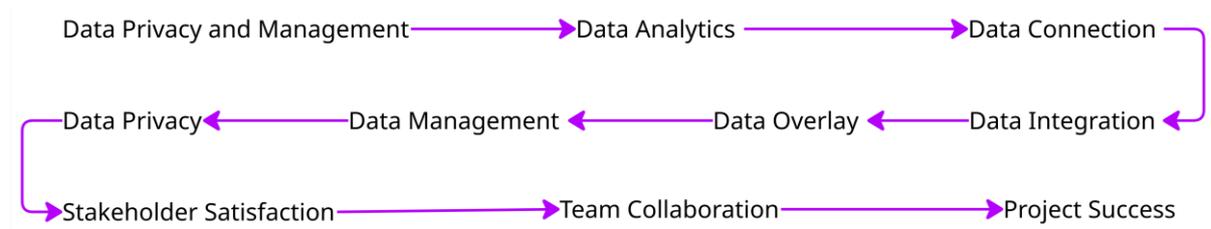


Figure 5.9: Relationship chain 8: Data management and success

The data management and success chain for the construction and engineering sectors highlights that the main focus areas include data privacy and management, as well as stakeholder satisfaction and team collaboration.

Real-time data are essential for AR technology in managing engineering and construction projects. Effective data integration, privacy and analytics ensure that AR can deliver immersive visualisation with real-time data and project success. It is evident that accurate real-time data and visual monitoring heavily depend on precision and the frequency of updated data (Liao & Luo, 2025). Additionally, having data management in place ensures data privacy and accurate data integration, as outlined by Degado et al. (2020), who state that there is a pronounced need for data security and data ownership.

Through grounded theory, the coding of interviews and open-ended survey questionnaires highlighted relationships with data analytics and data management, including data connection, data integration, data overlay, data privacy and legacy systems. Therefore, the relationship chain for data management and success was established. DeLone and McLean's IS success model outlines that the information quality, system quality and service quality drive user satisfaction and net benefits (DeLone & McLean, 2003). It is noted that stakeholder satisfaction is supported by AR systems that improve accuracy with real-time visualisation and data sharing through team collaboration, which enhances precision and efficiency (Bórquez et al., 2025). This is further justified by participant E4's response outlining the precision required in the manufacturing industry: *'a good application of it was when we would work on aircraft parts and drilling holes in the right location. So if the if*

augmented reality helped us overlay like a map of the holes in the right locations, it would give us a good sense check of where to drill them as a practical example. So it would have lots of applications in manufacturing.'

Participant C8 highlighted that data privacy and security is a large barrier if it is not integrated correctly: *'Barriers might include like, security, privacy, what else the cost, cost of what is going to also learning curve, so people might not know how to use it properly, and it'll just be It's all new to them. Security would be a big problem with tech, with any technology.'*

However, project success is reliant on many factors, and privacy and security are among them. Real-time data integration is also essential for quick decision-making (Han & Clevenger, 2025), ensuring stakeholder satisfaction through communication and team collaboration, as outlined by participant E10: *'And that's, you know, standing in a blank room, being able to put the headset on someone and say, This is what we're thinking as a communication tool as a sales tool, or from a maintenance perspective, where you can say, hey, our plan is to get in there and make sure that people know exactly what they're doing, without the constraint of having to have users or agents documents everywhere, and all that sort of stuff. So that data kind of two levels that would drive me to sort of say, Hey, I think we need this. I'm sure there are other uses for it. But there are two that springs to mind for me.'*

Therefore, the data management and success chain emphasises the need for a secure, efficient data management system for construction and engineering projects. The relationship chain, as demonstrated through grounded theory and supported by DeLone and McLean's IS success model, highlights the connection between data privacy, management, data integration, connectivity and analytics, all aligned with stakeholder satisfaction and team collaboration (DeLone & McLean, 2003).

5.2.2.9 Expert skills and knowledge chain

The relationship chain for expert skills and knowledge is illustrated in Figure 5.10.



Figure 5.10: Relationship chain 9: Expert skills and knowledge

The expert skills and knowledge chain for the construction and engineering sectors highlights that the main focus areas include expert skills and development, training, learning and the educational evolution that aligns with project success.

One of the findings in the relationship chain is the importance of ensuring that there are expert skill sets available. Skilled personnel are required to design and set up the technology, in addition to troubleshooting any identified issues and ensuring the AR systems is working accordingly. It is noted that there is a lack of skilled personnel and training, and upskilling is required (Delgado, Oyedele, Beach, et al., 2020; Hajirasouli et al., 2022; Han & Clevenger, 2025). It is also evident that there is a large amount of work that needs to be done for coursework integration with AR technology (Giancaspro et al., 2025). Familiarisation with AR technology is essential for emerging AR technology adoption (Arowoia et al., 2021; Harikrishnan et al., 2021).

This was also evident in the data analysis and grounded theory, where open codes were established and grouped into axial codes. Some examples include expert skills and lessons learnt. When analysing the data and reflecting on how these data relate to the literature review and relationship chain, participant E10 outlined that when utilising AR technology, skill sets are required: *'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 kind of 3d modelling system into a space, and that's a pretty specific skill set to be able to have.'* Additionally, when using software developers to create bespoke AR applications, the project requirements are necessary, as detailed by participant S21: *'when we're scoping out a project, we scope it out in regards to what we need to do on a technical perspective. And we also really get clarity from the client as to the nuts and bolts of what they need us to develop. And then we work very closely with them because we're creating something bespoke for their use case.'* It is noted that DeLone and McLean's IS success model identifies the service quality and user competence as factors influencing user satisfaction and net benefits (DeLone & McLean, 2003). This is supported by the data analysis and literature review.

Therefore, the expert skills and knowledge chain emphasises that expert skills are crucial for the successful integration of AR technology. As this technology becomes more established in the construction and engineering sector, AR will continue to evolve. Grounded theory and DeLone and McLean's IS success model demonstrate that the successful integration of AR technology depends on expert skills and knowledge (DeLone & McLean, 2003).

5.2.2.10 Project management and success chain

The relationship chain for project management and success is illustrated in Figure 5.11.

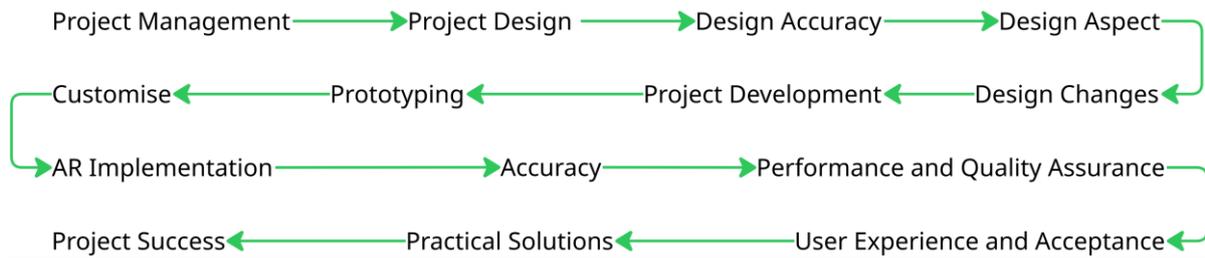


Figure 5.11: Relationship chain 10: Project management and success

The project management and success chain for the construction and engineering sectors emphasises that the main focus areas include project management, project development, performance and quality assurance. AR technology adoption requires project management with a proactive approach to digital transformation and innovation. For AR integration, the linked stages include effective project management, which relies on project design accuracy and change management; furthermore, project development and ensuring the performance and quality of AR systems are in place to guarantee user acceptance and project success.

It is evident that AR technology increases labour productivity and accelerates digitalisation processes (Alkan & Basaga, 2023), highlighting that project management is more efficient when it is well organised. In addition to effective project management, integrating AR technology reduces costs and saves time through efficient planning and the control of materials, machinery and resources (Hajirasouli et al., 2022). It is also noted that tasks were completed faster using AR technology (Alkan & Basaga, 2023), supporting AR technology implementation, accuracy, performance and quality assurance. Additionally, the use of AR technology highlighted the inadequacy of 2D drawings and manual inspections, which fail to meet real-time requests (Liao & Luo, 2025). Furthermore, the use of AR technology enables accurate designs and digital prototypes that can be analysed in real time with minimal costs (Arowoia et al., 2021).

This is also evident in the data analysis and grounded theory, where open codes were established and grouped into axial codes. The data analysis from grounded theory forms the relationship chain. Participant C16 highlighted project management on a construction site and how AR technology is utilised and managed with project design and project intent: *'The first one is for as as built verification, so it's like getting instant, or, you know, progressing review. So we're bringing the model on the phone, or the iPad, and it will bring on site and we overlay with existing the store has in store condition to check is displacing. Or at least it*

you know, depending on the accuracy of that model, we will at least to see whether the object sits in relatively close location as per the design intent. That's the one thing we do for verification, the other is for a check. So like the one case that we're using the project is there. They are going to install a very complicated steel structure on the roof. And they want to see and check and inspect whether the the fixing items and details were there and they're in the accurate position. So we will bring the steel structural model including all these particular details, fitting details, and then we will position the AR model using QR code to get more accuracy into the overlay and check whether these positions are correct or not. At this same time, the team can use it to see what's coming up in the next few weeks, because they can see the whole model whereas not just one For or, you know, where it's not just 2d drawings on on paper.' Furthermore, participant C17 highlighted how prototypes are used in construction: *'it's more about like, when you want it, we did discuss the realistic one, you know, interview with the environment and discuss, you know, the design, but how many clients would wear these kinds of Reality Devices to discuss this. Some of them will prefer to just make a prototype, as you mentioned about like these prototypes, they were just trying to make a physical prototype instead of like jumping into AR/ VR.'*

According to DeLone and McLean's IS success model, the system quality, information quality and service quality all impact user success and net benefits (DeLone & McLean, 2003). Leveraging this AR technology integration enables prototyping and design accuracy, driving user acceptance and leading to user benefits, digital transformation and innovation.

The relationship chain for project management and success is driven by project success through design reviews and innovation. With each project, success becomes a lesson learnt and provides knowledge in the management and design stages for AR technology. Grounded theory and DeLone and McLean's IS success model demonstrate that the successful integration of AR technology is linked to project management, project development, performance and quality assurance, all of which must be achieved to demonstrate success (DeLone & McLean, 2003).

5.2.2.11 Technology advancements, user acceptance and success chain

The relationship chain for technology advancements, user acceptance and success is illustrated in Figure 5.12.

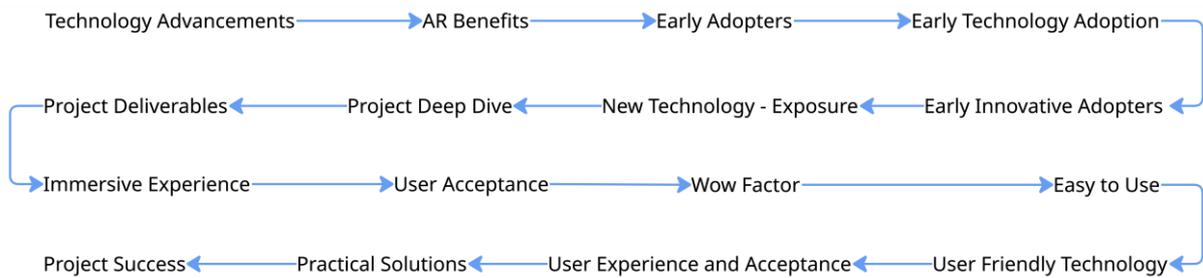


Figure 5.12: Relationship chain 11: Technology advancements, user acceptance and success

The technology advancements, user acceptance and success chain for the construction and engineering sectors emphasises that the main focus areas include technology progress, early adopters, exposure to new technology, project deliverables, user acceptance and experience. AR technology advancements and user acceptance rely on the capabilities of hardware and software integration.

It is noted that a core driver for AR integration is the rapid growth of AR technology (Ghorbani et al., 2024), and when AR technology is utilised in construction, the key enablers of user acceptance are integration with BIM, real-time data monitoring with defect detection and collaboration requirements (Alizadehsalehi et al., 2020; Liao & Luo, 2025). It is highlighted that AR technology is easy to use and understand, and it has been observed to be engaging and useful (Alkan & Basaga, 2023). Again, it is noted that user acceptance is based on defect detection, visualisation and having an immersive experience (Hajirasouli et al., 2022).

This was also evident in the data analysis through grounded theory, where open codes were established and grouped into axial codes. The data analysis from grounded theory formed the relationship chain for technology advancements, user acceptance and success. Participant C17 highlighted that user acceptance is related to practical solutions and what this can bring to the project: *‘it’s really about the benefit that it brings to them? Like you know, like a construction manager would we want to know whether the thing that would be according to design time, but you know, the engineers we like to know whether the factory has fabricated, the exact piece that they needed so it’s really depending on what benefits it’s bringing to the user. The construction manager does not care about, the specific piece because overall speaking when everything is correct, it should build up something that when they used the device it over lays that correctly similarly saying he’s not really down to the detail details of the parts but the trays engineers or you know, maybe our engineers when*

we you know, want to know whether, you know, this piece that shipped from the factory is it built according to the specification and requirements needed so it's different people have different grow even benefits.'

Data analysis using grounded theory also showed that technological advancements support project success by enabling the delivery of project outcomes. Participant E3 emphasised that reducing the time required to complete a complex task is a key benefit: *'So I think it's about, what we found really good is we've got a few practical applications where we're using it. So we have one application where we need to install power pins to hold a skin on the job while we present the part to the robot and across the skin, which is in the order of three meters by sort of nine meters. So it's quite big. There is various length pins in various different locations. And so we use the VR goggles to overlay the pin lengths at the various holes. So rather than an operator having to go and walk back look at the drawing and see, okay, there's medium pins in these four holes, then go walk back to the part and identify where those four holes are with the goggles on it. Just they look at the hole and it tells them what length faster goes in there. So we found that first when they were sort of trying in it, they were like, Oh, this is a really crappy job. It takes forever. And we said, we're gonna go get you the goggles, and the first operator put them on, and it's like, oh, this is awesome.'*

In reference to DeLone and McLean's IS success model, it is evident that the system quality, information quality and service quality impact user success and net benefits (DeLone & McLean, 2003). Leveraging this AR technology integration enables a positive experience and user-friendly technology that is easy to use, directly influencing user acceptance and project success.

Therefore, the relationship chain for technology advancements, user acceptance and success is essential for integrating AR technology and digital transformation. As outlined in the data, a good user experience and user acceptance are required for a strong positive outcome, which is supported by grounded theory and DeLone and McLean's IS success model, demonstrating that technology advancement and user acceptance are linked to project success (DeLone & McLean, 2003).

5.2.2.12 Communication feedback loop

The feedback loop for communication is illustrated in Figure 5.13.



Figure 5.13: Communication feedback loop

The communication feedback loop for the construction and engineering sectors emphasises that the main focus areas include communication and stakeholder management. Quality communication with all stakeholders is essential for successful AR technology integration, effective stakeholder collaboration and overall satisfaction and alignment.

Effective communication is essential when implementing AR technology, particularly when numerous stakeholders are involved. Therefore, effective communication through AR technology adds value by providing real-time, transparent visual data displays. This is further explained by participant S19, who outlined that communication can be enhanced with a visual component: *‘So two things on which work together, which is one being the communication tool. And for people to understand what they can expect to see in their local landscape, or, you know, like, in the story of, you know, taking it to community consultations, and letting stakeholders see, you know, what, for especially large infrastructure projects, how, yeah, you know, adding an element of transparency, but also, you know, enhancing the level of communication between private or public companies, with interested stakeholders, compared to having to do lengthy processes, often in photogrammetry, which is your traditional way of doing Photoshop on a strict viewpoint, you know, using augmented reality really takes that level of communication, transparency.’*

Delgado et al. (2020) emphasise that effective communication and collaboration foster a higher level of stakeholder understanding and productivity. It is also recognised that AR technology effectively communicates context to personnel who work on- or off-site and at different locations by aiding in reducing any misunderstandings (Harikrishnan et al., 2021). This is further elaborated by participant E10, who emphasised the importance of communication with AR integration: *‘So project management is all about communication, like very heavily communication, like 90%. So having another communication tool, whether it be for stakeholders, or subcontractors, or end users is really quite valuable.’*

Integrating AR technology offers many benefits, primarily driven by the need for improved communication. Some advantages of AR technology communication include improved stakeholder collaboration and on-site visualisation (Arowoiyi et al., 2021; Arvikar et al.,

2025; Bórquez et al., 2025). As found using the grounded theory approach during the collection of primary data, participant E10 stated that AR technology is a communication tool, and utilising AR technology stems from a need: *'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 like conveyancing say you're doing maintenance on aircraft or something in your had a setup is familiar with inside the landing gear augmented reality could point a maintenance person to a particular line to say that's what you need to do, and bring up information that actually shows what they need to do step by step.'*

According to DeLone and McLean's IS success model, the system quality, information quality and user success (DeLone & McLean, 2003) highlight information systems that reflect a communication feedback loop, which was collected through grounded theory. Leveraging DeLone and McLean's IS success model, it is evident that the communication feedback loop supports this.

It is evident that communication is essential for integrating AR technology. Both grounded theory, based on primary data, and the literature review, which includes DeLone and McLean's IS success model, support this.

5.2.2.13 Knowledge and lessons learnt feedback loop

The feedback loop for knowledge and lessons learnt is illustrated in Figure 5.14.

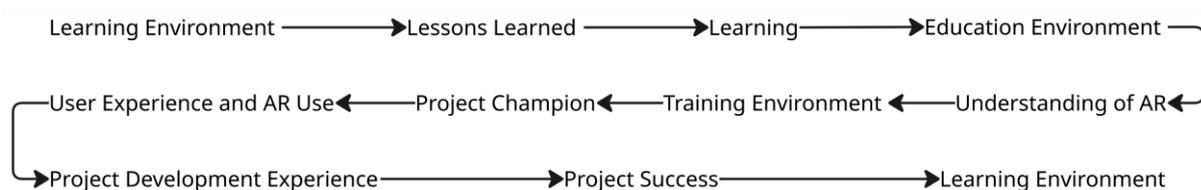


Figure 5.14: Knowledge and lessons learnt feedback loop

The knowledge and lessons learnt feedback loop for the construction and engineering sectors emphasises that the main focus areas include education, learning and the training environment, along with the user experience and user acceptance. AR technology integration and success are driven by knowledge, education, training and learning, and ensuring that knowledge is shared with lessons learnt contributes to an evolving cycle of project growth.

This feedback loop provides comprehensive training and educational resources that explain how to properly utilise AR technology. Moreover, fostering an environment that encourages continuous learning is essential, as it helps keep everyone informed about the latest developments and best practices in AR technology implementation.

There is a lack of adequate knowledge in AR technology, indicating a lack of training and understanding (Hajirasouli et al., 2022). Effective communication allows individuals to communicate the numerous benefits of AR technology, illustrating the value it brings to the project. Therefore, it is essential to educate the target audience about what AR technology can do for them. This was also made evident by participant S18, who stated that educating the target audience is essential for integrating AR technology: *'So the person who is directly involved in the purchasing decisions, they need to understand what it is and what it can bring to them. And who will be the target audience and what they can do. So even you show them a lot of advantage of doing this, this can add a lot of value. But many times they will be like now, because maybe they they're lacking knowledge or maybe they don't know what what can be done or how their target audience will react. Yeah, let me do a little bit educate themselves before they get something out of it. So yeah, so education. big factor.'*

It is outlined that using AR technology applications is a feasible method in workplace safety (Söbke et al., 2025), and a better understanding of AR technology is facilitated through a practical training environment (Han & Clevenger, 2025) and through visual data (Yin et al., 2023). Participant E3 highlighted that integrating AR technology in the engineering environment requires trained and skilled personnel, which in this case would be engineers who train the shop floor users: *'so my experience with it is obviously just being on the floor and grabbing the goggles from the people who'd set it up, so our robotics Mechatronics guys and helping the operators use them. So my role, I guess, was more facilitating the implementation of them onto the floor, yeah. But that said, I found them equally quite easy to sort of learn how to use, and I found it quite easy to pick the technology up.'*

When integrating AR technology, it is important to have a project champion to deliver training and knowledge. This is outlined by participant S14: *'where there was the main person through the whole project, he was then the one that we would then train and then show, and then he was the one who could do the troubleshooting and things. So that he could be the person that would then people could go to him and ask the questions. And then if he couldn't figure it out, he didn't come back to us. But having that one person who's that champion does make it a lot easier.'* This is further supported by Han and Clevender (2025), who state that a practical approach to training is better absorbed by participants; additionally, having a

better understanding of AR technology aligns stakeholders' expectations (Delgado, Oyedele, Demian, et al., 2020). However, it is noted that there is a lack of trained staff who can successfully deliver AR technology (Hajirasouli et al., 2022; Yunus et al., 2025).

According to DeLone and McLean's IS success model, it is evident that the system quality and information quality impact user success and net benefits (DeLone & McLean, 2003). When it comes to leveraging this AR technology, it is evident that the knowledge and lessons learnt feedback loop supports this.

Effective knowledge and lessons learnt stand as vital components in the success of any project, especially regarding the integration of AR technology. It is crucial to recognise that technology is in a constant state of evolution, characterised by regular updates and improvements. Therefore, ensuring that these advancements are shared effectively with all stakeholders is imperative.

Based on the research analysis of the user adoption of AR technology in the engineering and construction sectors, the data reveal a series of interconnected relationship chains and feedback loops. This results in a comprehensive causal loop diagram that visually illustrates how AR technology is adopted within these sectors.

5.2.3 Proposed framework for AR technology integration

The theoretical integration of the findings has emerged from both the data analysis and the current literature reviewed during the research. The respondents support the framework and relationships identified in the study, aligning well with the established literature and theories to further support the results.

The framework proposal was derived from the data analysed; it was formulated based on the codes, themes and relationships from the data analysis. This includes 248 open codes, 48 axial codes and 18 selective codes. From the coding process, relationships were formed. The relationships and theory derived from grounded theory encompass four key categories: organisational deliverables, project input and technology input, project output and communication and knowledge. From the data derived, there are six key findings. This is outlined in the following section: the framework proposed has four sections and six key proposed findings. This is all examined within the current literature and contributes to

answering the following research question: 'What are the dynamics of the user acceptance of AR technology in engineering projects?'

The data analysis outlines the proposed framework for engineering and construction projects incorporating AR integration. This data analysis has been conducted alongside the proposed framework within organisations. This framework incorporated three sections: organisational deliverables, project and technology inputs and project outputs. These three areas then have 18 relationships, with two relationships providing a feedback loop.

In relation to the research question – what are the dynamics of the user acceptance of AR technology in engineering and construction projects – the successful implementation of AR technology in engineering and construction projects depends on several critical factors. First, it involves clearly defined organisational deliverables, which include organisational deliverables and the project scope, financial deliverables, legal and regulatory deliverables and safety. These deliverables set the foundation for organisational deliverables and what needs to be accomplished.

In relation to organisational deliverables, it is highlighted that the insufficient advancement of AR technology is due to organisations not embracing digital technology (Alkan & Basaga, 2023). Financial deliverables must be outlined, as there is an initial cost associated with implementing this technology (Harikrishnan et al., 2021). It is further noted that AR integration requires contracts that are collaborative (Han & Clevenger, 2025), and AR technology improves workplace safety and can be used to remove unwanted hazards (Rohil & Ashok, 2022).

Second, the inputs related to both the project and the technology play an essential role. This includes project inputs, early adopters, project management, the specific use case and expert skills and development. Regarding technology inputs, this includes software and hardware integration, AI, automation and 3D environments, data privacy and device interaction. Properly assessing these inputs ensures that the necessary project and technology inputs are in place to facilitate the user acceptance of AR.

In relation to project inputs, AR technology is useful for improving project management (Sangiorgio et al., 2020); for a specific use case, AR technology facilitates real-time data feedback, therefore reducing defects (Liao & Luo, 2025). For expert skills, it is noted that

there is a lack of skilled staff who can support the integration of AR technology (Han & Clevenger, 2025).

In relation to technology inputs, software integration includes AR technology being compatible with other current systems, which may include BIM, a technology commonly used in construction (Liao & Luo, 2025). With hardware integration, HMDs are often utilised with AR technology, with a usage time of around 2 hours (Alkan & Basaga, 2023). AI integration makes it clear that this technology will be used with AR technology going forward (Ahn et al., 2019). Alizadehsalehi and Yitmen (2019) highlight that AR technology is a process that is automated in real time. However, data privacy and management are essential for AR technology input, as there are always data security concerns (Delgado, Oyedele, Beach, et al., 2020).

Third, the outputs of the project include the user experience and AR use, technology advancements, technology challenges, performance and quality assurance. This section explores the impact of AR technology on the project and examines how it influences user acceptance.

In relation to project outputs, it is evident that AR technology enables an immersive visual experience (Schmitt et al., 2025), and with technology advancing rapidly (Ghorbani et al., 2024), it is essential that the challenges and benefits of AR are fully understood. The benefits include enhancing decision-making and problem solving (Hajirasouli et al., 2022), and there are challenges such as the limited skills of personnel and an untrained workforce (Delgado, Oyedele, Beach, et al., 2020); this aligns with performance and quality assurance using AR technology, which can detect defects early on and prevent rework (Hajirasouli et al., 2022).

Lastly, it is essential to consider the feedback loop that integrates communication, knowledge sharing and the lessons learnt throughout the project lifecycle. This aspect plays a crucial role in influencing user acceptance, as effective communication is foundational to any successful project. The feedback loop highlights that communication, learning, education and the incorporation of lessons learnt are pivotal in enhancing user acceptance and driving project success.

In relation to knowledge and learning, AR technology is a sufficient method in terms of workplace safety (Söbke et al., 2025), and a practical training environment enhances the understanding of AR technology (Han & Clevenger, 2025). Delgado et al. (2020) outline that

collaboration and communication enhance cognitive understanding and increase productivity among stakeholders.

Finally, combining a well-structured approach to project deliverables, the project management of technological inputs and a focus on user acceptance through effective techniques is crucial for the successful adoption of AR in the engineering and construction sectors. This multilayered strategy enhances not only the efficiency of project execution but also the overall acceptance and integration of AR technologies within the organisation.

In addition to the framework and the data that have been analysed, various relationships that impact the use of AR technology can be identified. These relationships illustrate how the open, axial and selective codes contributed to the effectiveness of AR use through grounded theory.

5.3 Gaps in Research

The research findings outline significant gaps, which include a lack of validation in real-world scenarios, immature frameworks, unskilled end users and a lack of education concerning AR technology (Delgado, Oyedele, Demian, et al., 2020; Kolaei et al., 2022; Sangiorgio et al., 2020). Many of these items can be addressed at an academic level, where digital technology can be introduced early, before students enter the workforce. This is further elaborated through integration with academia, skill development, innovation in research and collaboration with organisations to enable students to learn how to use AR technology for appropriate work.

5.3.1 Skill development

AR technology requires specialised skills and expertise to develop and use. This extends beyond current practices in design, construction and engineering and requires adequate training and education. AR technology enables 3D immersive interaction with real-time data (Schmitt et al., 2025). However, the benefits are obtained when AR skills are developed and AR is integrated with other platforms, such as BIM for construction. Skill development in digital technology is crucial, and a lack of skill development can lead to underutilised AR technology and inefficiency in projects.

Therefore, skill development is essential for AR technology adoption; this is clearly demonstrated in the relationship chain. Further research should be conducted to understand

how AR technology and skill development can be achieved seamlessly with academia to bridge the gap between skills and digital technology innovation.

5.3.2 Innovation in research

To better understand innovation in research, it is essential to study how AR technology is currently used in construction and engineering. In addition, we need academic models that show how efficient these technologies are and explain why they work on a fundamental level. This will highlight the new methods that are needed to specifically focus on innovation, 3D immersion and the development of digital technology.

Having a better understanding of AR technology in the construction and engineering sectors can capture academic relationship chains or feedback loops in the causal loop diagram, which can be linked to organisational development. Integrating academic items with real-world items in the causal loop diagram can bridge the gap in education and training and establish consistency across all levels of AR technology user adoption.

Therefore, innovation in research is crucial for AR technology adoption and bridging the gap between education and organisational development. Further insights into innovation in research are needed to ensure that digital technology is fully understood and implemented in construction and engineering organisations.

5.3.3 Collaboration with organisations

Organisations that utilise AR technology can aid students in the construction and engineering sectors. It is noted that there is a lack of real-world studies with AR technology (Ghorbani et al., 2024; Han & Clevenger, 2025; Sangiorgio et al., 2020). If organisations allow students to learn how they use AR technology in real-world scenarios, they can better prepare students to join the workforce. Furthermore, this enables students to observe user acceptance and real-time decision-making.

Therefore, collaboration between organisations and academia is essential for bridging the gap between education and organisational development. Further efforts to build these relationships are needed to fully enable research partners to generate practical evidence in the research environment.

5.4 Conclusion

This chapter addresses the research question through the taxonomy, the framework and the causal loop diagram. This chapter also outlines the gap in the research. The previous chapters include Chapter 1, an introduction to the use of augmented reality in construction and engineering projects; Chapter 2, a literature review of previous research on augmented reality; Chapter 3, which outlines the methodology adopted for this research; and Chapter 4, the detailed data analysis. Chapter 5 presents the discussion, which will be followed by the conclusion.

Chapter 6: Conclusion

This chapter presents the conclusion of this research, including contributions such as the drivers and consequences of AR technology. It also discusses the implications for theory and research, covering organisational and skill development, connecting qualitative and quantitative data, relationships with digital technology, and theory development. Additionally, it explores expanding to other organisational sectors and broader theoretical implications. Furthermore, this chapter outlines the limitations and provides the overall conclusion of this research.

6.1 Overview

This thesis investigates the user adoption of AR technology in the engineering and construction sectors. With the use of digital technology rapidly increasing, AR technology is reshaping how projects are managed; however, a review of the literature shows that AR technology is poorly understood and not widely accepted. Although there has been considerable research on AR technology, its applications in real-world scenarios remain limited and mostly confined to controlled laboratory environments.

A literature review outlining existing gaps showed that there is limited research on AR systems tested on real-world projects (Hajirasouli et al., 2022). It is also indicated that AR technology has not been fully adopted in the construction sector (Alkan & Basaga, 2023). In this research, AR technology was found to be unsuitable and immature (Delgado, Oyedele, Beach, et al., 2020). Limitations related to the integration of other systems were identified (Schmitt et al., 2025). The research identified inconsistencies in AR terminology and confusion with MR and VR (Ghorbani et al., 2024). It also revealed a lack of standardisation in immersive digital technologies (Alkan & Basaga, 2023), a lack of skilled professionals and a need for upskilling (Delgado, Oyedele, Beach, et al., 2020). As a result, this technology requires further research and remains underdeveloped, and a comprehensive framework is needed (Delgado, Oyedele, Demian, et al., 2020; Kolaei et al., 2022; Sangiorgio et al., 2020).

This research addresses the question of user dynamics in AR technology within the engineering and construction sectors. This approach developed a taxonomy, project framework and causal loop diagram that identify relationships concerning the user acceptance of AR technology and provide a clear view of the benefits and limitations of AR technology acceptance. There were 23 semi-structured interviews and 27 open-ended

survey responses from managers and project leads in the engineering and construction sectors. The employers of the participants ranged from large to small organisations. The participants either used AR technology directly or worked for an organisation that utilised AR technology.

The data were analysed using the grounded theory approach, which involved identifying themes and relationships through the open coding, axial coding, and selective coding of transcribed interviews and the answers to open-ended survey questions. The models developed were derived from these themes and relationships. An understanding of the relationships that influence the user acceptance of AR technology contributed to the models, and from these data, further contributions, implications, limitations and directions for future research have been outlined.

This research addresses the question of user dynamics in AR technology through the findings and the relationships identified with the user acceptance of AR technology. These include 248 open codes, 49 axial codes and 19 selective codes, which illustrate the taxonomy of the user acceptance of AR technology. Additionally, this is organised within a project framework that has four sections: organisational deliverables, project input, technology input and finally, project output. Within the sections, communication and lessons learnt are also identified. Finally, the causal loop diagram highlights the interconnected relationships for the user acceptance of AR technology in the engineering and construction sectors. During the data analysis process, Otter was utilised to transcribe the interviews, which were then uploaded to NVivo to sort through the data; Miro was used to illustrate the models once the data analysis was finalised.

6.2 Research Contributions

There have been many studies on AR technology, and within these studies, it is notable that there is one sector or application that receives focused attention. This is evidenced by Hajirasouli et al. (2022), who identify the benefits within the construction sector, highlighting that digital technologies can reduce the project cost; however, there was limited research involving real-world scenarios in the construction sector, as the study focused on experiments, simulations and laboratory environments. In addition, Rohil and Ashok (2022) researched urban planning in construction, finding that AR technology allows walkthrough designs to be showcased at full scale; however, it is noted that this research is still in the initial phase.

Delgado et al. (2020) investigate the AEC sector and outline that the main factor limiting AR use in the construction sector is its technical limitations. Yi and Luo (2025) researched green construction and highlight that AR technology combined with BIM in the construction sector provides real-time defect detection and monitoring, thus offering innovation and practical solutions; however, they also state that in the construction sector, there is an absence of an integrated solution that provides both AR and BIM technologies.

The literature has highlighted many contradictions. While numerous researchers have explored AR technology, there is no single framework that describes real-world scenarios for both the engineering and construction sectors, with skilled software developers providing their perspectives.

This thesis has contributed to the literature and research by:

- Providing comprehensive insight into AR technology based on current practical outcomes correlated with AR technology in the engineering and construction sectors;
- By outlining the factors of the user acceptance of AR technology using a comprehensive taxonomy, a framework for projects and a causal loop diagram;
- This research includes rich data from real-world scenarios obtained from participants who either work directly with AR technology or work for an organisation using AR technology.

This research provides sector-specific insights into the successful use of AR technology, outlining the impacts that affect each sector and enablers. This also highlights that further research is required for areas such as standardisation in digital technology integration, long-term use and cross-platform use in areas such as BIM and digital twin (DT).

This research serves as the groundwork for other research supporting digital transformation in the construction and engineering environment through the development of frameworks and relationships for the user acceptance of AR technology in the engineering and construction sectors. This is achieved by theory building based on DeLone and McLean's IS success model (DeLone & McLean, 2003) and identifying the lack of existing theoretical models of the user acceptance of digital technologies. Furthermore, integrating IS systems with the grounded theory approach demonstrates that IS success models can be utilised to validate new methodologies.

Additionally, the study details key relationships and identifies relationship chains and feedback loops within a causal loop diagram. This research contribution provides structured models that bring together real-world scenarios, unlike the previous literature, which is limited to user acceptance. This research offers a comprehensive approach to incorporating AR technology in academia and organisations. This visual method emphasises the interactions influencing AR user acceptance and the dynamics of digital technology.

Therefore, the research contributions include advancing academic knowledge by integrating AR use into holistic models. Additionally, the research provides a taxonomy, framework and causal loop diagram that outline the relationships and feedback loops not previously captured in the literature, and lastly, this research provides a foundation for future studies with a qualitative and mixed-methods approach.

Therefore, this study provides evidence-based research that can contribute to both research and practical recommendations for digital technology implementation and user acceptance, including how organisational, technology and management inputs can provide a positive outcome for technology integration and lead to AR technology success (Liao & Luo, 2025; Rohil & Ashok, 2022).

6.3 Implications for Practitioners

One of the implications for practitioners is that the relationship chains and feedback loops are the organisational requirements for AR integration and project success. The research and data findings outline that resources, clear deliverables and leadership are the primary aspects that can prevent the insufficient advancement of digital technologies, which is the result of the inability to successfully embrace digital technology effectively (Alkan & Basaga, 2023). Therefore, highlighting areas such as a shortage of skilled personnel and a lack of upskilling within the current workforce is crucial. Managers must be proactive in addressing these issues to mitigate problems and ensure effective training (Delgado, Oyedele, Demian, et al., 2020; Liao & Luo, 2025).

This research also dives into theoretical models and strategies by integrating the DeLone and McLean IS success model and using grounded theory, highlighting that immersive visual communication and real-time data and collaboration are essential for digital technology (Alizadehsalehi et al., 2020; Yunus et al., 2025); this correlates with the IS success model in relation to the system quality and user satisfaction (DeLone & McLean, 2003).

The feedback loop outlined in the research consisting of knowledge and communication describes the vital dynamics of open communication and the learning environment in organisations and digital technology use. This research identifies that continuous ongoing communication concerning training, learning and education can optimise AR use and project success (Han & Leite, 2022; Söbke et al., 2025). It is also noted that the user acceptance of AR technology is dependent on the system's ability to perform, the immersive experience and how organisations integrate new technology, outlining how training and stakeholder alignment are essential for project success.

6.3.1 Drivers of adopting AR technology

This research can contribute to practitioners by providing insights into digital technology within the construction and engineering industry. The practical implications provide benefits for real-world projects for leaders, trainers and clients, as well as construction, engineering and project managers. The taxonomy, project framework and causal loop diagram identify the user acceptance of AR technology, providing the information that organisations and practitioners can use to maximise benefits and project success through the integration of AR technology.

6.3.1.1 Managers

Managers in the construction and engineering sectors can incorporate the findings of this research to enable better communication and collaboration within projects. This research highlights that AR integration enhances real-time visualisation through collaboration (Bórquez et al., 2025). For managers, this can be helpful by reducing the misinterpretation of complex information through the use of 3D visual overlays (Liao & Luo, 2025). In addition, it reduces defects and therefore saves time and reduces the cost of projects (Hajirasouli et al., 2022).

Real-world applications of AR technology in the construction and engineering sectors include digital overlays on construction and engineering sites. This enables any inconsistencies to be verified and highlighted. Additionally, AR enables improved workflow efficiency and project accuracy (Bórquez et al., 2025). If managers utilise AR technology, it ensures reliability and enhances processes to boost project success and identify any errors before they become apparent.

6.3.1.2 Leaders

Organisational leaders in construction and engineering gain from this research, which shows that adopting AR technology is vital for innovation. Leaders should embrace new technological trends, as they offer many benefits, such as real-time immersive visualisation. Technology integration is vital for innovation, and leaders should accept digital technology such as AR, as it provides many benefits, such as real-time immersive visualisation (Arowoia et al., 2021). Additionally, it is noted that one of the main reasons for insufficient labour productivity is the inability to adopt new technology (Alkan & Basaga, 2023). This indicates that incorporating AR technology early on can enhance innovation and productivity, enabling organisations to accelerate digitalisation.

Another aspect for leaders is the enhanced decision-making that simplifies AR integration, achieved through the taxonomy, project framework and causal loop diagram. By outlining all factors and areas, including benefits and limitations, this research enables better decision-making during the incorporation of AR technology. It is noted that one of the main factors that limits AR technology is technical limitations (Delgado, Oyedele, Beach, et al., 2020), and understanding this can make it possible to determine better ways in which AR technology can be used.

6.3.1.3 Trainers

Organisational development is essential, and delivering AR integration through a training programme, combined with effective knowledge transfer, is essential. This is illustrated through the causal loop diagram, taxonomy and project framework. AR technology enables immersive learning by simplifying complex materials, making it more effective than traditional visualisation methods (Yunus et al., 2025). Enabling skilled trainers to use AR technology as a training platform is essential for skill development and AR integration in organisations.

Skilled trainers can also utilise AR technology to simulate safety issues and hazardous settings. Using AR technology can enable visually immersive hazard scenarios to be demonstrated in an environment that is controlled and safe. Therefore, it enables skilled trainers to upskill the workforce, which is essential for organisations attempting to facilitate successful digitalisation in the construction and engineering sectors.

6.3.1.4 Clients

Stakeholder communication is vital for any project, and there can often be complexity in ensuring all stakeholders are aligned and in agreement. The research demonstrated that

integrating AR technology can aid in communication and stakeholder management, as it allows stakeholders and the client to have a better understanding of project outcomes prior to the project's initiation. Clients can benefit from AR technology, as it provides better decision-making and enables the client to visually see the design, providing confidence in the project.

Clients and stakeholders can benefit from AR technology, as it enables a one-to-one immersive 3D model to be overlaid on the real world, allowing a better understanding of the end product. This contributes to aligning expectations (Delgado, Oyedele, Beach, et al., 2020). By providing an immersive experience to the client, AR enables a clearer understanding of the project and reduces miscommunications.

6.3.2 Consequences of adopting AR technology

The research findings outline significant implications for practice, highlighting long-term organisational value when integrating AR technology in the engineering and construction sectors. It is noted that the literature review has outlined that AR technology improves decision-making, communication and collaboration (Delgado, Oyedele, Demian, et al., 2020; Sangiorgio et al., 2020; Schmitt et al., 2025). There is still a need to demonstrate strategic and transformational digital technology integration to organisations. Therefore, by integrating the literature review and the grounded theory approach with the data obtained through identifying relationships and frameworks, this research demonstrates a holistic approach to real-world scenarios with AR technology adoption.

The consequences of adopting AR technology for practitioners are outlined below, highlighting how AR technology can benefit practitioners in real-world scenarios. This includes training and upskilling, designing and prototyping, decision-making, workforce development, communication and collaboration. Highlighting these implications for practice demonstrates opportunities and challenges in offering sustainable AR integration and encouraging user acceptance.

6.3.2.1 Training and upskilling

One of the main gaps and areas for AR technology integration is the need for training and upskilling for users and organisations. AR technology provides an immersive experience with 3D data, real-time communication and decision-making. However, this is impacted by the need for specialised training and workforce upskilling when integrating AR technology (Delgado, Oyedele, Demian, et al., 2020; Harikrishnan et al., 2021; Yunus et al., 2025). When there is no structured training or education surrounding AR technology integration for

organisations and practitioners, this creates resistance to user acceptance and inefficiencies in full AR capabilities.

Training, education and learning within organisations and for end users create a feedback loop that influences user acceptance and project success, as presented in the causal loop diagram. AR technology training also provides clear communication and visualisation on how this can benefit projects and, therefore, provides enhanced efficiency for the project workflow.

Upskilling within organisations is essential for the construction and engineering sectors. The literature highlights that while there is a need to upskill, this will be a challenge, as there is a lack of trained personnel that can do this (Delgado, Oyedele, Demian, et al., 2020).

Upskilling and trained personnel are essential to ensuring that AR technology is integrated successfully with its full potential. Upskilling in the workforce can focus on the fluency of workers in digital technology, enabling each end user to be fluent in AR technology and how to use it to interpret real-time data and participate in immersive communication.

Training and upskilling extend beyond organisational and practical developments; they also involve organisational transformation and innovation, which improves efficiency and enables digital technology to be integrated with ease in this evolving digital environment. Upskilling and training align with strategic project outcomes, where the workforce skills align with the return on investment and user acceptance.

6.3.2.2 Design and prototyping

AR technology in the Australian engineering sector can enhance prototyping for the industrial and manufacturing industries. Manufacturing in Australia is costly compared to other countries; this is evident in Australia's manufacturing industry. Creating prototypes through AR technology and developing the first prototypes in Australia can then allow products to be manufactured in other countries to lower costs.

Prototyping is a low-risk approach that allows stakeholders to test and perfect 3D models and designs using AR technology without sustaining high costs. The initial manufacturing can take place in Australia, which is expensive, but this can later be outsourced to reduce costs. Incorporating AR technology into prototyping can help the Australian industry to manufacture the proposed design, thereby increasing workforce employment and upskilling manufacturing.

6.3.2.3 Decision-making

Decision-making in the engineering and construction sectors is influenced by costs, schedules and quality. AR technology provides an immersive visual display in real time, allowing organisations and practitioners to interpret complex designs easily, rather than relying on complicated 2D drawings. This reduces rework and enhances decision-making, accuracy and efficiency (Liao & Luo, 2025; Tsai et al., 2022).

Utilising AR technology in organisations allows better communication between stakeholders and ensures improved decision-making through real-time data. This is reflected in the relationship chains, as the user acceptance of AR technology is reflected in stakeholder satisfaction and decision-making.

AR technology enables real-time decision-making and highlights key insights in data analysis. Decision-making is crucial for any project, and it is noted in the causal loop diagram that good decision-making is related to project deliverables, the ROI and user acceptance. By utilising AR technology, decision-making can be completed in real time.

6.3.2.4 Collaboration and communication

Collaboration and communication play a vital role in any project and are significant in the engineering and construction sectors. This is reflected in the relationship chains, where there is a communication feedback loop. This feedback loop highlights the importance of stakeholder and project communication, which are linked to user acceptance and project success. In addition, the importance of stakeholder involvement and project collaboration is highlighted in the communication feedback loop.

AR technology enables collaboration and communication to be immersive and allows for better decision-making, particularly in the engineering and construction sectors. Integrating AR technology enhances visual communication and provides real-time data for effective stakeholder management (Delgado, Oyedele, Demian, et al., 2020). Utilising AR technology enables both non-technical and technical users to communicate effectively, leading to a better understanding of the project scope and collaboration between stakeholders (Harikrishnan et al., 2021). Therefore, AR technology can be leveraged to provide better communication between stakeholders and enhanced collaboration across teams and end users.

6.3.2.5 Remote accessibility

One of the main implications for AR technology is its potential to reduce the need for travel. In the construction and engineering industries, this is especially helpful, as stakeholders can use AR technology from their home or office, saving time. It also enables them to implement design reviews and visually inspect projects remotely.

Using AR technology enables stakeholders to have a bigger presence, as users can join the design reviews and inspections without the need for travel. It is also evident that AR technology reduces misinterpretation and miscommunication (Harikrishnan et al., 2021). Therefore, AR ensures consistency across the project and makes sure that all stakeholders understand and agree on the project scope.

AR technology enables remote access and promotes organisational adaptability by reducing the travel time and providing real-time data. Therefore, it is clear that AR technology in the construction and engineering sectors supports organisational growth and allows all technical and non-technical stakeholders to access information in real time while connecting projects.

6.3.2.6 User acceptance

The user acceptance of AR technology among organisations and practitioners in the construction and engineering sectors is essential. It is outlined that user acceptance is heavily influenced by how easy the technology is to use and trust in the technology's functions (Arowoija et al., 2021). It is also evident that the user acceptance of AR technology occurs when it is used to provide real-time visual communication data (Liao & Luo, 2025). This also aligns with the relationship chains in the causal loop diagram, where user acceptance is linked to project success, the wow factor, an immersive experience, stakeholder satisfaction and decision-making.

One of AR technology's main purposes is to reduce the complexity of 2D drawings and enable immersive interaction. Therefore, using AR technology can decrease complex data interpretation and improve decision-making with fewer defects (Liao & Luo, 2025). Therefore, AR technology's ability to deliver an immersive experience with real-time visual communication data improves the overall efficiency and user acceptance.

6.4 Implications for Theory and Research

The implications for theory and research go beyond the user acceptance of AR technology in the engineering and construction sectors. This research also contributes to theoretical development and future research. It is evident that previous studies have researched AR technology; however, this research offers a holistic view through qualitative methods and grounded theory, outlining the drivers and consequences of AR technology user acceptance. Therefore, the implications for theory and research are demonstrated by outlining the gaps in the literature, performing theory development and enabling future research to occur.

One of the main gaps identified in the literature is the lack of a well-defined framework that clearly identifies the benefits and challenges of the user acceptance of AR technology in real-world engineering and construction scenarios. Previous studies have indicated that AR technology has been explored in laboratory and research settings (Hajirasouli et al., 2022; Han & Clevenger, 2025; Sangiorgio et al., 2020; Schmitt et al., 2025); however, the literature did not clearly outline the dynamics of the user acceptance of AR technology in construction and engineering projects. This thesis fills that gap through the taxonomy, project framework and causal loop diagram, which clearly identify the relationships of the user acceptance of AR technology. Identifying the interconnected relationships in the causal loop diagram enables a clear understanding of the relationships that underpin successful AR technology integration.

This research provides a starting point for real-world scenarios with AR technology in the engineering and construction sectors. There are many other avenues through which this research can be further explored; however, from the findings and data analysis, there are some key areas that can be investigated further.

6.4.1 Organisational and skill development

Integrating AR technology with organisations in the engineering and construction sectors is complex, and expert skills are required to do this successfully and align with the proposed design intent. Larger organisations can handle this internally with the right skill sets; however, smaller and medium organisations will find this challenging and will need to source this externally, which will increase costs.

With the rise of digital technology and automation, organisational readiness is often misunderstood and underestimated. Data analysis indicates that training, learning and

education are essential for AR technology integration and user acceptance. Without structured programmes and change management, AR technology integration can cause resistance from users, as they may find the use of digital technology difficult and struggle to understand the full concept of how AR technology can be applied in construction and engineering projects.

The literature review highlighted that training programs are a necessity for organisations and staff (Kolaei et al., 2022). It was also noted that there is a lack of skilled professionals, which highlights the challenges with delivering quality training programmes (Han & Clevenger, 2025; Yunus et al., 2025). Therefore, to ensure user acceptance and the correct integration of AR technology, upskilling the workforce is essential (Delgado, Oyedele, Beach, et al., 2020).

Therefore, structured programmes and frameworks are essential for AR technology integration and user acceptance. Incorporating change management, structured frameworks and training programmes that provide expert skills can increase long-term user acceptance, and exploring this further would be beneficial for research and organisations looking to integrate digital technology.

6.4.2 Connecting qualitative and quantitative data

This research only looked at qualitative data; therefore, future research can benefit from connecting quantitative and qualitative data. These qualitative data were based on open-ended survey questions concerning the participants' experience with AR technology. Integrating quantitative data can provide a statistical output, which this research is lacking, on a numerical level, as reflected in multiple studies in the literature review.

A common quantitative method outlined in this research measures productivity improvements and enhanced workflows (Alkan & Basaga, 2023; Han & Clevenger, 2025; Oke & Arowoija, 2021) and aligns with improved decision-making and collaboration (Delgado, Oyedele, Demian, et al., 2020; Sangiorgio et al., 2020; Schmitt et al., 2025). However, without a statistical approach using quantitative data, it is harder to justify AR technology integration.

Integrating both quantitative and qualitative data will strengthen evidence-based user acceptance of digital technology. This mixed-method approach will provide a comprehensive view of user behaviours. Such integration will allow the research to deliver detailed,

statistically supported insights, therefore enabling researchers to achieve a robust and effective outcome.

6.4.2.1 Integrating with AI

Further research focusing on a qualitative and quantitative data analysis of AR technology and AI integration would be beneficial. Incorporating AI and AR technology can help bridge the gap. AI analytics can automatically collect data and aid in decision-making in real time, with a focus on organisational needs (Elmousalami et al., 2025). It is also highlighted that AR technology is compatible with AI (Bórquez et al., 2025; Rostami et al., 2025).

Therefore, by integrating AI technology with qualitative and quantitative data, future research can utilise a mixed-method approach that is derived from digital technology needs and organisational needs with AI. It is now common for organisations to develop a framework for AI and its management. Integrating this with AR technology in the engineering and construction sectors can enhance time management, decision-making and analytics.

6.4.3 Digital technology relationship and theory development

With the use of digital technology rapidly growing in the engineering and construction sectors, there is a need to develop the relationship and theory further. They can be further developed by designing a theory that encompasses all digital technologies and not just AR technology.

Developing a theory that helps organisations and practitioners to integrate new technology smoothly will support rapid technological growth and organisational needs. Without a theory and framework, it will be difficult to generalise, and the common limitations encountered when integrating technology will continue. The framework and causal loop developed in this research can serve as the baseline of future studies that may be adapted to incorporate digital technology as a comprehensive approach, rather than just AR technology.

6.4.4 Expand to other organisational sectors

This research focused on the engineering and construction sectors; further research can be conducted to expand on this. Future research in other sectors such as defence, emergency services, retail, healthcare, rehabilitation, education planning, tourism and customer service can further explore AR technology and user acceptance in real-world scenarios.

Further research into other organisational sectors could help develop a universal framework or theory that adapts to digital technology that can be tailored to AR technology, with a quantitative, qualitative or mixed-method approach, to enhance organisational capabilities.

6.4.5 Theoretical implications

The theoretical implications of adopting AR technology in the engineering and construction sectors have become clearer through the relationships outlined in the taxonomy and causal loop diagram. Through a qualitative grounded theory approach, these relationships emerged, creating a comprehensive model of the user acceptance of AR technology. The model highlights factors that influence acceptance, such as organisational deliverables, project management, project outputs, communication and stakeholder management. These insights help facilitate digital technology integration by providing a better understanding of the benefits and challenges.

The grounded theory approach developed relationships to show how they relate and build interconnections. This provides a better understanding of technology adoption. For complex technologies like AR, it establishes a baseline that other researchers can reference and expand upon. Consequently, this research offers interconnected relationships that bridge gaps in existing frameworks and support future research, which can build on this foundation.

6.5 Limitations

With all research, there are limitations that arise. The first limitation in this research was the Covid-19 pandemic, particularly in Victoria, Australia, which posed significant challenges. During the initial data collection phase, the data process was designed for face-to-face interactions involving the physical use of digital technology. During the pandemic, many participants who initially agreed to be interviewed declined the invitation due to the uncertainty at the time. Because of this, the scope of the data collection fully transitioned to online only and required a new method of inviting participants.

The original data sample included only the engineering sector; however, it was expanded to include the construction sector due to a need for more willing participants. Additionally, data samples were collected from skilled professionals who were software developers designing AR technology. By incorporating both the engineering and construction sectors, the results were made more consistent, as many engineering projects are carried out in construction environments.

Furthermore, the data samples were initially collected only for the Australian sector. However, when inviting participants, a software developer with businesses in both Australia and Colombia was included. This required updating the ethics application and pausing data collection until the approval was revised. Unfortunately, the participant, who initially accepted the invitation, declined; therefore, the data collection remains limited to the Australian sector. Nonetheless, a study like this could benefit from results that go beyond the Australian sector.

Another limitation in the study was the exclusive use of a qualitative method, which hinders access to information on measurable patterns, which can be obtained through methods such as statistical validation. Future research should include quantitative methods based on statistical modelling and surveys. Combining both quantitative and qualitative methods could provide a holistic validation of the user acceptance of AR technology in the engineering and construction sectors.

Another limitation of this research is the number of volunteers who participated. Initially, the aim was to have 100 participants; however, interviews and open-ended survey questionnaires resulted in 23 participant interview responses and 27 open-ended survey questionnaire responses. Both the interview and open-ended survey questionnaires contain the same questions, with a total of 50 responses. Initially, there were 65 participants; however, 10 declined after initially agreeing to participate. For this research, the 50 responses provided a generous amount of data.

Lastly, the original context of this study was digital transformation and VR technology. It was noted that VR technology, in the context of engineering and construction use, was not as useful, and AR technology was more aligned with engineering and construction due to the flexible nature of the AR devices. However, this was primarily a misuse of terminology. This research provides a better understanding of the digital technologies suitable for the engineering and construction sectors. It is also noted that professionals and non-professionals using this technology often mix up the terminology, calling AR glasses 'VR glasses', which can be misleading because some AR devices incorporate both AR and VR technology.

6.6 Conclusion

This research contributed to both the literature and practitioners by offering a taxonomy of relationships, a project framework and a causal loop diagram that outlines the

interconnected relationships of the user acceptance of AR technology in the engineering and construction sectors.

Implications for practitioners are demonstrated through the drivers of AR technology, such as managers, leaders, trainers and clients. The use of AR technology leads to benefits like training and upskilling, design and prototyping, better decision-making, improved collaboration and communication, increased remote access and user acceptance. This highlights the need for a more skilled workforce and improved education on AR technology to ensure better integration and user adoption. It also supports establishing prototyping and manufacturing in Australia, enabling better real-time decisions due to enhanced collaboration and communication among all stakeholders and also facilitating the use of AR in projects while reducing the need to travel.

The limitations of this research include the Covid-19 pandemic, which presented significant challenges with data collection, and the need to expand from the engineering sector to the construction sector. Additionally, there was a need to amend the ethical application because a participant had a business in Australia and Colombia related to software development, leading to expanding the data collection beyond Australia. This required the data collection to be put on hold until the ethical amendment was approved. The participant ultimately declined the invitation after initially accepting. Another limitation is the use of a qualitative method instead of a mixed-method approach. Moreover, the initial target was to recruit 100 participants, but the actual number of participants was 50; this still provided a substantial amount of data. Lastly, the original focus of this study was to investigate VR technology, which was later refined to AR for greater relevance.

The future direction of this research includes organisational and skill development, connecting both qualitative and quantitative data, integrating AI, expanding to other organisations beyond engineering and construction organisations, and addressing theoretical limitations through the application of grounded theory. Furthermore, future studies should focus on standardising digital technology integration, as well as examining long-term use and cross-platform compatibility with systems such as BIM and DT systems.

Therefore, this research demonstrates that the engineering and construction sectors are shifting towards digital transformation. AR technology is becoming more promising due to its benefits for real-time decision-making, communication and collaborative uses. Additionally, AR technology, through immersive real-world environments, addresses many limitations of traditional practices, such as interpreting 2D drawings and inefficient workflows and

communication in projects. This research highlights that AR technology offers enhanced accuracy and the easy interpretation of real-time data for both technical and non-technical users, leading to better decision-making and improved collaborative communication among all stakeholders. Consequently, this supports user acceptance in integrating AR technology.

By developing a taxonomy of relationships derived from primary data through real-world scenarios and further developing these data into relationship chains and causal loop diagrams, this research contributes to a holistic view of the user acceptance of AR technology, highlighting the benefits, limitations and implications. This research addresses the research question and provides answers by presenting detailed findings, providing a taxonomy of relationships for the user acceptance of AR technology. This was then further analysed to create a framework for project integration and reanalysed to develop relationship chains and a causal loop diagram.

In summary, this research, derived from a qualitative study through grounded theory, investigated the user acceptance of AR technology in the engineering and construction sectors. This research provides a taxonomy of relationships, a framework for AR implementation and a causal loop diagram representing interconnected relationships. This research contributed to both research and practice by identifying crucial elements of the user acceptance of AR technology.

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Appendix A: Ethics Approval

Quest Ethics Notification - Amendment Request Process Finalised - Application Approved



quest.noreply@vu.edu.au <quest.noreply@vu.edu.au>

Monday, 15 November 2021 at 3:16 pm

To: Amir.Ghapanchi@vu.edu.au; Cc: Gitesh.Raikundalia@vu.edu.au; lisa.sahyoune@live.vu.edu.au

Completed on Thursday, 7 August 2025.

Dear DR AMIR GHAPANCHI,

Your amendment request for the following ethics application has been formally reviewed and finalised.

- » Application ID: HRE20-123
- » Chief Investigator: DR AMIR GHAPANCHI
- » Other Investigators:
- » Application Title: Investigating the dynamics of User Adoption of the Virtual Reality technology in engineering projects
- » Form Version: 13-07

The amendment request for this ethics application has been accepted and deemed to meet the requirements of the National Health and Medical Research Council (NHMRC) 'National Statement on Ethical Conduct in Human Research (2007)' by the Victoria University Human Research Ethics Committee. Approval has been granted for two (2) years from the original approval date; 29/10/2020.

Continued approval of this research project by the Victoria University Human Research Ethics Committee (VUHREC) is conditional upon the provision of a report within 12 months of the above approval date or upon the completion of the project (if earlier). A report proforma may be downloaded from the Office for Research website at: <http://research.vu.edu.au/hrec.php>.

Please note that the Human Research Ethics Committee must be informed of the following: any changes to the approved research protocol, project timelines, any serious events or adverse and/or unforeseen events that may affect continued ethical acceptability of the project. In these unlikely events, researchers must immediately cease all data collection until the Committee has approved the changes. Researchers are also reminded of the need to notify the approving HREC of changes to personnel in research projects via a request for a minor amendment. It should also be noted that it is the Chief Investigators' responsibility to ensure the research project is conducted in line with the recommendations outlined in the National Health and Medical Research Council (NHMRC) 'National Statement on Ethical Conduct in Human Research (2007).'

On behalf of the Committee, I wish you all the best for the conduct of the project.

Secretary, Human Research Ethics Committee
Phone: 9919 4781 or 9919 4461
Email: researchethics@vu.edu.au

This is an automated email from an unattended email address. Do not reply to this address.

Appendix B: Invitation Template

Hello

You are invited to participate in a research project entitled “Investigating the Dynamics of User Adoption of Augmented Reality Technology in Engineering and Construction Projects”. This project is being conducted by Lisa Sahyouné at Victoria University.

This research aims to identify and explore the user adoption of Augmented Reality (AR) technology in engineering and construction projects. By investigating AR user acceptance, this research aims to explore the determinants of user acceptance of technology for engineering and construction projects, thereby identifying key factors influencing AR user acceptance. Furthermore, identifying “how” and “why” AR acceptance is linked to project success and failure in engineering and construction projects.

By participating in this study, you will enable us to identify and explore user adoption of Augmented Reality (AR) technology. The research findings will help provide a comprehensive overview of the factors that influence user acceptance of AR technology in engineering and construction projects, along with its underlying dynamics.

Link to survey questionnaire and project information:

https://vuau.qualtrics.com/jfe/form/SV_4TTlqanzXt0Ouay

If you are interested in participating in an interview, please contact me by email at lisa.sahyouné@live.vu.edu.au.

Please share this survey within your networks in the engineering or construction field.

Thank you.

Kindest regards,

Lisa Sahyouné
Victoria University

Appendix C: Participants Consent Form

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

Information to participants

You are invited to take part in Investigating the Dynamics of User Adoption of Virtual Reality Technology in Engineering and Construction Projects. The aim of this research is to identify and explore the user adoption of Virtual Reality (VR) technology in engineering and construction projects. By investigating VR user acceptance, this research will explore determinants of user acceptance of technology for engineering and construction projects, therefore determine factors in respects to VR user acceptance. Furthermore, identifying “how” and “why” VR acceptance is linked to project success and failure in engineering projects.

Certification by participant

By completing the questionnaire, I certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:

“Investigating the Dynamics of User Adoption of Virtual Reality Technology in Engineering and Construction Projects” being conducted at Victoria University by: “Lisa Sahyouné”.

By completing the questionnaire, I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me through the INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH form, and that I freely consent to participation involving the following questionnaire.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I understand that this interview or focus group will be recorded for the purpose of transcribing and by means of this I consent.

I have been informed that the information I provide will be kept confidential.

Any queries about your participation in this project may be directed to the researcher: “Lisa Sahyouné”, “Phone number: 0432 802 405”, “email address: lisa.sahyouné@live.vu.edu.au”.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

[*please note: Where the participant/s are aged under 18, separate parental consent is required (email the contact person if this applies); where the participant/s are unable to answer for themselves due to mental illness or disability, parental or guardian consent may be required (email the contact person if this applies).]

Appendix D: Information to Participants

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled “Investigating the Dynamics of User Adoption of Virtual Reality Technology in Engineering and Construction Projects”. This project is being conducted by Lisa Sahyouné at Victoria University.

Project explanation

The aim of this research is to identify and explore the user adoption of Virtual Reality (VR) technology in engineering and construction projects. By investigating VR user acceptance, this research will explore determinants of user acceptance of technology for engineering and construction projects, therefore determine factors in respects to VR user acceptance. Furthermore, identifying “how” and “why” VR acceptance is linked to project success and failure in engineering and construction projects.

What will I be asked to do?

- Take part in questionnaires.
- Participate in a one on one interview.
- Participate in group interviews.
- Take part in focus groups by being observed when using VR technology in engineering projects.

What will I gain from participating?

By participating in this study, you will allow us to identify and explore the user adoption of Virtual Reality (VR). By having the research findings, this will assist and provide a big picture of drivers that outline user acceptance of VR technology in engineering and construction projects and its dynamics.

How will the information I give be used?

- I am volunteering to have my thoughts regarding user adoption of Virtual Reality (VR) technology in engineering and construction projects.

- I understand that the data collected will be anonymous and I am not required any information that could identify me.
- I understand that the anonymous and aggregated feedback gained from this survey may be published as academic articles.
- I understand that this interview or focus group will be recorded for the purpose of transcribing.

What are the potential risks of participating in this project?

I understand that there is no risk associated with participating in this.

How will this project be conducted?

This project intends to use an interpretivist, qualitative approach with the incorporation of grounded theory to analyse the data. All responses will be gathered and analysed anonymously using the ethics department at the organisations.

Who is conducting the study?

Chief Investigator: "Lisa Sahyouné" from Victoria University

"Phone number: 0432 802 405"

"Email: lisa.sahyouné@live.vu.edu.au"

Any queries about your participation in this project may be directed to the Chief Investigator listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix E: Qualtrics Logic

Default Question Block

Introduction

You are invited to participate in a research project entitled "Investigating the Dynamics of User Adoption of Augmented Reality Technology in Engineering and Construction Projects". This project is being conducted by Lisa Sahyouné at Victoria University.

The aim of this research is to identify and explore the user adoption of Augmented Reality (AR) technology in engineering and construction projects. By investigating AR user acceptance, this research will explore determinants of user acceptance of technology for engineering and construction projects, therefore determine factors in respects to AR user acceptance. Furthermore, identifying "how" and "why" AR acceptance is linked to project success and failure in engineering and construction projects.

By participating in this study, you will allow us to identify and explore the user adoption of AR. By having the research findings, this will assist and provide a big picture of drivers that outline user acceptance of AR technology in engineering and construction projects and its dynamics.

* Please Note: Try and be as descriptive as possible in your answers, this would give a better qualitative data analysis for the research.

Participant form

Skip to

End of Survey if Yes, I agree to participate... Is Not Selected

Please see below in regards to the information to participants in Australia.

Any queries about your participation in this project may be directed to the Chief Investigator, Lisa Sahyouné from Victoria University directly on email, lisa.sahyouné@live.vu.edu.au

Print this page [Information to participants form](#)

Yes, I agree to participate in this study

No, I do not agree to participate in this study

Consent form

Skip to

End of Survey if Yes, I consent to the study Is Not Selected

By completing the questionnaire, I certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study: "Investigating the Dynamics of User Adoption of Augmented Reality Technology in Engineering and Construction Projects" being conducted at Victoria University.

Please see below in regards to the Consent form.

Print this page [Consent form](#)

Yes, I consent to the study

No, I do not consent to the study

End of Survey

We thank you for your time spent taking this survey.

Your response has been recorded.

(Your respondent's response summary will appear here)

Appendix F: Questions for Engineering and Construction Participants

Interview Questions

Research Question: What are the dynamics of user acceptance of technology in AR projects?

Questions for Customer - Augmented Reality (AR):

1. What is your understanding of AR?
2. What are the facilitators and barriers for you to accept and use this technology?
3. I'm primarily interested in finding out what factors drive users to accept and use this technology, what are your thoughts on that?
4. What are the barriers and the possible reasons for your resistance to use this technology and why?
5. What do you think are the factors that impact your decision to purchase AR technology?
6. Have you noticed that there are different level of acceptance with AR technology by different users?
7. How have you been trained and educated about AR system?
8. How do you come up with and communicate your requirements to the technology developer company?
9. How do you evaluate the success and performance of a specific AR product you have used?
10. What are your thoughts of the future of AR in projects?

Appendix G: Questions for Software Developers

Interview Questions

Research Question: What are the dynamics of user acceptance of technology in AR projects?

Questions for Technology Developers - Augmented Reality (AR):

1. What is your understanding of AR?
2. What are the facilitators and barriers for users to accept and use this technology?
3. I'm primarily interested in finding out what factors drive users to accept and use this technology, what are your thoughts on that?
4. When the customers approach your assistance for AR development, what can be the barriers and the possible reasons for their resistance to this technology? Why?
5. What do you think are the factors that impact the customers decisions to purchase your AR technology?
6. Have you noticed that there are different level of acceptance with your AR technology by different users? How would you group the users of your technology in different categories depending on their acceptance and use of this technology?
7. After you have developed the AR, how do you educate and train the users with this system?
8. How do you extract customer requirements when making an AR product for them?
9. How do you evaluate the success and performance of a specific AR product that you have developed for a customer?
10. How do you compare the outcome of the process (in the customers organisation) in traditional form as oppose to when they use your AR product?
11. What are your thoughts of the future of AR in projects?

Appendix H: Comprehensive List of Open Codes

#	Name	Files	References
1	360 Laser Scanning	2	2
2	3D Mapping	2	4
3	3d Storyboards	1	3
4	3D Virtual Environment	11	43
5	Accessibility	3	3
6	Accuracy	8	16
7	Ad-Hoc Training	3	3
8	Adaptability	3	3
9	AI Imagery	1	1
10	Application Programming Interface (API) AR	1	1
11	Applications on Devices	8	15
12	AR Availability	5	7
13	AR Benefits	9	16
14	AR Demonstration	5	6
15	AR Development	4	5
16	AR Elements - Limitation	1	1
17	AR Enhanced Experience	3	6
18	AR Equipment	14	56
19	AR First Impression	1	1
20	AR Implementation	4	5
21	AR Integration	8	9
22	AR Limitations	14	43
23	AR Packages	1	1
24	AR Programming	3	4
25	AR Projector	1	1
26	AR Side Effects	2	2
27	AR Software Comparison	1	1
28	AR Support Representative	2	2
29	AR Technology Advancements	9	14
30	AR Testing	2	2
31	AR User Case	10	24
32	Architectural, Engineering and Construction (AEC)	2	2
33	Artificial Intelligence (AI)	6	10
34	As Built Verification	2	2

35	Augmented Graphics	8	29
36	Automation	1	1
37	Battery Life	2	3
38	Bespoke Applications	2	3
39	Building Information Modelling Software (BIM)	2	2
40	Business as Usual (BAU) Aspect	3	6
41	Capabilities	14	49
42	Catia	1	1
43	Change Management	3	6
44	Cheaply	1	1
45	Collaborative	12	22
46	Commercial Application	2	5
47	Communicating Projects Needs	4	8
48	Community	1	4
49	Compatibility	4	8
50	Comprehensive Investigation	1	1
51	Computer Simulation	1	2
52	Consolitative Process	1	1
53	Construction	5	11
54	Construction Manager	1	1
55	Consultation	1	2
56	Content Gathering	1	1
57	Continuous Improvement	1	1
58	Contractual Requirements	1	1
59	Convenience	2	9
60	Cost Management	19	133
61	Cross Platform Integration	3	3
62	Customise	5	12
63	Data Connection	2	2
64	Data Integration	4	8
65	Data Overlay	7	11
66	Data Privacy	6	19
67	Decision Making	5	9
68	Design Accuracy	2	2
69	Design Aspect	7	22
70	Design Changes	1	2

71	Design Script	1	1
72	Design Troubleshooting	1	1
73	Device and Browser Authentication	1	1
74	Digitalisation	4	4
75	Documentation Management	1	2
76	Due Diligence	1	1
77	Early Adopters	4	7
78	Easy to Use	11	47
79	Economics	1	5
80	Education	10	16
81	Embracing Technology	4	5
82	Engineer	1	1
83	Engineering	2	4
84	Enterprise Licence	1	1
85	Enterprise Sectors	2	4
86	Entertainment Applications	2	5
87	Environment Interaction	3	3
88	Environmental Projects	1	1
89	Equipment Safety	1	1
90	Ethics - Technology	1	1
91	Evaluation Period	1	1
92	Expertise	4	7
93	Feasibility	2	2
94	Functionality	6	10
95	Future Concept	1	1
96	Game Engine AR	1	1
97	General Overview of AR Future	16	20
98	Generative AI	4	5
99	Hardware Availability	1	2
100	Headset Size	2	3
101	Headsets Used	9	22
102	Health and Safety	4	10
103	Human Factors	2	4
104	Imagery	1	1
105	Immersive Experience	3	3
106	Implementation of Hardware	2	2

107	Infrastructure	1	6
108	Initial Problems	1	1
109	Innovation	4	5
110	Inspections	1	1
111	Instruction Sheet	1	1
112	Interaction	9	17
113	KPIs	1	1
114	Learning	4	13
115	Legacy Systems	2	7
116	Lessons Learned	1	1
117	Level of Development (LOD)	1	2
118	Longevity of Technology	3	4
119	Manufacturing	4	5
120	Marketing	5	25
121	Medical Applications	1	1
122	Metrics	2	3
123	Misaligned Expectations	1	2
124	Modelling	9	15
125	Multiple Programs	1	1
126	Multiple Users	3	3
127	Native Applications	1	2
128	New Technology - Exposure	11	19
129	Older Generation	6	6
130	On Site Functionality	1	1
131	Onboarding Project	1	1
132	Other Devices	2	4
133	Permission Issues	1	1
134	Personal Reality	3	3
135	Physical Limitations	1	1
136	Physical Safety	1	1
137	Politics	1	1
138	Positive Impact	15	29
139	Potential Strategy	5	6
140	Practical	3	3
141	Preparation Time	2	2
142	Pressure	1	2

143	Problem Solving	9	16
144	Processes and Procedures	6	10
145	Procurement	1	1
146	Productivity (Efficiency)	11	55
147	Progressive Design Review	1	1
148	Project Benchmarking	1	1
149	Project Champion	4	6
150	Project Debrief	2	2
151	Project Deep Dive	1	1
152	Project Deliverables	3	4
153	Project Delivery	1	2
154	Project Development Experience	2	2
155	Project Direction	2	3
156	Project Feedback	8	13
157	Project Funding	1	1
158	Project Handover	2	3
159	Project Leadtime	3	3
160	Project Needs	5	15
161	Project Phase	2	4
162	Project Portfolio	1	1
163	Project Preconception	1	1
164	Project Success	4	5
165	Project Visualisation	9	13
166	Prototyping	8	12
167	Proven Systems	1	1
168	Proven Useful	2	8
169	QR Code	1	3
170	Quality Assurance and Quality Control (QAQC)	1	2
171	Quality Management	6	9
172	Quantify Savings	1	1
173	Questions and Answers (Q&A)	1	1
174	Real Time	9	21
175	Regulation	1	3
176	Reliability	5	10
177	Renewable Energy	1	7
178	Request for Proposal (RFP)	1	1

179	Requirements	1	1
180	Research Software Companies	1	2
181	Research Team	1	1
182	Resources	3	6
183	Response Time	1	1
184	Return on Investment (ROI)	2	6
185	Scope Creep	1	1
186	Scope Management	6	11
187	Self Trained	5	6
188	Set Up of Technology	4	4
189	Skill Sets	1	4
190	Social Licence	1	1
191	Software Applications	8	15
192	Software as a Service (Saas) Applications	1	1
193	Software Developers Experience	1	1
194	Software Ecosystem	1	1
195	Software Integration	8	16
196	Software Layers	1	1
197	Software Maintenance	2	4
198	Spatial Data	3	5
199	Stakeholder Alignment	3	5
200	Stakeholder Communication	4	15
201	Stakeholder Engagement	6	8
202	Stakeholder Satisfaction	5	6
203	Stealth Mode	1	1
204	Subject Matter Expert (SME)	1	1
205	Superimpose AR	1	2
206	Target Audience	1	2
207	Technical Perspective	1	2
208	Technology Accuracy	2	4
209	Technology Advise	1	1
210	Technology Availability	3	8
211	Technology Dependency	2	2
212	Technology Engagement	3	3
213	Technology Enthusiasts	1	1
214	Technology Insertion	1	1

215	Technology Interface	5	8
216	Technology Misconception	5	5
217	Technology Purpose	4	4
218	Technology Resistance	2	3
219	Technology Savvy	3	4
220	Time and Motion	1	1
221	Time Management	8	24
222	Trade Industry	1	1
223	Training	18	65
224	Transparency of Project Information	2	2
225	Trial Licence	3	3
226	Understanding of AR	18	30
227	Underutilised Equipment	1	1
228	User Acceptance	10	24
229	User Difficulties with AR Technology	1	1
230	User Expectation	7	11
231	User Experience	8	10
232	User Friendly Technology	4	6
233	User Support During Set Up	2	2
234	Utility	1	1
235	Validation	2	2
236	Verbal Communication	5	9
237	Virtual Asset	1	2
238	Visto	1	2
239	Visual Aids - Handover	1	1
240	Visual Communication	4	11
241	Visual Display	16	31
242	Visual Instructions	1	1
243	Web Browser Accessibility	6	6
244	Workflow	3	11
245	Wow Factor	5	6
246	Written Communication	5	11
247	You Tube	1	1
248	Younger Generation	5	6

Appendix I: Comprehensive List of Axial Codes

#	Axial codes	#	Open Code Reference
1	Project Deliverables	5	185, 186, 150, 224, 31
2	Organisational Deliverables	5	144, 244, 141, 159, 182
3	Financial Aspects	4	60, 184, 172, 157
4	Legal and Contractual	3	58, 133, 179
5	Licensing and Subscriptions	6	238, 247, 225, 190, 84, 42
6	Regulatory Aspects	6	40, 46, 175, 178, 79, 137
7	Cognitive Ergonomics	1	103
8	Safety	5	89, 135, 136, 102, 90 77, 151, 155, 160, 152, 93, 163,
9	Early Technology Adoption	8	128
10	Project Strategic management	5	139, 209, 217, 109, 167
11	Project Design	4	68, 69, 70, 71
12	Project development	15	165, 166, 62, 20, 94, 95, 131, 56, 241, 15, 50, 55, 14, 180, 76
13	Project deliverables	5	158, 67, 75, 153, 162
14	Schedule deliverables	4	220, 221, 174, 183 32, 82, 53, 54, 85, 119, 83, 222,
15	AR sectors	10	145, 107
16	Advertising	3	206, 120, 23
17	Environmental and sustainability	3	88, 87, 177
18	Generational Factors	2	129, 248
19	Expert Skills	5	207, 92, 204, 219, 189 86, 121, 192, 10, 11, 38, 191, 127,
20	AR Applications and Platforms	9	39
21	AR Capabilities	5	194, 196, 197, 41, 112
22	Software Analysis	1	27
23	Device Compatibility	6	73, 125, 126, 49, 243, 203
24	Integration	4	21, 24, 195, 61 37, 100, 101, 99, 106, 130, 132,
25	Hardware and Equipment	10	169, 18, 25
26	Technology User Connection	3	212, 214, 215
27	Machine Learning Integration.	3	98, 9, 33
28	Computer-Based Modelling	5	51, 237, 34, 124, 205

29	Technology Automation	2	36, 74
30	3D, Virtual Environments	8	1, 2, 3, 4, 198, 35, 96, 104,
31	Data Analytics	3	63, 64, 65
32	Data Management	2	66, 115
			6, 134, 228, 230, 231, 232, 233, 78,
33	User acceptability	13	245, 81, 154, 105, 193
34	Adaptability of new technology	2	8, 234
35	Augmented Reality Advantages	5	12, 13, 19, 17, 29
36	Project challenges	4	142, 123, 44, 108
			216, 218, 118, 211, 210, 16, 22, 26,
37	Technology challenges	11	229, 227, 5
38	Efficiency	3	168, 176, 146,
39	Project Evaluation	4	148, 117, 161, 208
40	Quality Control	5	170, 171, 235, 110, 91,
41	Practical Solutions	6	138, 140, 59, 213, 164, 143
42	Quality Improvement	5	147, 57, 72, 43, 30
43	Performance Criteria	2	122, 113
44	Project Collaboration	4	48, 181, 52, 45
45	Training Environment	6	7, 187, 188, 223, 149, 28
46	Learning Environment	4	80, 226, 111, 97
47	Education Environment	2	114, 116
			236, 246, 156, 173, 239, 240, 242,
48	Communication management	10	200, 201, 47
49	Stakeholder management	2	199, 202

Appendix J: Comprehensive List of Selective Codes

#	Selective and axial codes	# of Axial code	# of Open code
	Organisational Deliverables and Project		
1	Scope	2	
	Project Deliverables		5
	Organisational Deliverables		5
2	Financial Deliverables	1	
	Financial Aspects		4
3	Legal and Regulatory Deliverables	3	
	Legal and Contractual		3
	Licensing and Subscriptions		6
	Regulatory Aspects		6
4	Safety Deliverables	2	
	Cognitive Ergonomics		1
	Safety		5
5	Early Adopters	2	
	Early Technology Adoption		8
	Project Strategic management		5
6	Project Management	4	
	Project Design		4
	Project development		15
	Project deliverables		5
	Schedule deliverables		4
7	Specific Use Cases	3	
	AR sectors		10
	Advertising		3
	Environmental and sustainability		3
8	Expert skills and Development	2	
	Generational Factors		2
	Expert Skills		5
9	Software & Hardware Integration	7	
	AR Applications and Platforms		9
	AR Capabilities		5
	Software Analysis		1
	Device Compatibility		6
	Integration		4

	Hardware and Equipment		10
	Technology User Connection		3
10	Artificial Intelligence (AI) Integration	1	
	Machine Learning Integration.		3
11	Automation and 3d Environment	3	
	Computer-Based Modelling		5
	Technology Automation		2
	3D, Virtual Environments		8
12	Data privacy and management	2	
	Data Analytics		3
	Data Management		2
13	User Experience and AR Use	2	
	User acceptability		13
	Adaptability of new technology		2
14	Technology Advancements	1	
	Augmented Reality Advantages		5
15	Technology and Project Challenges	2	
	Project challenges		4
	Technology challenges		11
16	Performance & Quality Assurance	7	
	Efficiency		3
	Project Evaluation		4
	Quality Control		5
	Practical Solutions		6
	Quality Improvement		5
	Performance Criteria		2
	Project Collaboration		4
17	Knowledge and Lessons Learnt	3	
	Training Environment		6
	Learning Environment		4
	Education Environment		2
18	Communication	2	
	Communication Management		10
	Stakeholder Management		2
		<hr/>	
		49	248

Appendix K: Example of Transcript

Participant E3 – Transcribed by Otter

Mon, Oct 28, 2024 5:46PM • 17:09

SUMMARY KEYWORDS

augmented reality, installation instructions, VR goggles, point-of-use information, quality improvement, software integration, general acceptance, cultural change, practical applications, time and motion study, productivity savings, operator satisfaction, future technology, digital twins, AI integration

SPEAKERS

Speaker 1, Speaker 2

Speaker 1 00:01

Okay, so I'll start with question one, what is your understanding of augmented reality?

Speaker 2 00:10

Okay, so my understanding of augmented reality is that it is using, in addition to what you can actually see with your eyes, your overlaying information, be it from a model or like so in the context of my work, it would be overlaying what you can see with your eyes and what's actually in front of you on the product with the theoretical version of what should be there to help with installation instructions, or to be able to see what should go where. So it's, it's enhancing what you can actually see to help you build what you want, like, what, what we need to build with like to get that better quality product. Because you can see what should be and what is. Does that make sense?

Speaker 1 01:00

That makes perfect sense. And what, what products have you used?

Speaker 2 01:08

I am unfamiliar. I know we use, like the VR goggles, but I don't know what make they are. I can probably get you this information if you really need it. And, yeah, I don't know what software we use, but just make a note, and I will go and ask questions, and I'll All right, easy. I'll get the answer for you, because I don't know off the top of my head.

Speaker 1 01:38

All good. So second question, what the facilitators and barriers for you to accept and use this technology? So why would you use it? And why wouldn't you use it?

Speaker 2 01:51

Okay? So I think that for from my role in manufacturing, we would like to use it to improve quality, because the operator, rather than have to rely on work instructions or visual cues that are on a computer fire away. They're getting the point of use information while they do the job. So that's definitely going to help them make sure they get it right, because they're not having to go back and forth or forget anything is you're not relying on the person's memory, because it's all overlaid right in front of them, and they've got that point of use information it's also really good because often we have a lot of information that needs to be given on a large scale product, and so we scale that down to make it palatable in paper based forms. So the information is getting really tiny and hard to read, but if you actually have it coming through your goggles, then what you're seeing is presented and you get only the information need for the part that you're working on, rather than having to fish through all the information to find the piece that you're that's relevant for you at The time barriers for that, I guess that technology insertion in in our company is hard. So for us, it's about proving that it works and that there's no errors. So for us, I think it's more about finding the right software that then links and we can confirm that it's the information hasn't passed through multiple software bands to get to the operator that it's, you know, that's only been translated once, and so that we have more confidence it's correct. I guess the perception is, if it the more it travels through various software's, out of our modelling, our engineering modelling, and then into another software, and then into another software, that the data could get corrupted and therefore may not be correct, and maybe then causing quality issues. I think the other barrier is just general acceptance. And, you know, trying new things, people tend to get set in their ways, in their job, and don't want to try new things, because they perceive it's harder. Or, you know, but I already know how to do this, and, you know, I guess it's, it's just about overcoming that and working through the change and how technology can help. Rather than just, Hey, there's this new process, we're inflicting it on you. So it's, it's more about cultural change as well, I think, yeah,

Speaker 1 04:16

very good. So what? So question, the next question is very similar to this one, but it's more about, what are the factors that drive users to accept it? So what do you think that make users want to use it?

Speaker 2 04:33

So I think it's about, what we found really good is we've got a few practical applications where we're using it. So we have one application where we need to install power pins to hold a skin on the job while we present the part to the robot and across the skin, which is in the order of three meters by sort of nine meters. So it's quite big. There. Is various length pins in various different locations. And so we use the VR goggles to overlay the pin lengths at the various holes. So rather than an operator having to go and walk back look at the drawing and see, okay, there's medium pins in these four holes, then go walk back to the part and identify where those four holes are with the goggles on it. Just they look at the hole and it tells them what length faster goes in there. So we found that first when they were sort of trying in it, they were like, Oh, this is a really crappy job. It takes forever. And we said, we're gonna go get you the goggles, and the first operator put them on, and it's like, oh, this is awesome. But then he found it was hard to look up and down with the glasses on. So because it's a tomb operator job, anyway, we had it was about working out the best sort of sequence for the process as well. So we had one operator Put the goggles on and tell the other guy what to install wear, so we had one person directing and the other person doing, and that made it easier, because they weren't trying to do two things at once. So we found, I guess, what I'm trying to say is we found that the initial barriers, a willingness to try, but then working through those sort of teething problems of with them, yeah, what is the new best way to do this job, and sort of working out the new process and what works best. Because the barrier was sometimes you actually want the goggles to not be presenting information, and they get in the way when you're not looking at the job, but you need to pick up tools or what have you. So when we separated that out, we found we had a much better uptake and usage from the operators, because one person would do it and the other one would take the jobs that that were like harder with the goggles on. Does that make sense? Yeah, that

Speaker 1 06:49

Makes perfect sense. That's really good. So I'm gonna ask the next question, what are the barriers? So you've answered that one too, which is really good. So the next one is, what do you think that affect? What do you think are the factors that impact your decision or the company's decision to purchase this particular product?

Speaker 2 07:08

Definitely a cost. So what I'd say is, like it like in any scenario, it's bang for buck when we put a new technology in, we need to make sure that the benefits that you get are worth the cost of the product. So there's not, I can think of a lot of examples across the business where they'd be really useful so that therefore you can justify the cost of a few headsets. The other thing, I'd say, is making sure that they're able to do multi programs or multiple uses. So if

you had one set of goggles and it was only suitable for one task, you're then justifying the cost of those goggles on that one task alone, and it becomes a lot harder. Whereas if that one set of goggles can do five or six different programs or five and six different uses on the job, you're getting a lot more benefit for the value of the one set of goggles. So generally, what you find with technology insertion is just about showing the savings or the reasons you would bring it in in a quantifiable manner that justify the cost to the program, the recurring of setting it all up and training and all of those sorts of things. So that's, to me, the biggest barrier.

Speaker 1 08:24

That's good, yeah? So, like, would that include productivity, yeah? So

Speaker 2 08:31

Normally, like, so where we've used it at the moment, we've got examples where, like, if you did a time and motion study on not having the goggles. So the example I was talking about if we did a time and motion study on that person, and they were having to walk across, look at the picture of the various pin locations, walk back, pick up the pins and put the job in, and we took the time to do that job, and that's and that person's movements, etc, and then we did it again with the goggles, because we had two people on before, because the sheer time it took to walk back and forth and sort of, and the scale of the product, we still use the same two people, but the job happened much quickly, because there was no walking back and forth and time wasting, because it all the time then was spent with the goggles was just insert fast Nick here. Insert fast Nick here. Insert fast Nick here. And so what we could actually show was, rather than it taking, you know, in the order of two hours to get the pins in, it suddenly came down to about 30 minutes. So that's a saving for two people for an hour and a half. And that's just one instance and one job. So if those goggles could do that for like, six or seven jobs, you're saving a lot of hours. So we we basically the IES or the industrial engineers then go and do their time and motion and on both cases, and we can quantify exactly how much time we're saving. And. Then you can use that to extrapolate out for other case users, etc, and you start to build your business case pretty easily.

Speaker 1 10:06

Nice. Thank you. So I'm going to get to the next question. So have you noticed this, so with people using it, have you noticed that there's a different level of acceptance by different people? Yes,

Speaker 2 10:20

if I'm generalizing, we obviously have a range of, you know, operators who are in their 20s all the way through to operators in their 60s. Yeah, I have, I find, generally, the more a person has exposed to technology at a younger age, the more willing they are to uptake it. But it's the same, I would say it's the same with, you know, the changes that have been made in technology through, you know, just normal cell phones, through the smartphones. And it just takes people who are less familiar with technology in general that little bit longer to jump on board that. Said, I am really generalizing. We've had some of our older members are like, this is awesome because, you know, it's something quite different and exciting for them, so all across the spectrum. But I think with any change, you have some people who are more keen to get on board based on lived experience. So if they've been doing this job for 10 years and they hate it, and, you know, it takes forever, and we're telling you, hey, that was suddenly, you're going to get to do it in half the time, they're probably more likely to get on board than, say, someone else in another area who's never had to deal with it. Yeah, you know the time wasting and things like that. So yeah, there's a few ways to look at that, but generally, I've noticed the more you let people try and ask questions on their own time. So come come to the technology on their own, rather than having a foisted on them, you get a much better result.

Speaker 1 11:46

Yeah, that's good. And have you ever been trained or educated in this type of system?

Speaker 2 11:54

No, so my experience with it is obviously just being on the floor and grabbing the goggles from the people who'd set it up so our robotics Mechatronics guys and helping the operators use them. So my role, I guess, was more facilitating the implementation of them onto the floor, yeah. But that said, I found them equally quite easy to sort of learn how to use and I found it quite easy to pick the technology up. Yeah,

Speaker 1 12:26

so how do you I'm not sure if this is you or someone else, but how do you come up and communicate your requirements for what you want done with this technology to whoever's building it? In the background,

Speaker 2 12:40

I can only assume, because I was not involved in this sort of, in the, like preconception side of things. But I think based on where we've got, where we've used them, we've now got a whole bunch of examples where I think we'd like to implement them from us. It all stems

from the engineering requirements. So we can look at the engineering requirements and say, Okay, this is the information we need to impart, and then we give that to the programming team. So to say, like, usually, where it's information that we're printing out on paper visually is sort of where we've targeted to implement it. So where we've got a visual representation of our engineering that we then print out on paper for the for the team on the floor, where, like, I printed on paper when we visually display it for them. Yeah, in rather than 's so that's, I guess, for the most of the applications we've incorporated so far, where the sort of requirements have been communicated. It's like, here is the information in 3d in a model that we'd like to present in 3d in real life. Yeah,

Speaker 1 13:46

really good. So how do you evaluate the success and the performance of using this?

Speaker 2 13:57

I guess there's two ways. So, you know, I talked about being able to quantify the savings to the company in terms of labor, yeah. So that's, I guess, the bottom line the company cares about is money. What most people care about is money. But then the second quantification, I guess, or is it more qualitative, but speaking to the people who do the job and seeing their satisfaction with it. So yeah, if you're getting those quantifiable money savings, generally, you also see that the an increase in productivity and general satisfaction of the operator doing the job as well. So you generally see a bit of a morale boost as well, because their job is easier, they're enjoying it more, yeah, so on and so forth. So I guess there's the quantifiable and the qualitative yeah side of things as well, but they generally go hand in hand.

Speaker 1 14:53

And last question, what are your thoughts on the future of this technology?

Speaker 2 14:59

I. I think it's quite good. I mean, we're only sort of really scratching the surface on what it can do on site here. I know XXXX, in the greater scheme of things, has looked is also sort of seeing where we can use it. Like I said at the moment, we're really using it only for where we currently want to give three dimensional information, but we're currently printing it out in 2d so we can take it straight to 3d visually representation for the operator. But I think there's way more opportunities to go beyond that in the work that we do. And I know XXXX is moving towards using or increasing the links between the digital theoretical world and the what we actually, what we actually build, and having a more clear link between, you know,

theoretical digital model and coming up with digital twins, so having the model reflect the as built condition as well. And so I think that all of the VR goggles and those sorts of things, and augmented reality can help create that link company as well. Sorry, I articulated that really badly. Did you get where I was going?

Speaker 1 16:13

No, no, no, that's good. But have you used? Is there any AI in anything that you use,

Speaker 2 16:21

not that I'm aware of. Okay, I think XXXX is really in its infancy with AI at the moment, yeah, being a company that values its security higher than anything else, yeah, I think it's just a little bit,

Speaker 1 16:36

yeah, of course.

Speaker 2 16:40

I think it will come too, but technology shifts tend to happen reasonably slow in big companies. So I think the VR, I think augmented reality and VR goggles and those sorts of things are much easier sort of thing to incorporate and start using without adding AI as well. But I have no doubt it will come in sort of the next years.

Appendix L: Interview Data

#	Interviewee's code	Industry	Duration	Pages	Words	Codes
1	E1	Construction	<1 hour	3	826	26
2	E2	Engineering	<1 hour	5	1672	26
3	E3	Engineering	<1 hour	7	3041	40
4	E4	Engineering	<1 hour	4	1391	25
5	E5	Engineering	<1 hour	3	737	23
6	C6	Construction	<1 hour	6	1153	20
7	C7	Construction	>1 hour	7	1657	32
8	C8	Construction	>1 hour	7	1657	32
9	C9	Construction	<1 hour	5	943	18
10	E10	Engineering	<1 hour	9	3319	61
11	E11	Engineering	<1 hour	8	3358	30
12	S12	Software	<1 hour	11	3569	41
13	S13	Software	<1 hour	12	4166	26
14	S14	Software	<1 hour	15	5600	46
15	C15	Construction	<1 hour	11	5099	64
16	C16	Construction	<1 hour	18	4171	49
17	C17	Construction	<1 hour	16	5723	61
18	S18	Software	<1 hour	10	3551	31
19	S19	Software	>1 hour	23	9777	101
20	S20	Software	>1 hour	23	9777	101
21	S21	Software	<1 hour	6	2586	39
22	S22	Software	<1 hour	6	1727	16
23	S23	Software	<1 hour	17	5172	48

Appendix M: Organisational Data

#	Title	Reports to	Industry	No. of employees	Communication
E1	Manager	Manager	Construction	<1000	Down/Up
E2	Manager	Manager	Engineering	>1000	Down/Up
E3	Engineer lead	Manager	Engineering	>1000	Down/Up
E4	Manager	Manager	Engineering	>1000	Down/Up
E5	Engineer lead	Manager	Engineering	<1000	Down/Up
C6	Manager	Manager	Construction	<100	Down/Up
C7	Director	Director	Construction	<100	Down
C8	Manager	Manager	Construction	<100	Down/Up
C9	Director	Director	Construction	<100	Down
E10	Manager	Manager	Engineering	>1000	Down/Up
E11	Engineer	Manager	Engineering	>1000	Down/Up
S12	Director	Director	Software	<100	Down
S13	Director	Director	Software	<100	Down
S14	Director	Director	Software	<100	Down
C15	Manager	Manager	Construction	>1000	Down/Up
C16	Manager	Manager	Construction	>1000	Down/Up
C17	Manager	Manager	Construction	>1000	Down/Up
S18	Director	Director	Software	<100	Down
S19	Director	Director	Software	<100	Down
S20	Manager	Manager	Software	<100	Down/Up
S21	Director	Director	Software	<100	Down
S22	Director	Director	Software	<100	Down
S23	Director	Director	Software	<100	Down