Enhancing Construction Health and Safety Training using Handheld Augmented Reality for Site Safety Protocols in New Zealand

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A thesis/research component submitted to
Auckland University of Technology
in (partial) fulfilment of the requirements for the degree of
Master of Creative Technology (MCT)

2025

School of Future Environments

Abstract

Recent studies have explored the use of augmented reality (AR) to improve safety training in construction. Multiple studies conclude that it is more effective and engaging than traditional methods. However, limited research exists on how specific trades such as crane operators and riggers accept and adopt AR applications in their workflows. My research aims to explore the development of a handheld AR training application designed to support compliance with safety protocols and improve hazard awareness, specifically within the New Zealand infrastructure construction context. Using a mixed-methods approach combining pre- and post-training surveys with focus group discussions, the study evaluates changes in participants' knowledge and attitudes.

The research question guiding my study is: *How can a user-friendly handheld AR training application be designed to improve safety awareness and hazard preparedness for crane operators and riggers in infrastructure construction?* The objective is to evaluate its usability, realism, and effectiveness using a mixed-methods approach.

Early prototyping revealed that expert advice emphasises user friendly designs, realism and site-specific activities to ensure a contextually relevant AR training application. My study encourages future research on exploring the long-term retention of adopting handheld AR in existing site safety processes to observe the benefits of AR incentivised training programs.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

11 July 2025

Acknowledgements

I would like to express sincere appreciation to my supervisors Dr Rachel Shearer and Dr Stefan Marks for their guidance in developing this thesis. I also want to thank Dr Ali GhaffarianHoseini, for his early guidance and insightful suggestions that helped shape the conceptual direction of this research. In addition, I would like to thank Riggers and Operators Limited (R&O) for providing their valuable consultation and support in collecting data on their employees.

Ethics Approval

To conduct this research, ethical approval was applied for on 26/09/24 and granted by the AUT Ethics Committee (AUTEC) on 21/10/24 under the number 24/300 (see Appendix A).

Chapter 1 Introduction

1.1 Research Context

The construction sector plays a vital role in New Zealand's economy, contributing over NZD 17 billion to GDP in 2024 and employing more than 200,000 people—approximately 10% of the national workforce (Statista, 2025). Despite its economic significance, the industry faces persistent safety challenges. Between June 2022 and May 2023, WorkSafe reported 6,240 injury cases resulting in more than a week away from work (WorkSafe, 2025). These incidents are often linked to inadequate training, especially among workers in small to mid-sized firms where formal induction and refresher programs are limited or absent (Namian et al., 2016).

1.2 Augmented Reality Technology and Application

As stated by Azuma et al. (2001), AR is defined as the overlay of digital models onto physical environments. AR belongs to the broader reality-virtuality continuum, which includes virtual reality (VR) and augmented virtuality (AV) (Milgram & Colquhoun, 1999). Unlike VR, AR systems operate interactively in real time and align virtual content with real-world objects, making them particularly suitable for safety-critical applications. AR is categorised under three primary display types.

- Video-See-Through (VST) systems, such as smartphones and tablets, which overlay digital content onto live video feeds.
- Optical-See-Through (OST), such as smart glasses and head-up-displays, which superimpose digital overlays onto their field of view.
- Projective AR which uses external projectors to project digital content directly onto physical surfaces (Khorrami Shad et al., 2024).

AR has demonstrated value across several domains within the industry such as architecture, maintenance, and inspection (Souza, 2019; Adamska, 2023). To ensure the deployment of my mobile AR training system, I have investigated available Software Development Kits (SDK) targeted for both hardware platforms, such as ARKit

(Apple) and ARCore (Google), which are commonly built using the Unity 3D AR Foundation package (Unity Technologies, 2025).

1.3 Problem Statement

This study investigates how a handheld AR training application can be designed to improve safety awareness and hazard preparedness for crane operators and riggers in New Zealand’s infrastructure construction sector. The primary objective is to develop and evaluate a user-friendly AR tool that represents site-specific hazards and supports safer lifting practices. The main research question asks: How can a user-friendly AR training application be developed to target site-specific safety hazards and improve safe lifting practices for crane operators and riggers? In order to answer the main research question, the study was guided by four sub-questions that split the inquiry into four distinct areas: usability principles, accurate hazard representation, design features for hazard recognition, and user perceptions of AR training compared to conventional methods. The sub-research questions are as follows:

Sub-Research Questions:

1. What usability principles are most effective for handheld AR safety training in construction contexts?
2. How can site-specific hazards be accurately represented in AR for crane operators and riggers?
3. What design features support user participation and hazard recognition in AR training modules?
4. How do users perceive the effectiveness of AR training compared to traditional methods?

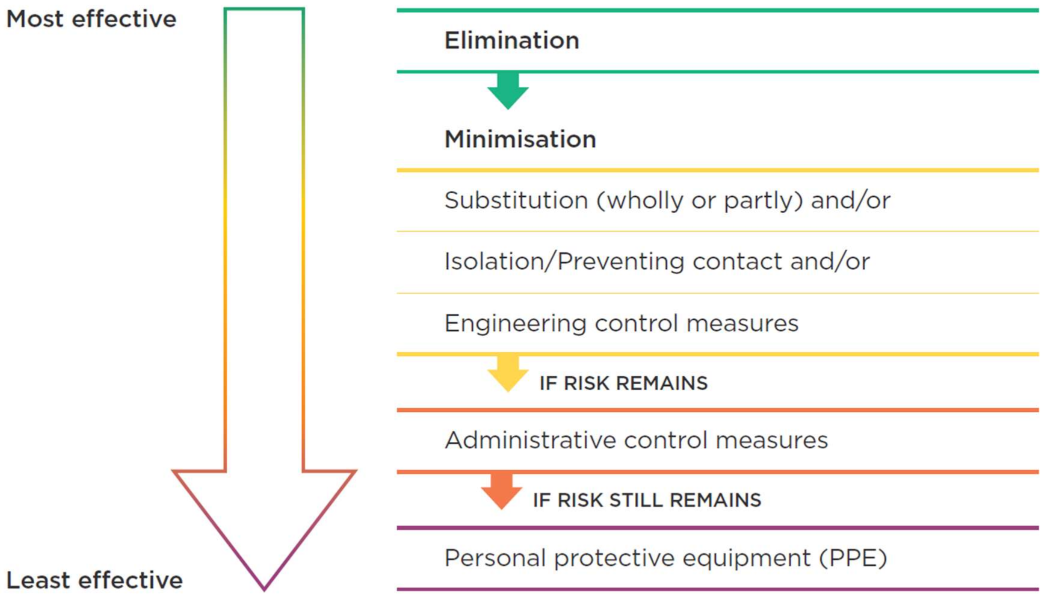
Chapter 2 Literature Review

2.1 Traditional Safety Training in Construction

Previously research has shown that safety training plays a vital role in improving worker compliance with occupational health and safety (OHS) requirements. While many safety regulations are embedded across organisations, they are best understood through the application of the hierarchy of controls, which is a structured framework that prioritises risk management measures from most to least effective (see Figure 1) (WorkSafe, 2017). This hierarchy, outlined in New Zealand's Health and Safety at Work (General Risk and Workplace Management) Regulations 2016, guides Persons Conducting a Business or Undertaking (PCBUs) to "eliminate or minimise risks so far as is reasonably practicable" (WorkSafe, 2017).

Figure 1

Risk management; Hierarchy of controls (WorkSafe, 2017)



The hierarchy of controls are usually applied in the following order:

- Elimination – Remove the hazard entirely from the workplace.
- Substitution – Replace the hazard with something less harmful.
- Isolation – Separate people from the hazard (e.g. barriers, enclosures).
- Engineering Controls – Use physical means to reduce risk (e.g. ventilation, machine guards).
- Administrative Controls – Change how people work (e.g. training, procedures, scheduling).
- Personal Protective Equipment (PPE) – Use protective gear as a last line of defence

In New Zealand, regulatory bodies like WorkSafe provide construction workers with guidelines to perform tasks safely and responsibly (WorkSafeNZ, 2017a). Safety is such a priority in this instance, and having the right guidelines helps to ensure that workers and trainees are safe and skilled to perform their duties well. In this sense, a skilled and trained workforce results in a productive organisation while reducing the number of accidents and injuries onsite.

Burke et al. (2006) conducted a comprehensive meta-analysis at Tulane University, USA, to evaluate the relative effectiveness different worker safety and health training methods. The researchers reviewed 95 quasi-experimental field studies carried out between 1971 and 2003, spanning 15 countries and involved approximately 20,991 participants. Training methods were categorised based on three levels of trainee engagement:

- Least engaging: Passive formats such as lectures, printed materials, and instructional videos
- Moderately engaging: Programmed instruction, feedback mechanisms, or computer-based training
- Most engaging: Hands-on learning, behavioural modelling, and simulation-based methods incorporating dialogue and reflection (Burke et al., 2006).

The researchers revealed that more interactive methods consistently correlated with stronger outcomes across each dimension, safety knowledge, safety behaviour and safety and health. Specifically, the most engaging training approaches resulted in effect sizes approximately three times larger than those associated with passive training in terms of safety knowledge acquisition. Additionally, hands-on methods were most effective in reducing accidents and injuries. While all forms of training showed some positive effect on safety behaviour, the gains were more modest and more sensitive to task complexity. The researchers also observed that even minor improvements in interactivity, such as including feedback or structured reflection, led to significant enhancements in learning retention and application (Burke et al., 2006). These findings challenge the overreliance on passive, one-way instructional models (including some modern e-learning formats) and support a shift toward learner-centred, participatory training frameworks, particularly for high-risk work environments.

International research further reinforces the importance of structured training and supervisory enforcement. In Kenya, Abaya & Ondieki (2021) explored the impact of OSH training on safety-related behaviours among construction workers and supervisors in Embakasi South. Using surveys and interviews with 250 participants, they found that trained individuals were more capable of identifying hazards, using PPE correctly, and following safe operating procedures. Supervisors who received training were more likely to initiate toolbox talks, monitor compliance, and intervene when unsafe behaviours were observed. This was revealed further after regression analysis confirmed a statistically significant link between training and site-level safety performance (Abaya & Ondieki, 2021). In South Africa, Othman (2012) investigated the causes of non-compliance with health and safety regulations among contractors in the KwaZulu-Natal region. Through surveys and interviews with 40 contractors from small to large sizes from the Master Builders Association, the study identified key factors such as worker negligence (48%), poor PPE use (24%), inadequate training (15%), and poor supervision (13%) as drivers of non-compliance. This is echoed further by Umeokafor & Umeadi (2014), who conducted a literature-based review of OSH compliance in Nigeria’s construction sector. Their analysis identified five broad determinants of compliance: institutional/legal (e.g. outdated legislation, weak enforcement), socio-cultural (e.g. fatalism, poor attitudes), organisational (e.g. limited training, cost-driven decisions), socio-economic (e.g. low awareness, informal labour), and industrial (e.g. weak client enforcement, poor procurement practices). These systemic issues contribute to inconsistent implementation of safety standards in international contexts settings and point to the importance of interventions that effectively enforce these safety standards.

2.2 Crane Safety Protocols and Compliance

Crane safety regulations in New Zealand have been developed to manage the critical risks associated with lifting operations, protecting workers, the public, and physical assets (WorkSafe, 2019). These obligations are formally backed by the *Health and Safety at Work Act 2015* (HSWA), which empowers regulatory bodies such as WorkSafe New Zealand to enforce risk management practices. To support this framework, the Approved Code of Practice (ACOP) for Cranes, originally published under the Health and Safety in Employment Act 1992 and now administered by WorkSafe, remains a recognised guide for preferred work practices. While not formally updated to reflect HSWA 2015, it continues to provide practical procedures for crane inspection, operator certification, load handling, exclusion zone setup and site communication procedures (Department of Labour, 2010). For example, the ACOP specifies key requirements that operationalise HSWA duties, such as operator and rigger competency through recognised NZQA unit standards, implementing correct rigging techniques, accurately reading and applying crane load charts, maintaining clear exclusion zones, and using consistent communication methods like hand signals or radio. It also provides equipment-specific standards for a range of cranes, including tower, mobile cranes, truck loaders and gantries, and introduces structured tools such as inspection checklists, risk assessments, and lift planning protocols to enhance hazard management (Department of Labour, 2010).

Although the ACOP defines these procedures, WorkSafe’s Crane Safety for Construction Site Managers and Supervisors fact sheet reinforces them by identifying common failure pathways and site-level checks (WorkSafe, 2017). Some dangers associated with crane operations are noted, such as uneven or soft ground conditions, under-extended outriggers, proximity to buried utilities or power lines, and miscalculated loads. Additionally, mechanical failures from poorly maintained equipment, incorrect rigging practices, and exceeding the crane's rated capacity may often stem from overlooked planning factors (WorkSafe, 2017). While structured tools, such as checklists, lift plans, and risk assessments, form the procedural foundation of crane safety management, their effectiveness relies on being actively supported by real-time site supervision. WorkSafe (2017) advises that site managers play a critical role not just in reviewing documentation but in verifying that exclusion zones are enforced, lifting equipment is compliant and fit for use, and that safe lifting sequences are executed as planned. This dynamic oversight ensures that paper-based safety controls are translated into real-world actions that reduce the risk of tip-overs, collisions, and dropped loads (WorkSafeNZ, 2017a).

Site Safe's Toolbox Talk: Rigging and Dogman Best Practices expands on the riggers responsibilities by providing practical guidance around safe lift planning, selection of certified lifting equipment, and the application of correct slinging techniques (SiteSafeNZa, 2024). During a planned lift, for example, the rigger is responsible for ensuring that the combined weight of the load and associated rigging components remain within the crane's designated Working Load Limit (WLL) (Department of Labour, 2010; WorkSafe, 2019). This includes using certified equipment, such as slings, shackles, hooks, and thimbles, and routinely verifying that all gear remains fit for purpose.

International research conducted in Europe by Aneziris et al. (2008) provides a systems-level perspective on crane-related incidents. The researchers employed Functional Block Diagrams (FBDs) and bowtie models to map causal pathways, drawing on data from the Dutch GISAI (2005) database, which included 102 reported crane accidents. The researchers highlighted the significance of maintaining safe spatial distances between personnel and cranes, with worker positioning in "dangerous zones" identified as a major risk factor. The models emphasised the role of engineering and procedural controls, such as rigging stability checks, proper load management, and physical barriers, in preventing fatalities. Aneziris et al. (2008) categorised risk states as either "proper" or "improper," where the former reflects adherence to control measures and the latter indicates their absence or failure. For example, during lifting operations, the presence of exclusion zones, stable crane placement, and clearly communicated lift initiation points are critical to minimising the likelihood of contact between workers and suspended or falling loads.

Researchers from Western Sydney University in New South Wales (NSW), Australia investigated whether crane and scaffold operations on large construction sites complied with Work Health and Safety (WHS) laws (Saha et al., 2018). They three case incidents that occurred on construction sites in Sydney:

- A 2012 crane collapse at the University of Technology Sydney
- A 2014 scaffolding collapse in Mascot
- A 2014 crane fire at the Barangaroo development project

The researchers focused mainly on the causes of failure and the level of compliance with WHS regulations in each incident. Several key issues were highlighted throughout each of these cases: this included non-compliance with WHS protocols, particularly around maintenance, inspections, communication, and safety culture which were all contributing factors. Moreover, the Ultimo crane fire and collapse resulted from fuel leaks and lack of maintenance, which nearly caused widespread casualties in the surrounding CBD area. The Mascot scaffold collapse was attributed to broken cables, debris load, and prior unresolved safety concerns, leading to injuries and structural damage. While, the Barangaroo crane fire originated from a welding-related formwork fire in the crane’s vicinity, prompting site evacuation and full crane integrity review (Saha et al., 2018). Each of the cases highlighted the absence of regular safety and maintenance checks which needed to be carried out to ensure that the cranes were safe to work on site.

Beavers et al. (2006) conducted an in-depth empirical analysis using data from the U.S. Federal OSHA Program’s Integrated Management Information System (IMIS). Using search keywords such as ‘crane,’ ‘derrick,’ and ‘boom,’ and identified 125 crane-related fatal events that occurred between 1997 and 2003. This analysis was based on full OSHA case files, that provided an in-depth view of each incident by classifying cases across several key dimensions: (1) proximal cause and contributing physical factors, (2) victim’s occupation, (3) worksite by end-use, (4) construction operation, (5) employer’s safety and health program, (6) union representation, (7) type of crane, (8) certification and experience, and (9) OSHA citations. The analysis revealed multiple contributing factors behind crane-related fatalities, including improper rigging, inadequate supervision, and lack of formal training. These findings underscore a systemic issue in safety compliance and training particularly for workers involved in crane lifting operations.

Recent national data on WorkSafe's fatality summary revealed a 12-month period from the beginning of 2024, that underlined 12 work-related fatalities that occurred in the construction sector, resulting in a fatality rate of 4.81 per 100,000 workers (WorkSafe, 2025a). While fatality rates vary across industries such as agriculture, transport, manufacturing, disaggregated data show that many of the recorded deaths were linked to high-risk incident types: vehicle-related events (28 fatalities nationally), rollovers (8), and being struck by falling objects (7).

These incident types are closely associated with crane-related operations, including site mobility, load handling, and lifting tasks. As Beavers et al. (2006) observed in their analysis of crane fatalities, such patterns underscore the need for targeted safety interventions, particularly during operational phases like mobilisation, steel erection, and lifting.

2.3 Augmented Reality in Safety Training

Past literature has suggested using game-based technology for virtual training to address limitations of traditional methods. For example, Guo et al. (2012) created a multi-user safety training platform that applies game technology into safety training for construction plant operations. The researchers built a platform using the game engine software, 3DVIA Virtools, that supports the use of human-computer interaction, multi-user operation, and intelligent functionality in simulating real-world conditions of a virtual environment (Guo et al., 2012).

The authors describe a conceptual framework, consisting of three components, which they applied in their research design (see Figure 2).

Figure 2

Conceptual framework for game technology. Adapted from (Guo et al., 2012); figure not reproduced due to copyright restrictions.

The key components describe the following:

- Interactive Instrument: Workers can engage with digital simulations of construction sites, using game controllers, keyboards, and multi-user collaboration tools to replicate crane operations and safety procedures.
- Multi-User Instrument: The platform allows multiple users to operate and train simultaneously, enhancing team coordination and communication, which are critical in high-risk construction activities.
- Intelligent instrument: Embedded intelligent algorithms identify potential hazards, providing real-time warnings and suggested corrective actions to prevent accidents.

The researchers evaluated the training platform with fifteen trainees across five construction projects using interviews and questionnaires survey, and found that trainees generally reported feeling positive towards the training as well as identifying safety risks (Guo et al., 2012). Additionally, trainees felt they could collaborate more efficiently especially during the crane tower tasks as communication was essential. Although an effective solution, some of the participants critiqued the platform, suggesting that as many safety problems arise because of the operatives personal behaviour and attitude, resulting in risky occurrence appearing in the first place (Guo et al., 2012).

In their comprehensive review, Chiang et al. (2022) who are based in Shanghai, China, explored the use of AR in vocational education and on-the-job training (OJT) across a 21-year span (2000–2021). They systematically analysed 80 peer-reviewed studies across several academic databases. Using specific inclusion criteria, they identified 17 empirical studies, and 12 of these were selected for a meta-analysis to assess the overall impact of AR on training outcomes. Their method combined bibliometric mapping to visualise research trends with qualitative and quantitative analyses of the selected studies. The findings revealed that AR was commonly applied in industry (35%), vocational institutions (26%), and healthcare (13%), with applications ranging from maintenance and welding to hazard identification and surgical training. Their review concluded that AR was shown to significantly improve vocational skills, particularly in procedural accuracy, spatial visualization, and learner motivation.

In the field of Occupational Safety and Health (OSH) a study by Kamal et al. (2022) explored the effectiveness of an AR application called HazHunt, which was created by researchers at the university of Malaysia, as a method of improving OSH in mechanical and chemical hazards. Their study outlined three key objectives:

1. What is the effect of implementing AR technology (HazHunt) towards academic performances in OSH training?
2. What is the motivational impact of deploying HazHunt as a part of the OSH training?
3. What is the usability level of the developed AR tool (HazHunt)?

To achieve this, the researchers first built the HazHunt application using the Vuforia Software Development Kit (SDK), which delivers AR content on mobile devices and applied hazard pictograms depicting several types of hazards such as corrosion, explosion, fire, general, health, oxidizer, and toxicity hazards (see Figure 3) as AR image markers. These markers contained media such as videos, descriptions and quizzes, which all related each hazard type (Kamal et al., 2022).

Figure 3

HazHunt Hazard Pictograms (Kamal et al., 2022).

Secondly, the training was then conducted in two short online training sessions, in late 2021, during the COVID19 pandemic. The researchers carried out a quasi-experimental design that involved an experimental group (EG) and control group (CG), consisting of 22 participants each, who were all university staff and students. The CG's training was delivered using a presentation lecture followed by a Q&A slot and a post-quiz, while the EG's training were provided with the HazHunt APK file to download. Each training group involved officers from the Department of Occupational Safety and Health (DOSH) who instructed the participants and acted as trainers. Their performance was measured using a post-quiz that assessed their knowledge retention and hazard identification skills using multiple-choice questions. Post training, a Reduced Instructional Materials Motivation Survey (RIMMS) based on the ARCS model and System Usability Scale (SUS) were filled out by both groups, to assess their motivations and usability perceptions of the AR application (Kamal et al., 2022). Interestingly, their findings indicated, that the EG who used HazHunt, scored slightly higher in their post quiz assessment than the CG groups who received traditional training. Additionally, the RIMMS survey and SUS highlighted that AR significantly boosted confidence and attention of users, as learners noted the AR application to intuitive and highly engaging to use as a training tool. However, these comments did not reflect the AR system's success in improving knowledge retention, as the findings suggested that users only felt that the app enhanced the overall experience of certain hazard identification tasks instead.

In Melbourne, Australia, researchers compared the impacts of AR and VR training to traditional classroom methods in construction safety education using a hybrid evaluation framework based on Keller's ARCS motivational model (Shringi et al., 2023). They recruited 60 trainees who were from construction and engineering fields from Monash University who were divided into three groups, each exposed to training across the three training platforms, using Australian safety codes as content (Shringi et al., 2023). The AR training was delivered using the Microsoft HoloLens 2 headset, the Samsung Odyssey for VR, and the traditional method relied on presentation slides. A classroom space was used to allow trainees to view life-sized hazards in both AR and VR, such as workers falling, PPE use, or improper ladder positioning. They found AR was more effective in promoting motivation and knowledge retention in safety training compared to traditional and VR training methods (Shringi et al., 2023).

Further evidence comes from Paes et al. (2024) who developed an optical see-through AR fire safety training system that improved fire safety training. The training required users to navigate hallways while completing fire response tasks while being guided by a virtual firefighter. A controlled between-subject experiment was used with 50 participants, randomly assigned between two control groups; one who received AR using a Hololens 2 and one who received a first-person video on a screen (Paes et al., 2024). Results from their pre-training, post-training and four-week follow-up questionnaire revealed a key reception towards the AR group who demonstrated greater confidence towards fire emergencies responses compared to the video-based control group.

A case study was conducted by Gong et al. (2024) who applied AR training towards a metro construction site in Suzhou, China (Gong et al., 2024). The researchers used accident reports and stakeholder interviews to inform their AR training design, which resulted in 15 scenarios covering one of six hazard types identified within the accident reports; Crane-related accidents, Falls from height, Vehicle injuries, Collapses, Mechanical injuries and Object strikes (Gong et al., 2024). A controlled experiment involving 72 participants were randomly assigned between an AR group, who received a QR code that was scanned using a mobile app and a slides group (Gong et al., 2024). The training involved three parts.

1. General site specifications: Introduces how personnel should operate appropriately on site.
2. Hazard-specific practices: where six hazard types are presented and explored.
3. Construction safety protection: Focuses on the correct use of safety equipment (Gong et al., 2024).

Their findings revealed that AR-trained individuals performed significantly better in hazard identification, risk assessment, and response tasks than those trained with traditional slides.

In his case-study developed at the University of Niš, in Serbia, Tatić (2018) developed an AR system that improved the occupational safety of circuit breaker tasks, found in electrical substations. This AR system had specific key goals to evaluate its success; keepi the attention of workers to ensure necessary steps were applied, provide precise visual information directly at the workplace, reduce the time in explaining instructions by safety officers, and keeping records of all examined task instructions in a database for future monitoring and job tracking (Tatić, 2018). Their AR system used several modules consisting of UI, AR and tasks that delivered safety and work instructions through two registered image plate markers. A case study was conducted on existing workers at the substation who tested the AR system, that focused on changing a circuit breaker within the electrical substation (Tatić, 2018). Experts in the related field of electro-energetics also validated the AR system and approved of its practical value, and potential in improving occupational safety across the electro-energetic industry.

A systematic literature review, conducted by Khorrami Shad et al. (2024) explored a number of studies which reflected the trends of AR combined with construction 4.0 technologies as of late 2021 to 2022. The researchers applied PRISMA to filter out 29 out of 386 total articles, from several databases, that focused on AR within construction safety. Each article was analysed according to their safety aim which related to either their pre-event, during-event, or post-event application. Pre-event applications aimed to prevent construction-related incidents, while during-event applications assisted with managing active hazards, and post-event systems supported damage assessment and response (Khorrami Shad et al., 2024). Additionally, each event fell under different sub-safety aims, for instance, pre-event applications aligned with sub-safety aims such as intelligent operation, training, safety inspection and hazard alerting (Khorrami Shad et al., 2024). During-event applications fell under hazard pinpointing and post-event included damage assessment. Khorrami Shad et al. (2024) found that 89.7% or 26 studies focused on pre-event applications, 6.9% focused on during-event and post-event applications, and only 1 explored post-event safety. Of the reviewed studies, five 4.0 technologies emerged; BIM, IoT, AI, robotics, and cloud computing (Khorrami Shad et al., 2024). BIM was identified by 59% of studies to be the most frequently used technology combined with AR in safety applications.

As mentioned by Khorrami shad et al. (2024) in their review, the application of AR and construction 4.0 technologies is dependent on its pre-, during- and post-events application. Furthermore, my research aims to explore more closely the barriers and perceptions of these AR technologies as it appears towards specific pre-event and sub-safety aims.

2.4 Perceptions of AR Technology

Sitompul & Wallmyr (2019) conducted a systematic literature review on the application of AR technologies in heavy machinery operations, focusing on cranes, tractors, and construction vehicles. The researchers utilised keywords such as “augmented reality” and “cranes,” (used across each machinery type), to identify 233 articles, which were later filtered down to 39 relevant articles based on applicability of AR enhanced operator assistance. The studies reviewed were categorised by technological approaches and classified into two primary operational types:

- In-Cabin Operation, where AR enhances visibility and hazard detection for operators working inside machinery cabins.
- Tele-Operation, where AR provides remote support for operators, assisting in manoeuvring and task execution from a distance.

The researchers revealed in one of the studies that a group of six employees who were mobile crane operators acquired a head-down display assistive system designed to provide visual guidance during lifting operations. This system presented critical visual data on the operations, including load capacity warnings, lifting path indicators, and proximity alerts, on a fixed display positioned within the crane cabin. While this system intended to improve the situational awareness and precision of workers, Sitompul & Wallmyr (2019) notes that it also required operators to divert their attention away from the lifting area, which increases the cognitive workload and response time from workers. Additionally, this system experienced technical limitations which affected its usability within the field, including a limited field of view, inaccurate sensors and object recognition, which leads to misaligned tracking of visual overlays (Sitompul & Wallmyr, 2019). While head-down display systems in mobile crane operations remain largely experimental, their integration into standard workflows is still limited due to operator unfamiliarity and lack of practical exposure (Sitompul & Wallmyr, 2019).

Porcelli et al. (2013) conducted an industrial case study, investigating the implementation of AR in a live industrial environment maintenance assistance services, and found challenges, that stemmed from unstable hardware performance, unintuitive interfaces, and the overall difficulty of integrating AR into existing maintenance protocols. The researchers note that in collection with limited staff training and user unfamiliarity with AR environments, this led to a growing hesitation and resistance during deployment. Therefore the researchers suggested that, the successful adoption of AR in this industrial environment would depend not only on the availability of AR systems but on how cantered they are with organisational workflows and the preparedness of end-users (Porcelli et al., 2013).

This similarly aligns with findings from Finnish researchers, at Tampere University who presented an examination on the organisational adoption of mixed-reality technologies (XR), by focusing on the managerial expectations of resistance found by employees (Jalo & Pirkkalainen, 2024). The researchers utilised quantitative modelling and qualitative interview deployed in two parts, the first part, which was based on a conceptual framework, the Technology–Organisation–Environment (TOE), which categorised the influences on perceived resistance and value. The second part involved interviews with 58 managers from European industrial companies. The researchers revealed in that an employee's perceived resistance intersects with organisational value which influences their intention to adopt (Jalo & Pirkkalainen, 2024). Employees will prohibit the uptake of technology such as AR, even when the clear strategic benefits of it are demonstrated (Jalo & Pirkkalainen, 2024). Only after certain readiness measures are made available, which are labelled under three types; employees existing familiarity to AR tech or similar, internal training support, and trial periods; will in an increase of an employees perceived organisational value of the this tech, and and decrease their resistance towards it (Jalo & Pirkkalainen, 2024).

In the realm of consumer markets, a qualitative study by Berglund (2023) investigated user-centric onboarding processes as a strategy to minimise adoption thresholds for AR. Their study examined the structured onboarding approaches of two Scandinavian technology suppliers, focusing on their market presence, openness, and activity in the AR domain. Using a multiple holistic case study approach, Berglund (2023) conducted semi-structured interviews with six industry professionals responsible for onboarding programs, alongside additional follow-ups with technical specialists. These interviews explored customised onboarding frameworks, including step-by-step product training, remote installation and commissioning workflows, and interactive knowledge transfer models. The interviews revealed that a gradual implementation approach greatly reduced the resistance to adopt AR. Although pertinent to AR adoption, this study's focus was not in the context of construction related safety, as it focused primarily on consumer products.

Wang & Dunston (2007) conducted a qualitative study at Purdue University, USA, and the University of Sydney, Australia, the challenges of adopting AR in construction training. They developed an AR-based training system (ARTS) designed to help novice heavy equipment operators gain hands-on experience in real-world construction environments using virtual materials and interactive instructions. Their research led to key barriers to AR adoption being identified, such as technology transfer issues, social attitudes, and technological maturity Wang & Dunston (2007). Additionally, they found that the limited industry-wide adoption, compatibility concerns, and the absence of standardised AR training frameworks made large-scale implementation of AR difficult. It is interesting to note that many experienced operators in the study preferred the conventional training method, as scepticism and concern a primary sentiment towards AR and the hesitancy to adopt new technologies in general into their workflow (Wang & Dunston, 2007).

To overcome these adoption concerns, models had been established to provide us with the metrics that examine the acceptance and adoption criteria of new technology systems by users. For example, Davis (1989) explored in his seminal study, “Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology”, at the University of Michigan, measurement scales that was validated based on two key constructs: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). He defined PU as "the degree to which a person believes that using a particular system would enhance his or her job performance" and PEOU as "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 330). To test these constructs, Davis conducted two empirical studies involving 152 users across four application programs, assessing how PU and PEOU influenced system usage (Davis, 1989). His findings revealed that PU had a significantly stronger correlation with usage behaviour than PEOU, indicating that users prioritised functionality over ease of use when adopting new technologies (Davis, 1989). In addition, it was later demonstrated using regression analysis that PEOU influenced PU, enforcing the idea that systems that are easier to use are perceived as more beneficial and useful (Davis, 1989). These findings led to the foundation of the well-known Technology Acceptance Model (TAM), which has since evolved within the domains of IT (Davis, 1989). This model has since then been tested in different domains such as construction safety. While Davis’s TAM framework has faced critique for its age and simplicity, its core constructs, perceived usefulness and perceived ease of use, remain directly relevant to understanding user acceptance in technology-based training. Recent studies (Taherdoost et al., 2024; O’Dea, 2025), have proposed more complex frameworks, yet these often introduce methodological overhead and context-dependent variables that may dilute focus in sector-specific applications. For this study, TAM was selected due to its empirical reliability, clarity, and proven applicability across domains including construction safety. Its simple structure enables targeted insights into behavioural intent, making it a pragmatic choice for evaluating AR training adoption among crane operators and riggers.

More recently, an empirical study in late 2020 was conducted by a group of researchers out in Chile, who developed a mobile AR training application which allowed construction workers to interact with virtual safety elements related to hazard prevention of scaffolding assembly (Placencio-Hidalgo et al., 2022). The researchers incorporated marker-based tracking which utilised a mobile device to access the virtual overlays of crucial scaffolding components. These included fastening points, railings, skirting boards, and structural bracing, (see Figure 4). The researchers assessed the app's impact and acceptance, using a survey that measured key TAM variables; PU, PEOU, attitude toward using (ATU), and behavioural intention to use (BIU). Their study involved a sample of about fifty construction workers originating from 29 Chilean construction companies, these all consisted of trainers and training managers. A survey was presented to all construction workers and their responses were collected and measurements were evaluated using Cronbach's Alpha. The results indicated that trainers and training managers perceived the AR application as being highly beneficial for illustrating scaffolding safety concepts and indicated a user-friendly response to the app's design in minimising cognitive overload.

Figure 4

AR training application on scaffolding. Adapted from (Placencio-Hidalgo et al., 2022); figure not reproduced due to copyright restrictions.

A recent 2024 study led by a team of researchers at the Luxembourg Institute of Science and Technology (LIST) developed an AR system, SMARTLab, which simulates a training scenario on the correct sequences required to mix two different chemicals in a lab; Hydrochloric acid (HCI) and potassium hydroxide (KOH) (Ismael et al., 2024). They incorporated the Unity3D engine and the Hololens 2 within their design. The researchers tested their AR system on 13 participants aged from 20 to 50 years-, who were all existing lab users from a science research department within the institute and had no prior experience with AR (Ismael et al., 2024). The SMARTLab differed from other AR systems as it included unique visual cues such as the attention funnel, in-situ arrows and virtual assistant which guided trainee attention interactively to the positions of virtual objects required to complete each task (Ismael et al., 2024). The training involved two stages, equipment selection and lab tests; where the equipment selection required trainees to correctly choose personal protective equipment (PPE) and be guided by the visual cues, represented as a flying robot (Ismael et al., 2024). While the lab tests involved performing a controlled sequence of steps to pouring hazardous chemicals supported by the same virtual guidance (Ismael et al., 2024). At the end of the training, the researchers collected free-form written responses & Likert scale questionnaires consisting of 42 questions from the participants. About 35 out of the 42 questions covered nine independent dimensions, assessing the user's perceived acceptance (Ismael et al., 2024). These questions were derived from and adapted based on the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2), originally proposed by (Venkatesh et al., 2012). UTAUT2 is an extension of the original UTAUT model which evolved from TAM, this model was designed to better explain consumer adoption of emerging technologies. It incorporates nine core constructs: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), Hedonic Motivation (HM), Price Value (PV), Habit (HT), Behavioural Intention (BI), and Use Behaviour (UB). In the study by Ismael et al. (2024), additional dimensions such as Personal Innovativeness (PI), Emotional Reactivity (ER), Spatial Presence (SP), Attention (At), and Realism (Re) were included to tailor the framework to the context of immersive technologies like AR, where user experience and perceptual engagement play a critical role in adoption behaviour.

2.5 Summary of gaps

From the literature reviewed, while active, hands-on training methods such as simulations and behavioural modelling outperform passive formats in improving safety outcomes, current approaches often fail to reflect the operational realities of crane work. Existing AR training tools tend to generalise hazards and overlook the nuanced spatial, mechanical, and procedural demands specific to crane operators and riggers. Moreover, the emphasis on pre-event hazard awareness leaves a gap in tools that support real-time decision-making and dynamic risk response during lifting operations.

Despite AR's growing presence in vocational education, its integration into high-risk construction roles remains fragmented and underdeveloped. Technical limitations, high implementation costs, and resistance from experienced operators, particularly when AR disrupts familiar workflows—continue to hinder adoption. Additionally, the lack of standardised evaluation frameworks and the absence of immersive design features such as spatial presence and realism further limit AR's effectiveness in safety-critical contexts.

To address these gaps, this research proposes a mobile AR training system designed specifically for crane operators and riggers. The system aims to deliver task-specific, experiential learning that not only reflects the complexity of lifting operations but also supports real-time hazard awareness and communication. By prioritising accessibility, usability, and contextual relevance, the proposed solution seeks to overcome both the technical and behavioural barriers identified in the literature and contribute to a more effective and scalable model for AR-based safety training.

Chapter 3 Methodology

The following chapter outlines the design and interactive features of the AR training application, including onboarding navigation, hazard scenario development, and real-time feedback mechanism. These elements were designed to support user engagement and safety awareness through scenario-based learning, error correction, and cognitive scaffolding aligned with industry training standards.

3.1 Approach

The primary research question guiding my research is:

RQ: How do I design a user-friendly AR training application that targets site specific dangers in infrastructure construction that are relevant to crane operators and riggers*?*

To address this, the following sub-questions were explored:

1. What usability principles are most effective for handheld AR safety training in construction contexts?
2. How can site-specific hazards be accurately represented in AR for crane operators and riggers?
3. What design features support user engagement and hazard recognition in AR training modules?
4. How do users perceive the effectiveness of AR training compared to traditional methods?

To answer these questions, both qualitative and quantitative approaches were used within my study. Qualitative methods of data collection incorporate interviews & groups discussions, which provides greater insight into the causes and behavioural perceptions of participants following an intervention. In contrast, quantitative methods use numerical values like reports and questionnaires to describe how many people might feel those behaviours. This combined the process of three data collection sources, literature reviews, site visits and interviews. The CEO of R&O was interviewed for my research. As time was a major factor, I acknowledged that this was a limiting factor, as the company's goals were prioritised. Logistical and access constraints meant that other stakeholders' interviews could not be conducted with (such as managers & trainers). The initial prototype of the AR application was developed following these data collected, which illustrated an inspection protocol regarding the pre-crane setup and lift. A follow-up consultation was then conducted with the CEO to further verify the contents of AR experience and the application's usability.

As described by Mackenzie2006), four research paradigms are outlined which shape the foundations of any study, whereby selecting the appropriate paradigm should align with your research question. The research paradigms that are highlighted include:

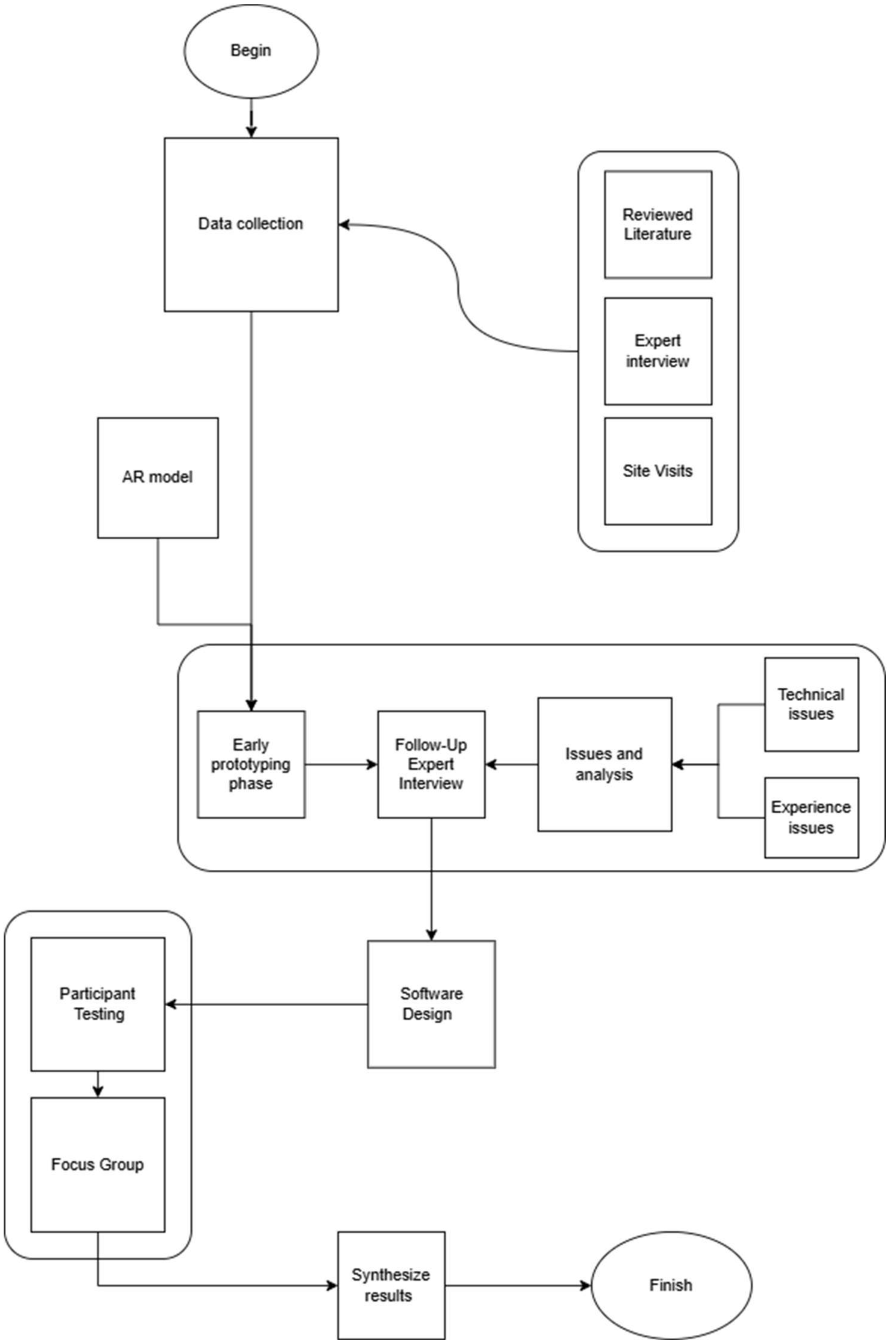
- Positivism
- Interpretivism
- Transformative
- Pragmatic

While positivism focuses on objective measurement and hypothesis testing, my research required flexibility to explore user perceptions and contextual factors. Interpretivism on the other hand, while valuable for understanding meanings people assign to experiences, this too lacked the practical orientation needed for technology deployment. The transformative paradigm focuses on social change and advocacy, which was not the primary aim of this research. Pragmatism, by contrast, supports mixed-methods inquiry and real-world problem solving, making it the most appropriate foundation for evaluating AR training tools in dynamic construction environments. Elements of constructivism were also incorporated to reflect the role of user experience and interpretation in shaping technology acceptance. The TAM framework was integrated into my study's mixed methods design to guide the development of survey instruments and interpret user feedback. Its constructs informed both quantitative measures and qualitative probes during interviews and focus groups. This approach fits well with the pragmatic paradigm's focus on producing practical results and allowing flexibility in methods, thereby supporting the study's aim to design a user-friendly AR training application that targets site-specific dangers for crane operators and riggers.

As (Figure *5*) presents, this research framework outlines the iterative process used to design and evaluate the AR training application for crane operators and riggers. The framework integrates multiple data sources, including reviewed literature, expert interviews, and site visits, which informed the early probing phase and initial design considerations. A follow-up expert interview and issue analysis helped refine the technical and experiential dimensions of the app. Participant testing involving pre- and post-surveys, followed by a focus group discussion were then conducted to evaluate usability, engagement, and perceived effectiveness. The findings were synthesised, and the outcomes directly informed the final recommendations for industry deployment and future research.

Figure 5

Research Framework



3.2 Method

3.2.1 Participants and Evaluation Design

For my research, I partnered with crane company Riggers and Operators ltd NZ, who are a small growing business, based in Auckland, New Zealand that provide crane and scaffolding services. As reflected in my literature, it was important to design an AR training application that aligned with the end-user. For my study, I aimed to co-design and develop the AR training application with trainers, supervisors, crane operators and dogmen (riggers). However, this was an unlikely outcome as the company R&O were committed to growing their own company's operations. This proved to be a major constraint in my study's design, as I initially anticipated conducting two phases of data collection and user testing to improve the AR application through an iterative process. For my participant selection, 3 workers from the company were involved in this study to collect data from. Prior to the study session, participants were provided a consent form which outlined the purpose of this research (see Appendix B). Amongst the participants, these included a crane operator with over 5+ years and 2 dogmen with 5-10 years of experience. Pre-tests and post-tests survey were developed to measure the changes in effects of the AR training application and its perceived use and realism. A focus group session was conducted to gather deep behavioural feedback from participants regarding the AR training.

The primary outcome of this study was safety awareness, assessed via a custom Likert-scale survey administered pre- and post-training. Success was defined as any positive shift in individual scores. The sample size (n=3) reflected logistical feasibility and limited access to crane and rigging personnel during the scheduled training period. My research incorporated three instruments to evaluate participant experience and outcomes: a custom safety awareness survey (see Appendix B), the System Usability Scale (SUS), and the NASA Task Load Index (NASA-TLX). For the custom survey, participants rated items on a 5-point Likert scale, with higher post-training scores interpreted as improved safety awareness. The survey was reviewed by one academic expert and one construction consultant, who confirmed the relevance and clarity of each item. SUS scores range from 0 to 100, with scores above 68 indicating acceptable usability (Brooke, 1996). Additionally, NASA-TLX scores range from 0 to 100 across six workload dimensions, with lower scores reflecting lower perceived cognitive and physical demand (Hart & Staveland, 1988).

3.2.2 Development Framework

In the design phase, I chose the Unity game engine (2021.3.6f1) as a development framework that supported the built environment of a mobile application in AR. I additionally selected Blender as the modelling software that I'd develop my 3D models within, to import into my AR application. Additionally, a number of premade 3D models were chosen from the marketplace store within Unity and other free open-source platforms, which included a main mobile crane model, construction materials and construction workers.

3.2.3 Data Collection

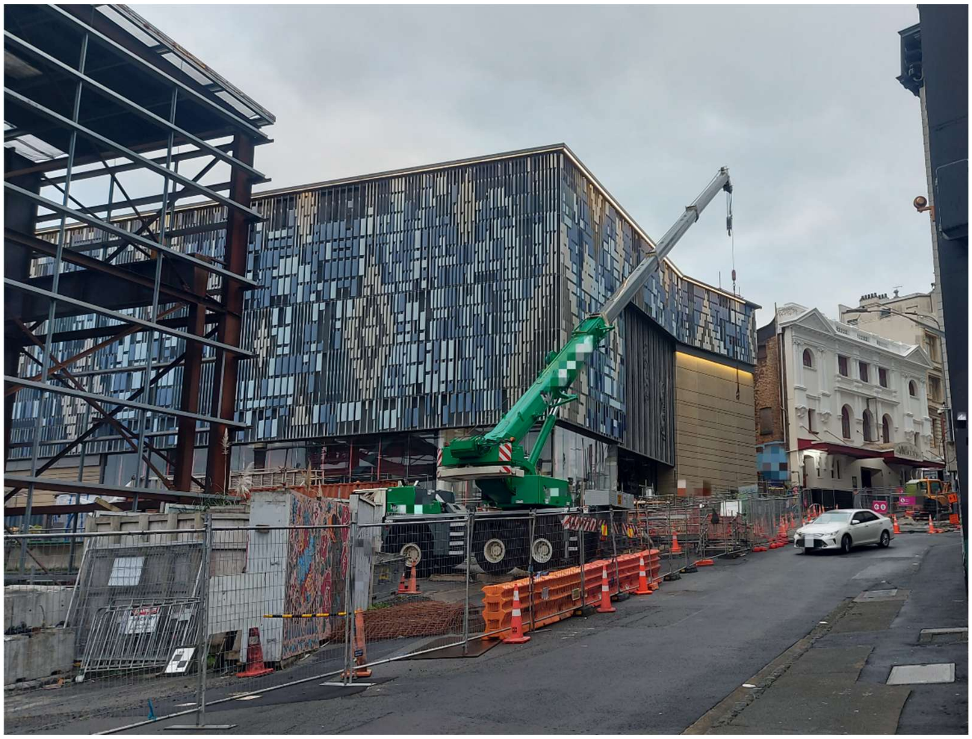
To begin this process, I initially brainstormed the most important hazards and accidents commonly experienced by crane operators and riggers on construction sites. The central problems were based on accidents report and guidelines presented by the official reports by WorkSafe New Zealand (WorkSafeNZ, 2017a). The most common accidents that were experienced as presented by the report included being struck by a falling object, powerline electrocution, crane tip-over, unsecured load. These hazards correlated most with mobile type cranes, which are often stationed within dense residential areas or infrastructure sites. Ultimately, I chose to focus on infrastructure construction sites for its often challenging and dynamic environment. In addition, most mid-large size construction projects require workers to be formally trained and inducted to ensure all responsibilities are carried out.

For each the site visit, I looked at infrastructure construction sites in my local area, the Auckland Central Business District. This allowed me to capture data that were relevant to mobile crane hazards on the construction sites.

The first site visit was an underground train station also known as Karanga-a-Hape Station (see Figure *6*) which is an infrastructure project in development. Within its' open space there is little room for the mobile crane's boom to manoeuvre which increases the risk of boom collision against nearby structures. Additionally, this scene also represents a potentially unsafe situation in which the crane's boom could be overextended onto oncoming traffic, which results in an obstruction hazard.

Figure 6

Site visit 1 – Karanga-a-Hape Station, Entrances at Beresford Square and Mercury Lane, off Karangahape Road, in Auckland CBD, Aotearoa New Zealand, visited on 08 October 2024.



The second visit was in another similar narrow space, where a small business building was under development. Much like site visit 1, (Figure *7*) presents a similar scene, having the mobile crane positioned outward towards a public road. The narrow zone involving a mobile crane near a public road, creates a situation where the risk of a load dropping caused by unsafe manoeuvres with the much heavier load, or incorrect rigging setup. One of the controls in this scenario is to include spotters and exclusion zones that provide a safe zone for the mobile crane's lift.

Figure 7

Site visit 2 - MOXY HOTEL | 16fl | 61–63 Wakefield St | Under Construction, Auckland Central, visited on 08 October 2024.

After capturing the data from two sites site visits, I sought to develop my initial AR scenes that demonstrate some of the unsafe scenarios from each scene. Due to constraints on time and limited access to larger project sites, I was unable to capture additional data on sites that had mobile cranes. Capturing additional data from other similar sites would improve the relevancy of contents and site conditions, in relation to crane operations. Since different infrastructure sites incorporate different types of cranes, tower or mobile, this study continued to focus on the telescopic boom crane type and enforce the hazards observed around this type of crane, situated within infrastructure projects. Therefore, while these valuable additions were not doable, I decided to move on to the next data collection method to further validate these unsafe factors.

3.2.4 Stakeholder Interviews

During this study, two informal interviews were conducted with the CEO of Riggers and Operators (R&O) who gave consent to provide his contextual feedback to inform my applications design. With over a decade of experience in crane operations across multiple sectors, the CEO underlined the critical hazards prevalent in crane operations, focused on site-related hazards, as they appear in infrastructure sites. The initial interview was conducted to detail these types of hazards, and a second follow-up interview was conducted to validate the accuracy and relevance of the AR module during an initial development phase. The CEO's qualifications are outlined as follows:

- 10+ years of experience in crane industry
- Oil and gas, Stevedore, Construction field
- General manager/Director

First Interview:

1. *What hazards are most prevalent and should be considered within operations overall?*
2. *What type of hazards and appear on site-specific conditions such as those in infrastructure projects?*
3. *What do you think of AR style training to improve the hazard recognition skills of crane operators and riggers?*

Site-specific Hazards (Infrastructure projects):

- "Hazard such as PPE are important to be checking with our guys. Is the worker wearing the correct PPE?, Safety goggles, helmet, safety boots, safety harness."
- "Sometimes there is unstable or muddy terrain, wet terrain, particularly in lift zones"
- "Wet or slippery ground conditions, impact the rigging stability; is the load secured properly?"
- "Overhead loads and swing radius risks, especially in confined environments; is the boom at risk of structural failure if it needs to overextend to reach load."
- "Communication breakdowns between crane operators and dogmen, especially during complex lifts"
- "I do think that AR training has the potential to improve the hazard awareness of personnel"

Second Interview:

1. *Are the hazards conveyed in each of these scenarios relevant to what crane operators and riggers might face as they appear on unique environment conditions in infrastructure projects?*
2. *Do the iterative features of this AR application appear to be easy and intuitive to use?*
3. *What improvements and suggestions would you add to improve the contents of the application to tailor it to the operators and riggers on site?*

Validation of AR content:

- Hazards such as muddy terrain, wet surfaces, and overhead loads are common and often overlooked until they become critical, which the AR application has conveyed quite clearly.
- The AR module's realism and clarity were seen as strengths, and its simplicity—activated via a marker and navigated through basic tap interactions are also considered easy-to-use.
- The risks simulated appear to be site-specific and dynamic, which indicates a positive impression from the CEO.
- This type of AR-based application helps pre-visualise hazard zones, reinforce spatial awareness, and pre-lift planning.

Suggestions for improvement:

- Some suggestions were made, regarding the hazards outlined, such as uneven terrain, overhead loads, and unstable rigging, which included the inclusion of animations and dynamic overlays. These elements could simulate the real-time consequences and reinforce hazard recognition through visual cues. The CEO also suggested the application clarified hazards contextually during different set-up scenarios to minimise cognitive load while improving the workers situational awareness.

3.2.5 Early Prototyping Phase

Initially the scale of the AR experience was brainstormed that would demonstrate that the application matched the expectations of a user-friendly scale. Setting this scale was important as this directly affected how the workers interacted with the AR application. This meant that the AR experience was shaped by its tracking method, with two known approaches applied in this context: marker-based and marker-less tracking. While marker-less supports the use of computer-vision to portray virtual points of known as features points, within the physical environment, these act as anchors for the AR host to appear in the real-world context. This can be difficult to calibrate however, as live site operations are often affected by weather and other environmental factors, causing a ‘drift’ in the AR experience; a tracking error that causes 3D objects to shift from its originally tracked position. The other option is a marker-based approach, which operates by using predefined visual markers such as a pattern or 2D image. The AR system uses the device’s camera to detect the image in the physical environment, calculate its position and orientation, and render certain virtual content at the location of the marker. There are several methods of marker-based tracking, such as QR code, Hiro markers, Image references and Real-life objects. I’ve reviewed these different lists of AR tracking methods, and each illustrate an advantage over the other; yet the most commonly identified methods; Hiro and image-reference are the most familiar and well-research approaches used by researchers (Kamal et al., 2021; Placencio-Hidalgo et al., 2022; Wang & Dunston, 2007). The image reference method was used in my study as illustrated from the early prototype phase, and this is conjured from three hazard signages common in mobile crane operations, as shown in (Figure *8*).

Figure 8

Crane Hazard Signages (SafeCrane, 2016; HealthAndSafety, n.d.; abcHealthandSafety, n.d.)

The marker was programmed using AR foundation's image tracking component, based in the unity game engine, which stored the images as references and allowed the 3D models and animations of each scene to be hosted in AR. This would then be activated after the phone's camera scanned the marker. The signage hazards were placed within unity's scene, where I could ensure that I could effectively position and correct the orientation of the 3D models and triggers within the scene (Figure 9).

Figure 9

Unity AR-marker - Crane Hazard Signage

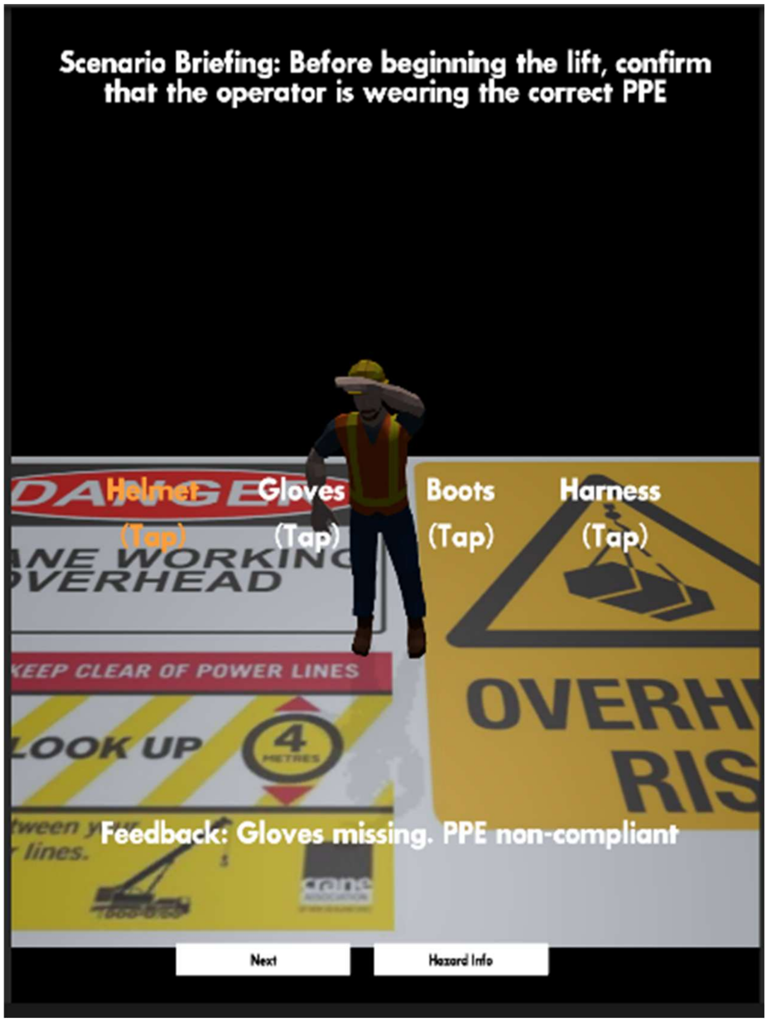
I aimed to select the key hazards that would simulate the AR training scenarios based on the hazards outlined in the interviews and the site visits. This involved using 3D models that focused on hazards that related to a pre-setup crane operation as it may occur in infrastructure site environments. Textures and materials were employed which help the 3D models appear realistic. I avoided complex extrusion and sculpting techniques that often enhance the realism feature of 3D models, though this leads to a higher polygon count, which results in performance issues in the app. It is therefore encouraged to use lower polygon count or less objects in scenes, as to not over process the hardware. To avoid a time-consuming approach like sculpting, I developed and assigned textures and PBR materials for 3D construction models that I had created within my scenes. Additionally, I developed 3D models of loads and slinging assets to help construct the hazards tied to a rigging instability module. I incorporated three different types of rigging type, chain slings, wire-rope and web-slings, each with their own shackle, and spreader configurations. This was important to ensure that I could create diversified scenarios within the same instability load module, which presents unsafe situations related to infrastructure sites. Since models needed to avoid being complex, the balance between realism and low poly count was struck based on the priority of the hazards scenarios that I was trying to simulate within my AR modules. To help me achieve this development and save time, I chose pre-made 3D models that were selected from free opensource platforms, some of which included the mobile crane pack, construction prefab pack and road pack, that all helped to demonstrate key hazards within the AR modules. I ended up emphasising realism in each asset in this case, and each asset was tested within the scene for usability to ensure that the application could run without excessive instances of lag from relatively high poly count based models.

To demonstrate the range of hazards addressed within this application, six scenarios were initially developed to represent key stages of mobile crane operations where risks are most likely to emerge. Each scenario highlights conditions that could lead to similar or recurring incidents, thereby encouraging the identification of corrective measures to minimise or eliminate those risks.

As presented in Figure 10, a scenario was developed to present a pre-operational briefing focused on verifying whether the crane operator is equipped with the required personal protective equipment (PPE) before commencing work on site. The scene provides four options of PPE that the participant can select to identify which of those items is missing. These options are based on standard site-specific PPE requirements for crane operators. Upon selection, a brief description confirms whether the response is correct and visually highlights the missing PPE item.

Figure 10

PPE Compliance



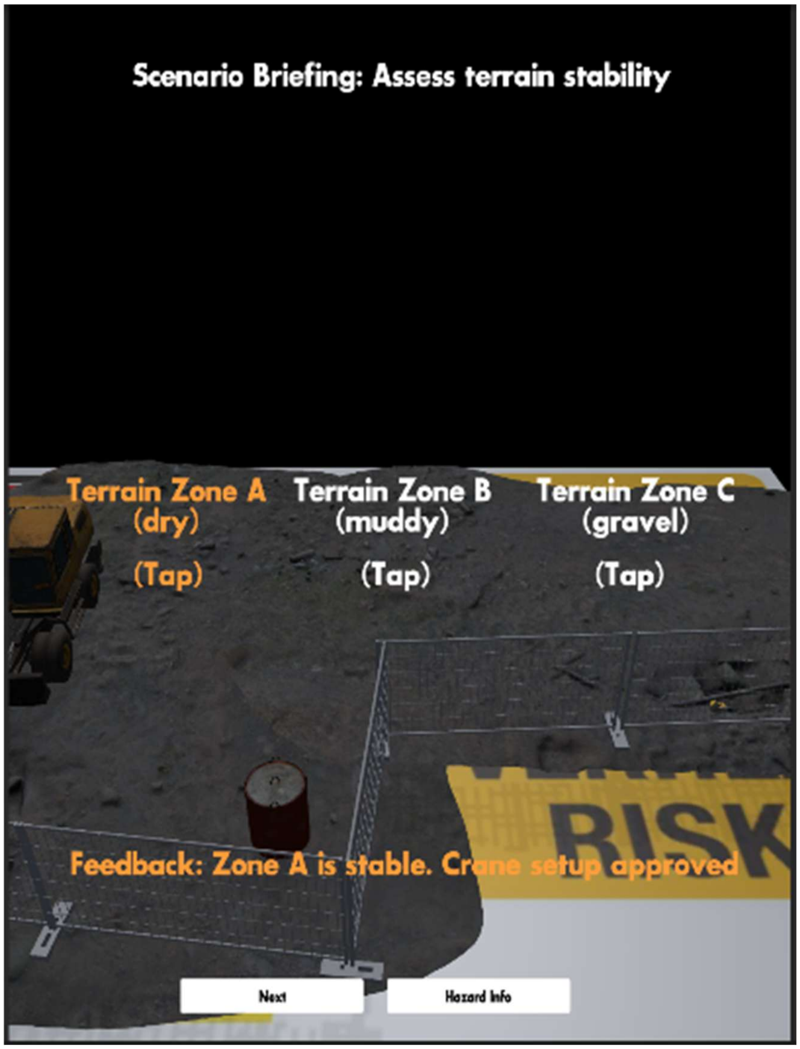
Scenario Briefing: Before beginning the lift, confirm that the operator is wearing the correct PPE

Feedback: Gloves missing. PPE non-compliant

An uneven terrain scenario was developed based on observations from Site Visit 2 to highlight the importance of ground stability in mobile crane setup (Figure 11). The terrain was divided into three visually bounded zones, each requiring assessment to determine which area provided the most stable foundation for crane placement. This scenario reinforces the need for pre-lift terrain evaluation, particularly in constrained environments.

Figure 11

Unstable Terrain



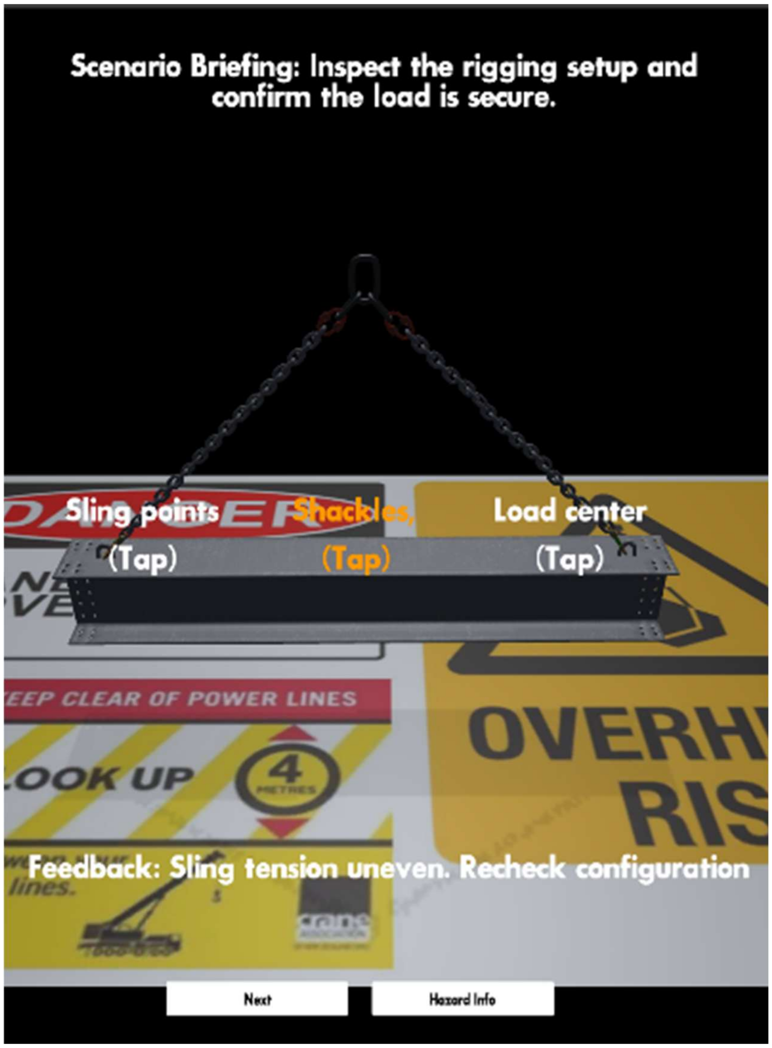
Scenario Briefing: Assess terrain stability

Feedback: Zone A is stable. Crane setup approved

An unsecure load scenario was developed to examine the hazards surrounding different load’s configuration that could lead to load dropping during a lift (Figure 12). This focused on three critical elements: Sling attachments points, shackle integrity, and load centre alignment. To demonstrate this, three rigging types were selected, such as chain slings, wire-ropes, and web-slings. Each offer distinct advantages for securing different load types. These loads and rigging slings are inspired by site visit (2) and the supporting literature (Department of Labour, 2010).

Figure 12

Unsecure Load

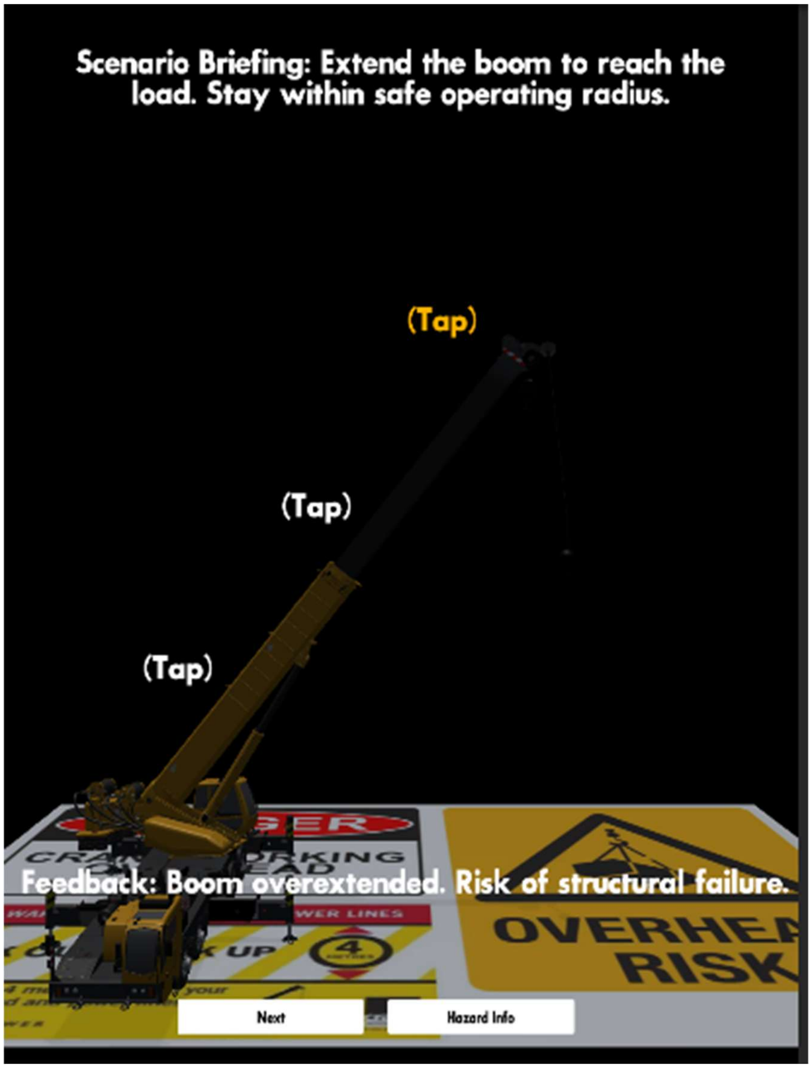

Scenario Briefing: Inspect the rigging setup and confirm the load is secure.

Feedback: Sling tension uneven. Recheck configuration

A boom overextension scenario was developed to illustrate the risk of structural failure when a crane boom is extended beyond its safe operating radius in an attempt to reach a load. This condition compromises the crane's stability and can result in mechanical collapse if not properly managed. This situation is also inspired by Site Visit (2) (Figure 13).

Figure 13

Boom Overextension



Scenario Briefing: Extend the boom to reach the load. Stay within safe operating radius.

Feedback: Boom overextended. Risk of structural failure.

The next scenario describes a communication protocol between the dogman(rigger) and the operator. The dogman communicates one of the three outlined signals in this scenario; ‘swing left’, ‘stop’ and ‘hoist’ which is represented by a hand signalling icon, as affirmed from the Approved Code of Practice (ACOP) for cranes (Department of Labour, 2010). Three responses are offered for this scenario for the purposes of enforcing the signals portrayed during lifts. The incorrect response leads to the lift being halted (Figure 14).

Figure 14

Dogman Signal Miscommunication

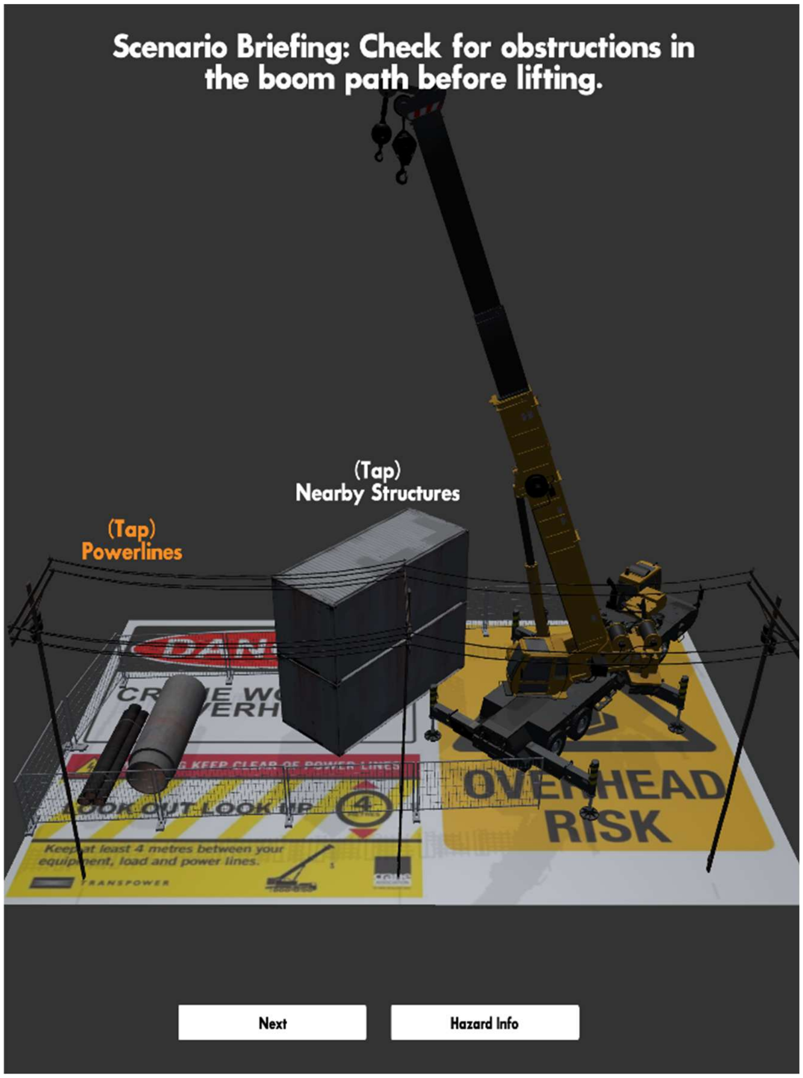
Scenario Briefing: Respond to the Dogman's signal or radio command correctly

Feedback: Incorrect response. Lift halted.

A crane boom path scenario was implemented that evaluates potential collision risks with nearby structures and overhead powerlines (Figure 15). Each obstruction is represented as a distinct zone, alongside a designated clear zone that indicates a safe lifting path. Before initiating a lift, each zone must be assessed to determine whether it presents a clear or obstructed path. These pre-check decisions were informed by spatial constraints observed during Site Visit (2) and supported by literature addressing common obstructions such as powerlines (SafeCrane, 2016).

Figure 15

Obstructed Path



Scenario Briefing: Check for obstructions in the boom path before lifting.

The next stage involved gathering Initial feedback on the AR application and its interactive features to ensure these safety protocols were validated, as the second round of consultation was engaged with the CEO in a follow-up interview.

3.2.6 Software Design

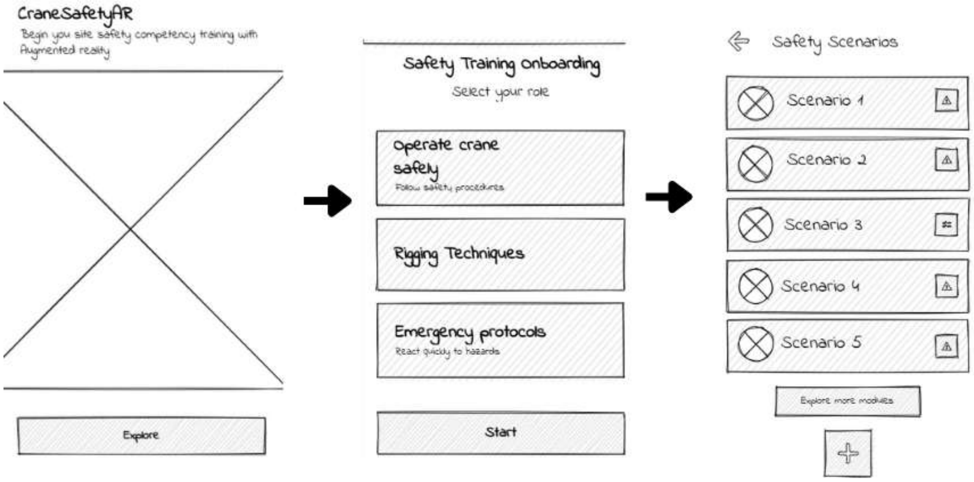
Following the second stakeholder interview with the CEO, I further developed the AR training application to emphasise experiential and reflective learning. These core principles are best described by Swiss psychologist Piaget in his seminal work “The Theory of Stages in Cognitive Development”, which describes how new knowledge is constructed through exploration, experience, and interaction within an individual’s own environment (Piaget, 1971). The stages of cognitive development follow the order of sensorimotor (hands-on exploration) to preoperational (symbolic thinking), concrete operational (logical problem-solving), and finally formal operational (abstract reasoning and hypothesis testing) (Piaget, 1971). To emphasise these principles within my AR application, I have focused on the applying each principle of Piaget’s theory, in the following ways:

- Hands-on interactions (Sensorimotor) - Users physically explore AR objects to understand concepts:
- Symbolic representations (Preoperational) - Visual elements are used to simplify abstract ideas:
- Logical problem-solving (Concrete Operational) - Encourages users to apply reasoning through the interactive challenges:
- Abstract thinking (Formal Operational) - Promotes hypothesis testing and problem-solving within the AR scenarios:

My study emphasises the user navigation of first-time or returning users, by implementing a simple onboarding menu screen to ease the navigation into the AR scenarios (Figure 16). Wireframes of the app’s onboarding interface were developed using a prototyping tool, Uizard. This begins with an introduction screen that guides users through role selection; crane operator safety and rigging safety are the two core training paths for this application. Following this, a task overview page presents a series of unsafe scenarios each linked to an option for live exploration in augmented reality.

Figure 16

Onboarding UI wireframe – AR Crane safety app

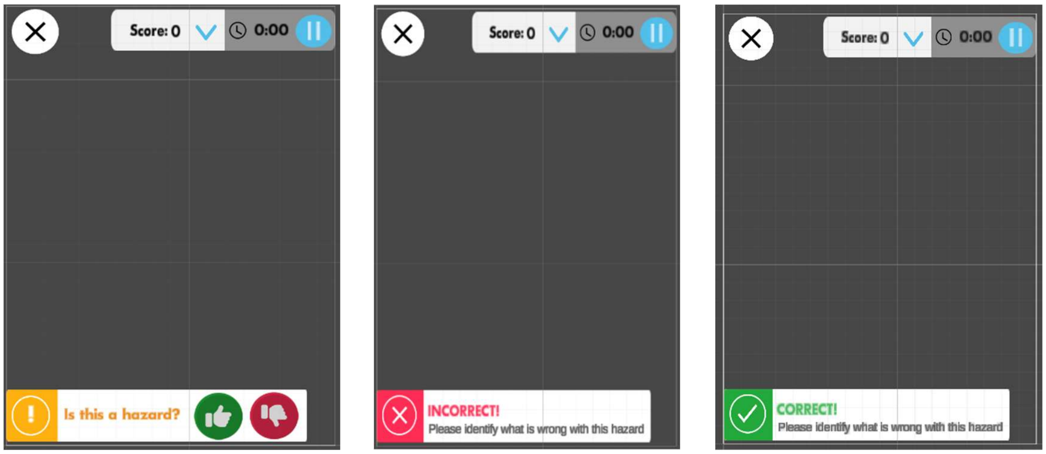


To enhance the interactivity, an error-correcting feedback loop was introduced, inspired by the feedback from the second expert interview. This system utilises a multiple-choice quiz format, with visual colour coded feedback. When the user selects an answer, the system immediately displays a green or red banner to indicate correctness, accompanied by contextual explanations. This is illustrated below in (Figure 17).

Figure 17

AR Hazard quiz UI

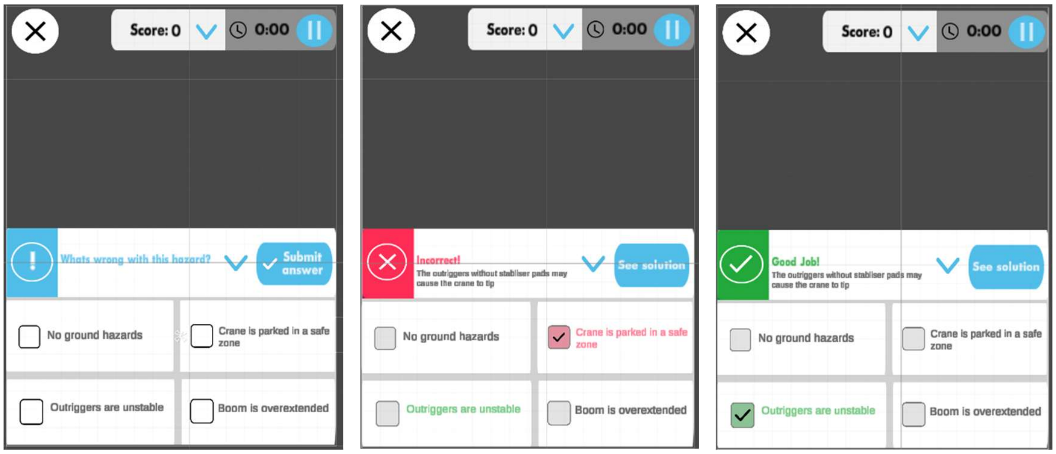
a. Caution banner *b. Incorrect – banner* *c. Correct – banner*



INCORRECT!
Please identify what is wrong with this hazard

CORRECT!
Please identify what is wrong with this hazard

d. Option based quiz *e. Incorrect option selected* *f. Correct option selected*



Incorrect!
The outriggers without stabiliser pads may cause the crane to tip

Good Job!
The outriggers without stabiliser pads may cause the crane to tip

Each quiz option is mapped to a unique tag identifier (ranging from 1 to 4), allowing the system to track user selections with precision. When the correct option is selected, a corresponding "Correct" banner is triggered, providing immediate visual confirmation. Conversely, selecting an incorrect option activates the "Incorrect" banner, accompanied by a brief explanatory description. This feedback clarifies why the chosen response was inaccurate, and the system provides guidance by highlighting the correct answer. For every correct response, a score increment is recorded and stored within the app’s internal tracking system. Additionally, a stopwatch feature was implemented to monitor the duration of the user's training session, which provided insight into task completion.

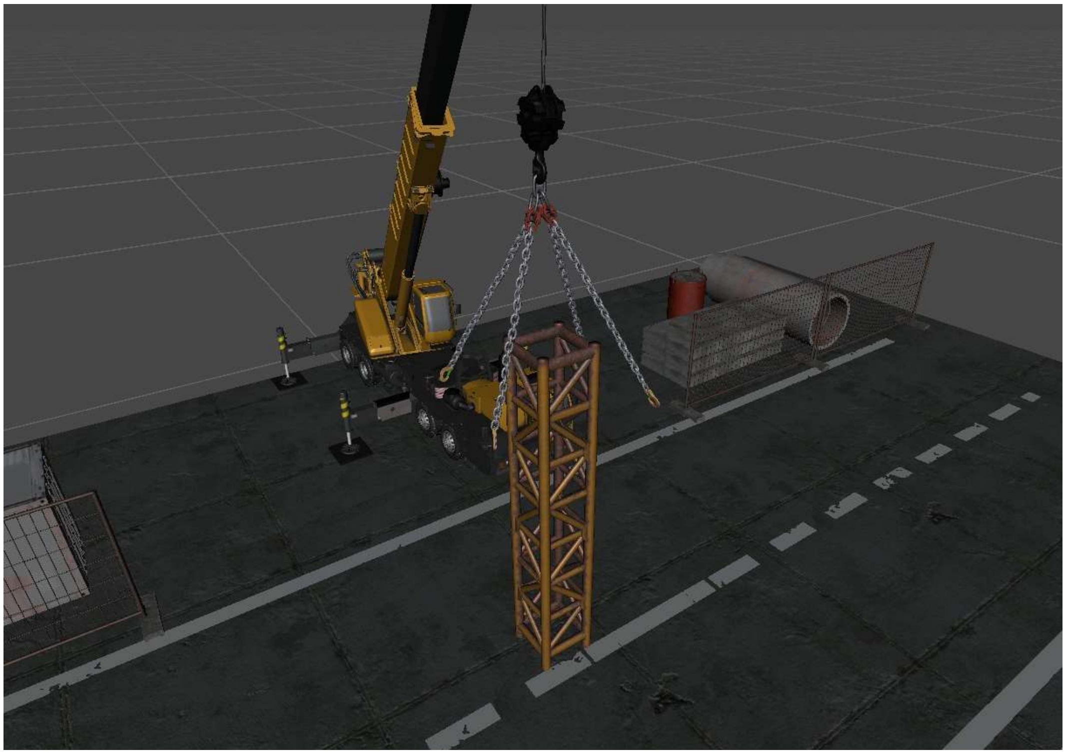
Three distinct UI prompts were developed to display either a "Caution," "Correct," or "Incorrect" label, each initiated upon the activation of each hazard. For instance, when the first hazard is introduced, a caution banner appears after a brief delay, prompting the user to respond by selecting either the green or red button. This interaction triggers a follow-up banner that visually confirms the user's choice—either a "Correct" or "Incorrect" indicator—represented by a thumbs-up or thumbs-down icon. To maintain a clean and unobstructed AR viewing experience, a dropdown toggle was implemented, which ensured users could expand or collapse the option panel. This design choice aligns with best practices in user experience, ensuring the interface remained intuitive, responsive, and minimally intrusive.

The design of the multiple-choice quiz features was based off established pre-competency assessments, such as those SiteSafe (2019) and SiteWise (2018) for crane operator qualifications. The structure and phrasing of the questions were informed by the official guidebook developed by Crane Association of New Zealand (2016) and the hazard awareness resources provided by (SafeCrane, 2016). While safety standards continue to evolve, this guidebook remains a foundational resource for crane operations and safety awareness. However, to ensure ongoing compliance and relevance, this should be cross referenced with current legislation, particularly the *Health and Safety at Work Act 2015* (HSWA) and its associated regulations and codes of practises, which are actively being reformed to better address critical risks and industry needs (Department of Labour, 2010).

An additional scenario was incorporated (Figure 18), which simulates a tower crane structure lift, emphasising the need for inspection at each stage. This scenario was inspired by site visit (1) and highlights critical safety hazards, including the absence of missing exclusion zones, spotters and properly deployed outriggers.

Figure 18

Roadside Hazard – Tower Crane Structure



To ensure the stability of the mobile crane, all four outriggers must be extended prior to initiating the lift. The next step involves selecting the appropriate slings, determined by the loads working load limit (WLL). A red warning overlay visually marks the area surrounding the load as unsafe, prompting immediate corrective action, and the implementation of proper lifting protocols. If the incorrect actions are selected, an animation is triggered that depicts a negative consequence, specifically, the load being dropped (Figure 19).

Figure 19

Roadside Hazard – Tower Crane Structure Unsafe

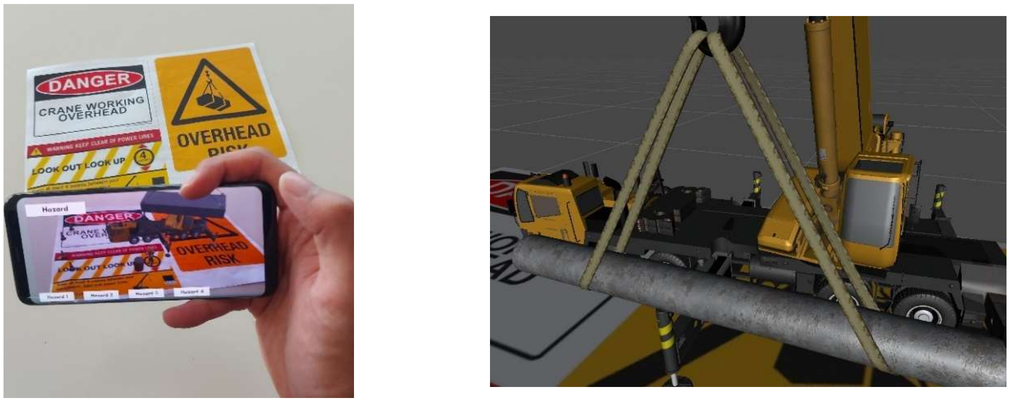
As shown in (Figure 20) a telescopic boom truck crane has been used across each scenario, since it represents a commonly cited mobile type involved in crane accidents (Beavers et al., 2006). While this model was chosen for its relevance and accessibility, it does not fully capture the nuance of other mobile crane types, such as crawler cranes or lattice boom configurations. Due to certain technical constraints in developing these different mobile crane types, the telescopic boom type was retained through each scenario. Scene variations were introduced to highlight specific hazards, including the use of worn or damaged slings. One scenario depicts a compromised web sling lifting a hollow metal load, illustrating the high risk of load failure. Another scenario features uneven terrain, requiring users to identify a stable zone for proper outrigger deployment. Additionally, a fuel hazard was simulated, where extending the boom near fuel barrels poses a risk of fire or explosion. In each case, the incorrect action would trigger a negative consequence, such as a hazard escalation or dropped load.

Figure 20

AR model and the hazard training scenarios

a. In-person view of scanning crane danger sheet using a smartphone camera in AR.

b. Worn-out Web Sling



c. Crane Load Dropping

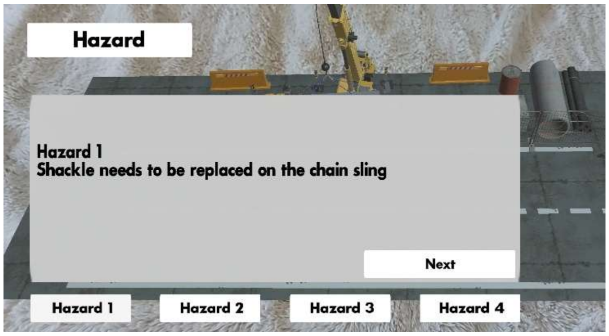
d. Incorrect PPE

e. Unstable-Ground Hazard

f. Fuel Barrel Hazard

g. Select Safety Scenario Menu *UI*

h. AR hazard explained



Hazard 1
Shackle needs to be replaced on the chain sling

Chapter 4 Results

This chapter presents the findings from participant evaluations of the AR safety training app, including pre- and post-training Likert-scale surveys, and post-training usability and workload assessments. It also synthesises insights from the focus group sessions, outlining critical factors such as perceptions of realism, deployment barriers, and integration potential.

4.1 Survey Results

This study involved 3 participants which included two riggers and one crane operator, all currently employed on infrastructure construction sites. All were male, aged between 36 and 45, with 6 to over 10 years of experience in their respective roles. Their educational backgrounds included trade certificates and a high school diploma, and their ethnic background all included Māori and/or Pasifika. The table below presents a compact result of the workload and usability outcomes of the software and noted down each participant's score related to the task time, error rate, SUS score, workload, and safety awareness changes during the training (see Table 1). The total SUS scores of all participants revealed a range from 65 to 78; with two participants exceeding the benchmark of 68. This indicates an above-average usability perception amongst the group. Supplementary to that, the NASA-TLX workload ratings of each participant ranged from low to moderate, suggesting that the cognitive and physical demands of the AR task were manageable.

Table 1

Participant Evaluation Results

Participant	Role	Task Time (min)	Errors	SUS Score	NASA-TLX (Workload)	Pre/Post Safety Awareness Change
P1	Dogman/Rigger	4.0	0	72	Moderate	+1 level
P2	Dogman/Rigger	3.8	0	78	Low	+1 levels
P3	Crane Operator	4.2	0	65	Moderate	+1 level

Note: SUS scores range from 0 to 100, with scores above 68 indicating above-average usability. NASA-TLX workload ratings are based on participant self-assessment across six dimensions. Safety awareness change reflects Likert-scale shifts before and after training.

None of the participants had prior experience with AR technology, and their frequency of digital technology use ranged from occasional to weekly. Their attitudes toward digital tools for safety training were cautiously positive, with one participant expressing a positive view and two indicating slightly positive perceptions. Each participant undertook the AR training using their own smartphones and spent an average total time of 4 minutes. Before going through the training, each participant completed a pre- test survey consisting of 10 Likert-scale items designed to assess usability expectations, protocol understanding, hazard recognition, confidence, and attitudes toward AR-based safety training. Upon completing the AR training, a post-test survey was administrated consisting of similar Likert-scale items. Their responses were scored on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree), and their mean scores were calculated across all items. This is illustrated in a clustered bar chart below which compared the mean pre- and post-test scores across all items is illustrated below (Figure 21).

Figure 21

Mean Likert scores for survey items before and after AR safety training.

The chart reveals a consistent upward trend in participants' perceptions following AR-based safety training. The most notable gains were observed in endorsement of AR technology. Scores for *"AR training improves safety"* and *"Prefer digital/AR training"* increased significantly, indicating strong support for the use of immersive tools despite participants' lack of prior exposure. These results suggest that AR was not only well-received but also perceived as a valuable enhancement to traditional safety methods. Scores for *"AR app easy to use"* and *"Understand training purpose"* showed modest improvements, reinforcing that the interface was intuitive and did not interfere with comprehension of safety protocols. In terms of hazard recognition, *"Recognise crane-specific hazards"* improved slightly, suggesting that the AR module effectively highlighted role-specific risks. Meanwhile, *"Identify common hazards"* and *"Familiar with procedures"* also showed positive shifts, indicating broader gains in hazard awareness and procedural understanding. Confidence-related items such as *"Confident in safety protocols"* and *"Prepared to respond"* remained stable or improved slightly, contradicting any assumption of diminished self-efficacy. These results may reflect a nuanced recalibration effect, which indicates how participants became more critically aware of their limitations without losing overall confidence. Interestingly, *"Traditional training sufficient"* remained relatively flat, suggesting that while AR was positively received, participants still recognised the foundational value of conventional methods.

4.2 Focus Group Findings

Following the AR training session, the participants engaged in a facilitated focus group discussion to reflect on their experience. Their discussion was recorded by audio, and the transcript was thematically analysed, and their discussion categorised into five core themes. These related to the perceived value, limitations, and future potential of the AR safety training tool. These themes are presented below (Table 2) with participant quotes. The focus group discussions revealed nuanced perspectives on the AR module's design, usability, and future potential. Participants emphasised the realism of the scenarios, noting that hazards such as unstable terrain and lift zones mirrored actual site conditions. This realism appeared to prompt reflection on risks that are often normalised in daily operations, reinforcing the module's value in promoting site-specific hazard awareness. While the interface was generally praised for its intuitiveness, concerns were raised about its practical deployment—particularly in relation to PPE compatibility, weather conditions. Conversely, participants also expressed strong interest in integrating AR into existing safety workflows, such as toolbox talks and pre-start briefings. This suggests that AR is seen not as a replacement for traditional training, but as a complementary tool that could enhance engagement and retention. The participants also mentioned the barriers of adopting the app, which related to cultural resistance to new technology, regulatory constraints, and the need for buy in from safety managers. All the participants agreed that this AR application could be enhanced, with proposals to include multi-role scenarios which includes multiple users, collaborating to engage a lift.

Table 2

Focus Group Themes and Participant Insight

Theme	Summary	Operational Relevance	Participant Quote
Realism and Relevance	AR scenarios reflected actual site hazards and workflows.	Reinforces site-specific hazard recognition and encourages critical awareness.	“That’s exactly the kind of stuff we deal with—especially around lift zones and uneven terrain.”
Usability and Accessibility	Interface was intuitive but concerns about PPE and weather conditions.	Highlights deployment constraints in real-world settings.	“It’s easy to use, but not sure how it’d work with gloves or in the rain.”
Integration Potential	AR could complement toolbox talks or site inductions.	Suggests blended training integration.	“Would be good to run this before a lift—like part of the morning briefing.”
Adoption Barriers	Cultural resistance, regulatory approval, and scalability concerns.	Indicates need for stakeholder engagement and policy alignment.	“Some of the older guys won’t touch it. And you’d need sign-off from the safety manager.”
Improvement Suggestions	Desire for more complex, team-based and dynamic scenarios.	Points to future development opportunities.	“Would be good to see how the dogman and operator work together—like a team version.”

Chapter 5 Discussion

This chapter addresses each of the sub-RQ's based on the feedback gathered by participants during training session. Each sub-RQ explores how the observed shifts in perception, confidence, and hazard recognition reflect the underlying pedagogical and operational factors that shape crane and rigging safety practises.

Sub-RQ 1: What usability principles are most effective for handheld AR safety training in construction contexts?

The findings suggest that usability in handheld AR safety training is shaped by principles of simplicity, intuitiveness, and contextual adaptability. The survey results indicated above-average usability perceptions, with SUS scores ranging from 65 to 78 and two participants exceeding the benchmark of 68. This suggests that the AR interface was generally easy to navigate and did not impose excessive cognitive load. NASA-TLX workload ratings further supported this, with participants reporting low to moderate demands, suggesting that the training tasks were manageable within the handheld format. The focus group discussions supported these outcomes. Participants described the interface as intuitive and straightforward, noting that it did not interfere with their comprehension of safety protocols. However, concerns were raised about deployment in real-world conditions, particularly regarding PPE compatibility and weather constraints. One participant remarked, *"It's easy to use, but not sure how it'd work with gloves or in the rain,"* highlighting the importance of designing for environmental and occupational realities. Together, these findings indicate that effective usability principles for handheld AR safety training include clarity of interface design, minimisation of workload, and alignment with the physical conditions of construction sites. While the current module demonstrated strong usability in controlled settings, future development should incorporate design adaptations for field conditions to ensure sustained effectiveness.

Sub-RQ 2: How can site-specific hazards be accurately represented in AR for crane operators and riggers?

The findings demonstrate that AR can effectively represent site-specific hazards when scenarios are designed to mirror the operational realities of crane and rigging work. The pre- and post- scores indicated modest but positive gains in hazard recognition. Scores for "Recognise crane-specific hazards" and "Identify common hazards" improved following the AR training, demonstrating that participants were able to connect the virtual scenarios with risks encountered in their daily roles. This improvement highlights the importance of embedding hazards that are directly relevant to crane operations, rather than relying solely on generic site conditions. Participants commented within the focus group sessions on the realism of the AR scenarios, noting that hazards such as unstable terrain and lift zones closely resembled actual site conditions. This realism prompted reflection on risks that are often normalised in routine operations, thereby strengthening hazard awareness. One participant remarked that "That's exactly the kind of stuff we deal with, especially around lift zones and uneven terrain," underlying the operational credibility of the module. The effectiveness of site-specific hazard representation in this study is emphasised within prior literature that mention the importance of realism and contextual fidelity as critical for immersive learning (Bower et al., 2014; Shringi et al., 2023), while extending these insights to trade-specific crane and rigging workflows.

Sub-RQ 3: What design features support user engagement and hazard recognition in AR training modules?

Specific design features within the AR module contributed to both user engagement and hazard recognition. The survey results revealed notable increases in endorsement of AR technology. Scores for *"AR training improves safety"* and *"Prefer digital/AR training"* rose significantly after the training, suggesting that participants found the interactive and visual design features engaging. Gains in *"Recognise crane-specific* *hazards"* and *"Identify common hazards"* further demonstrate that hazard-related content was effectively communicated through the module's design. Focus group insights reinforced these findings. Participants highlighted the realism of the scenarios, noting that hazards such as unstable terrain and lift zones mirrored actual site conditions. This realism was perceived as a critical design feature that enhanced hazard recognition and credibility. The interactive format was also praised for its intuitiveness. However, concerns were raised about practical deployment, particularly in relation to PPE compatibility and weather conditions, which may limit engagement in real-world contexts. Additionally, participants also expressed interest in more complex, team-based scenarios, indicating that collaborative design features could further strengthen engagement and hazard recognition. This suggests that while individual hazard-focused modules are effective, expanding to multi-role interactions would enhance authenticity and deepen user involvement.

Sub-RQ 4: How do users perceive the effectiveness of AR training compared to traditional methods?

Users perceived AR training as a valuable complement to traditional safety methods, rather than a replacement. Survey results showed significant increases in endorsement of AR technology. Scores for *"AR training improves safety"* and *"Prefer digital/AR training"* rose notably after the training, indicating strong support for immersive tools despite lack of prior exposure from participants. At the same time, the item *"Traditional training sufficient"* remained relatively flat, suggesting that participants continued to recognise the foundational role of conventional safety instruction. This balance highlights that AR was perceived as an enhancement to existing practices rather than a standalone solution. Participants during the focus group session expressed enthusiasm for integrating AR into established workflows, such as toolbox talks and pre-lift briefings as a way of sustaining engagement, but also emphasised that it should complement, not replace traditional training. One participant noted, *"Would be good to run this before a lift, like part of the morning briefing,"* emphasising the perceived value of AR as an additive tool. However, they also noted several barriers to adoption and concerns related to cultural resistance and regulatory approval, highlighting that successful implementation would require buy-in from safety managers and union representatives. These findings suggest that AR deployment is not only a technical challenge but also a cultural and institutional one. These barriers align with TAM's emphasis on perceived usefulness and ease of use (Davis, 1989), and with UTAUT2's recognition of institutional support (Venkatesh et al., 2003). The participant's concerns about regulatory approval and cultural resistance highlight the importance of these constructs in shaping adoption.

Chapter 6 Conclusion

6.1 Conclusions

My study aimed to address the following research question *"How do I design a user-friendly AR training application that targets site specific dangers in infrastructure construction that are relevant to crane operators and riggers?".* To explore this, four sub-research questions were developed, each addressing a distinct focus of the AR training design and evaluation. These are discussed below:

Sub-RQ 1: What usability principles are most effective for handheld AR safety training in construction contexts?

A usable handheld AR safety training app should involve a clear design interface that minimises the cognitive load to use. Additionally, the handheld AR safety training app should be adaptable across changing construction site environments, including weather and noise, impact of PPE on device use, and practical demands of crane and rigging tasks. The current AR module demonstrated strong usability in controlled settings; however, these refinements would be essential to ensure a consistent level of effectiveness in real-world contexts.

Sub-RQ 2: How can site-specific hazards be accurately represented in AR for crane operators and riggers?

For site-specific hazards to be accurately represented in AR, the training modules should simulate the real working conditions of crane and rigging operations as best as possible, enhancing its credibility and familiarity with reoccurring or site-specific hazards. Hazards such as uneven terrain, and lift zones, should be incorporated within the AR training module, to convey the dynamic operational risks apparent on site, which in turn reflects the contextual relevance and accuracy of hazards. Making the training more effective in preparing workers for hazards on different sites.

Sub-RQ 3: What design features support user engagement and hazard recognition in AR training modules?

AR training modules should involve design elements that enable users to simulate real-time consequence of hazards in context to the site that their working on. Additionally, intuitive user flow and collaborative learning features that allow safety managers to get involved, will enhance the user engagement and compliance as progress can be tracked and monitored. These features would encourage active participation in hazard recognition that extend beyond individual tasks and into routine practises.

Sub-RQ 4: How do users perceive the effectiveness of AR training compared to traditional methods?

AR training modules are perceived as most effective when integrated into blended safety frameworks that complement traditional practises such as toolbox talks and pre-lift briefings. While AR enhances engagement and hazard recognition compared to traditional methods, its adoption depends on organisational readiness, stakeholder support, and regulatory alignment.

***RQ:** How do I design a user-friendly AR training application that targets site specific dangers in infrastructure construction that are relevant to crane operators and riggers?*

This study demonstrates that a user-friendly AR training application for crane operators and riggers must combine clear usability principles, accurate representation of site-specific hazards, and design features that foster engagement and hazard recognition. Effectiveness is maximised when AR modules are embedded into blended safety frameworks that complement traditional practices, while adoption depends on organisational readiness, stakeholder support, and regulatory alignment. Together, these findings provide a structured basis for designing AR safety training that is both credible in real-world contexts and sustainable within industry practice.

6.2 Limitations

This study had several limitations. For instance, only a small sample (n=3) of experienced crane and rigging personnel were recruited due to contextual constraints. The single-phase pre/post design lacked longitudinal follow-up, limiting insights into long-term knowledge retention and behavioural change. Testing occurred in a controlled environment (AUT, WG Building Level 10), which did not replicate real-world site conditions such as weather, ambient noise, or operational time pressure. Additionally, the AR app featured a limited number of simulation tasks with low complexity, which may not fully reflect the dynamic challenges of live rigging operations. As a result, these factors constrain the generalisability of findings to broader construction crews and less experienced users.

6.3 Recommendations

6.3.1 Recommendations for Industry Stakeholders

To improve and scale the AR safety training app across crane and rigging operations, industry stakeholders should prioritise aligning site-specific risk scenarios with current legislation, including the *Health and Safety at Work Act 2015* (HSWA) and its evolving codes of practice (Department of Labour, 2010). Furthermore, the AR app could be deployed during toolbox talks, onboarding or pre-lift briefings through the personal or company issued smartphones. As a visual aid, the app can support the hazard preparedness of personnel and their awareness of hazards, as well as procedural compliance. This is especially important for improving language accessibility and presenting clear, intuitive warnings that help prevent mistakes caused by unclear instructions or overlooked risks. Stakeholders may consider integrating the AR modules with existing Learning Management Systems (LMS) or digital site registers to centralise training records and automate compliance tracking. Other practical considerations around device management include safe and hygienic use. For instance, with shared handheld devices, stakeholders should establish clear hygiene protocols, including regular sanitisation, use of protective casings, and handover procedures. Additionally, site IT policies that involve secure access controls, such as user authentication, role-based permissions, and data encryption, should be implemented to protect sensitive information. Where possible, hands-free usage options should be prioritised to maintain operational safety and minimise manual interaction during active lift operations or high-risk workflows.

6.3.2 Recommendations for Future Research

Future studies should involve a larger and more diverse participant pool to improve generalisability and statistical power. This includes recruiting workers from multiple infrastructure sites, a range of age groups, and varied roles such as crane operators, dogmen, supervisors, and engineers. Such diversity would enable deeper analysis of role-specific training needs and usability patterns. Longitudinal research is also needed to assess the retention of safety knowledge, behavioural changes on-site, and evolving attitudes toward AR technology. Follow-up surveys or observational assessments conducted 4–6 weeks post-training could provide valuable insights into long-term impact. Participants in this study expressed interest in scenarios that simulate team-based coordination, particularly between crane operators and dogmen. Future iterations of the AR app could explore multi-user experiences, where groups interact with shared AR content to identify hazards during synchronized lifts.

Finally, future research should evaluate how AR modules perform when embedded within existing safety protocols, such as site inductions and toolbox talks. This includes assessing usability, engagement, and knowledge retention across different deployment formats. Collaborative studies with safety managers and training coordinators will be essential to ensure alignment with operational workflows, policy requirements, and practical constraints. These investigations will support the evidence-based refinement of mobile-first AR tools for crane and rigging safety systems.

References

Abaya, P. M., & Ondieki, S. (2021). Influence of Training on Occupational Safety and Health Compliance for the Construction Projects in Embakasi South Nairobi City County. *International Journal of Engineering Research & Technology*, *10*, 403–411. https://www.ijert.org/research/influence-of-training-on-occupational-safety-and-health-compliance-for-the-construction-projects-in-embakasi-south-nairobi-city-county-IJERTV10IS020179.pdf

abcHealthandSafety. (n.d.). *Overhead Risk*. Retrieved June 10, 2025, from https://www.promohealthandsafetysigns.co.nz/product-page/overhead-risk

Adamska, I. (2023, June 15). *Augmented reality & remote inspection | Nsflow*. https://nsflow.com/blog/ar-remote-inspection

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, *21*(6), 34–47. https://doi.org/10.1109/38.963459

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in education – cases, places and potentials. *Educational Media International*, *51*(1), 1–15. https://doi.org/10.1080/09523987.2014.889400

Brooke, J. (1996). SUS - a quick and dirty usability scale. In P. W. Jordan, B. Thomas, I. Weerdmeester, & A. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189–194). Taylor & Francis.

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., & Islam, G. (2006). Relative Effectiveness of Worker Safety and Health Training Methods. *American Journal of Public Health*, *96*(2), 315–324. https://doi.org/10.2105/AJPH.2004.059840

Chiang, F.-K., Shang, X., & Qiao, L. (2022). Augmented reality in vocational training: A systematic review of research and applications. *Computers in Human Behavior*, *129*, 107125. https://doi.org/10.1016/j.chb.2021.107125

Crane Association of New Zealand. (2016). *Lift planning guide: Your guide to Crane Association lift plans.* https://www.safecrane.nz/uploads/2/0/5/7/20572552/crane_association_lift_planning.pdf

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340. https://doi.org/10.2307/249008

Department of Labour, N. Z. (2010). *Approved code of practice for cranes: Includes the design, manufacture, supply, safe operation, maintenance and inspection of cranes*. Department of Labour. https://www.worksafe.govt.nz/dmsdocument/410-approved-code-of-practice-for-cranes

Gong, P., Lu, Y., Lovreglio, R., Yang, X., & Deng, Y. (2024). Comparing the effectiveness of AR training and slide-based training: The case study of metro construction safety. *Safety Science*, *176*, 106561. https://doi.org/10.1016/j.ssci.2024.106561

Guo, H., Li, H., Chan, G., & Skitmore, M. (2012). Using game technologies to improve the safety of construction plant operations. *Accident Analysis & Prevention*, *48*, 204–213. https://doi.org/10.1016/j.aap.2011.06.002

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (Vol. 52, pp. 139–183). North-Holland. https://doi.org/10.1016/S0166-4115(08)62386-9

HealthAndSafety. (n.d.). *Crane Working Overhead Danger Sign*. Retrieved August 5, 2024, from https://healthandsafetysigns.co.nz/product/crane-working-overhead-danger-sign/

Ismael, M., McCall, R., McGee, F., Belkacem, I., Stefas, M., Baixauli, J., & Arl, D. (2024). Acceptance of augmented reality for laboratory safety training: Methodology and an evaluation study. *Frontiers in Virtual Reality*, *5*, 1322543. https://doi.org/10.3389/frvir.2024.1322543

Jalo, H., & Pirkkalainen, H. (2024). Effect of user resistance on the organizational adoption of extended reality technologies: A mixed methods study. *International Journal of Information Management*, *75*, 102731. https://doi.org/10.1016/j.ijinfomgt.2023.102731

Kamal, A. A., Junaini, S. N., & Hashim, A. H. (2022). Evaluating the Effectiveness and Usability of AR-based OSH Application: HazHunt. *International Journal of Advanced Computer Science and Applications*, *13*(5). https://doi.org/10.14569/IJACSA.2022.0130513

Kamal, A. A., Junaini, S. N., Hashim, A. H., Sukor, F. S., & Said, M. F. (2021). The Enhancement of OSH Training with an Augmented Reality-Based App. *International Journal of Online and Biomedical Engineering (iJOE)*, *17*(13), 120–134. https://doi.org/10.3991/ijoe.v17i13.24517

Khorrami Shad, H., Tak Wing Yiu, K., Lovreglio, R., & Feng, Z. (2024). State-of-the-art analysis of the integration of augmented reality with construction technologies to improve construction safety. *Smart and Sustainable Built Environment*, *13*(6), 1434–1449. https://doi.org/10.1108/SASBE-07-2022-0151

Mackenzie, N. (2006). Mackenzie, N. M., & Knipe, S. (2006). Research dilemmas: Paradigms, methods and methodology. Issues in Educational Research, 16(2). *Issues in Educational Research*. https://www.academia.edu/1104997/Mackenzie_N_M_and_Knipe_S_2006_Research_dilemmas_Paradigms_methods_and_methodology_Issues_in_Educational_Research_16_2_

Milgram, P., & Colquhoun, H. (1999). A Taxonomy of Real and Virtual World Display Integration. In Y. Ohta & H. Tamura (Eds.), *Mixed Reality* (pp. 5–30). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-87512-0_1

Morse, K., Fey, M., Kardong-Edgren, S., Mullins, A., Barlow, M. L., & Barwick, S. (2019). *The changing landscape of simulation-based education*. https://doi.org/10.1097/01.NAJ.0000577436.23986.81

Namian, M., Albert, A., Zuluaga, C. M., & Behm, M. (2016). Role of Safety Training: Impact on Hazard Recognition and Safety Risk Perception. *Journal of Construction*

Engineering and Management, *142*(12), 04016073. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001198

O'Dea, M. (2025). Editorial: Are technology acceptance models still fit for purpose? *Journal of University Teaching and Learning Practice*, *21*(8). https://doi.org/10.53761/1bdbms32

Paes, D., Feng, Z., King, M., Khorrami Shad, H., Sasikumar, P., Pujoni, D., & Lovreglio, R. (2024). Optical see-through augmented reality fire safety training for building occupants. *Automation in Construction*, *162*, 105371. https://doi.org/10.1016/j.autcon.2024.105371

Placencio-Hidalgo, D., Álvarez-Marín, A., Castillo-Vergara, M., & Sukno, R. (2022). Augmented reality for virtual training in the construction industry. *Work*, *71*(1), 165–175. https://doi.org/10.3233/WOR-205049

Porcelli, I., Rapaccini, M., Espíndola, D. B., & Pereira, C. E. (2013). Technical and Organizational Issues about the Introduction of Augmented Reality in Maintenance and Technical Assistance Services. *IFAC Proceedings Volumes*, *46*(7), 257–262. https://doi.org/10.3182/20130522-3-BR-4036.00024

SafeCrane. (2016). *Common Crane Hazards*. http://www.safecrane.nz/1/post/2016/04/common-crane-hazards.html

Saha, S., Cauchi, B., & Douglas, G. (2018). An investigation into crane and scaffold safety in construction industry. *Proceedings of International Structural Engineering and Construction*, *5*(1). https://doi.org/10.14455/ISEC.res.2018.8

Shringi, A., Arashpour, M., Golafshani, E. M., Dwyer, T., & Kalutara, P. (2023). Enhancing Safety Training Performance Using Extended Reality: A Hybrid Delphi–AHP Multi-Attribute Analysis in a Type-2 Fuzzy Environment. *Buildings*, *13*(3), 625. https://doi.org/10.3390/buildings13030625

SiteSafeNZa. (2024). *Lifting Operations and Dogmen | Site Safe*. https://www.sitesafe.org.nz/help-and-advice/guides-resources/toolbox-talks/lifting-operations-and-dogmen/

Sitompul, T. A., & Wallmyr, M. (2019). Using Augmented Reality to Improve Productivity and Safety for Heavy Machinery Operators: State of the Art. *Proceedings of the 17th International Conference on Virtual-Reality Continuum and Its Applications in Industry*, 1–9. VRCAI '19: The 17th International Conference on Virtual-Reality Continuum and its Applications in Industry. https://doi.org/10.1145/3359997.3365689

Souza, E. (2019, April 14). *9 Augmented Reality Technologies for Architecture and Construction*. ArchDaily. https://www.archdaily.com/914501/9-augmented-reality-technologies-for-architecture-and-construction

Statista. (2025, February 7). *Topic: Construction industry in New Zealand*. https://www.statista.com/topics/5725/construction-industry-in-new-zealand/

Taherdoost, H., Mohamed, N., & Madanchian, M. (2024). Navigating Technology Adoption/Acceptance Models. *Procedia Computer Science*, *237*, 833–840. https://doi.org/10.1016/j.procs.2024.05.172

Umeokafor, N., & Umeadi, B. (2014). *Compliance with Occupational Safety and Health Regulations: A Review of Nigeria's Construction Industry*.

Unity Technologies. (2021). *Unity (Version 2021.3.6f1)* [Computer software]. https://unity.com/

Unity Technologies. (2025). *Install AR Foundation | AR Foundation | 5.0.7*. https://docs.unity3d.com/Packages/com.unity.xr.arfoundation@5.0/manual/project-setup/install-arfoundation.html

Venkatesh, V., Thong, J. Y. L., & Xu, X. (2012). Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. *MIS Quarterly*, *36*(1), 157–178. JSTOR. https://doi.org/10.2307/41410412

Wang, X., & Dunston, P. S. (2007). *Design, strategies, and issues towards an augmented reality-based construction training platform*. *12*, 363–380.

WorkSafe. (2017). *Risk management*. WorkSafe. https://www.worksafe.govt.nz/topic-and-industry/hazardous-substances/managing/risk-management/

WorkSafe. (2025). *Construction focus topic | WorkSafe*. https://data.worksafe.govt.nz/focus/construction

WorkSafe. (2025a). *Fatalities summary | WorkSafe*. https://data.worksafe.govt.nz/graph/summary/fatalities

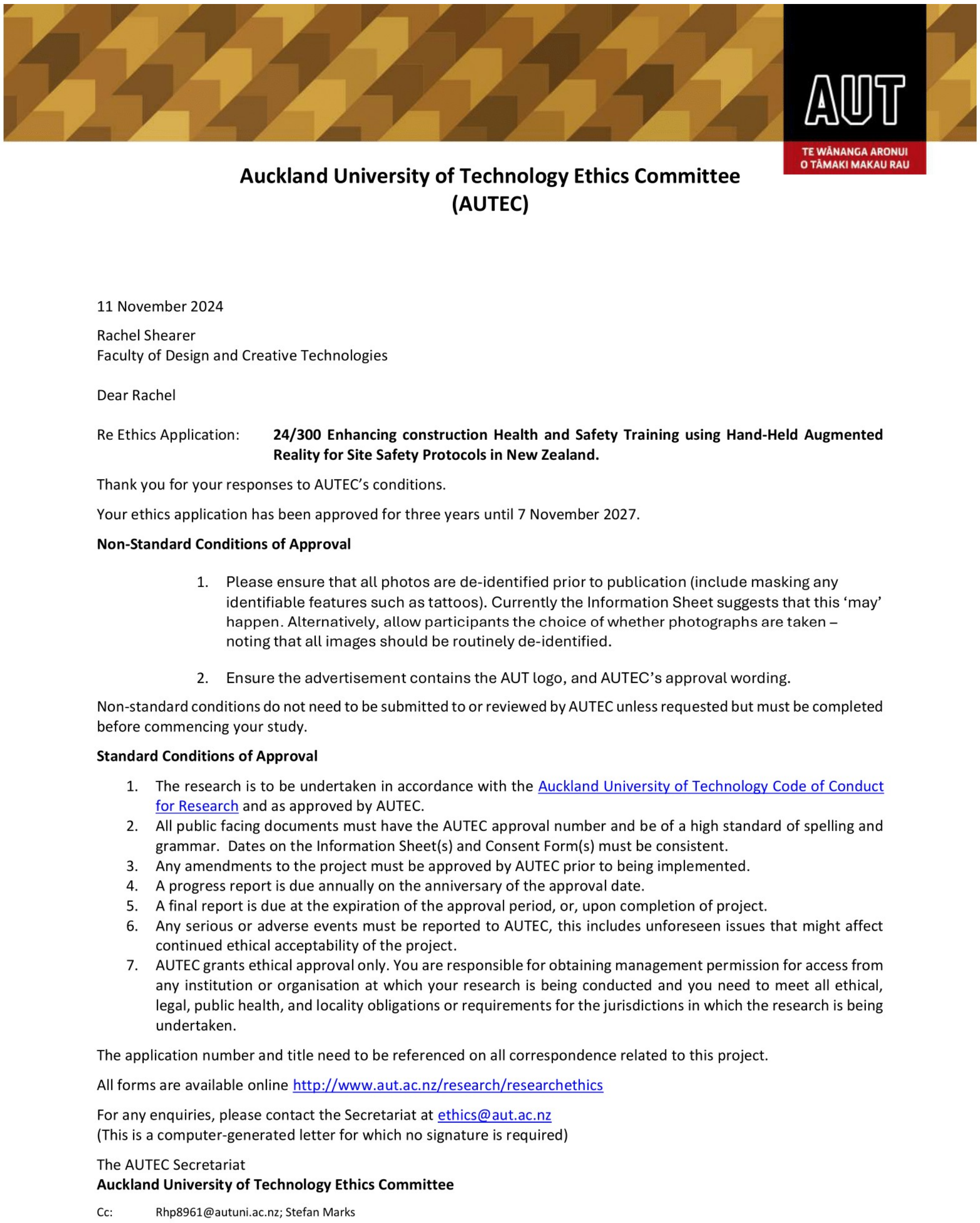
WorkSafeNZ. (2017a). *Crane safety for construction site managers and supervisors—Fact sheet*. WorkSafe. https://www.worksafe.govt.nz/topic-and-industry/cranes/crane-safety-construction-managers-supervisors-fs/

Glossary

AR	Augmented Reality
SDK	(Software Development Kit) software tools and programs used by developers to create applications for specific platforms.
Polygon	A 2D, closed, flat shape, which has straight sides and various angles
OHS	Occupational Health and Safety
App	Application software

Appendices

Appendix A *Ethics Approval Letters*



TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

**Auckland University of Technology Ethics Committee
(AUTEC)**

11 November 2024

Rachel Shearer
Faculty of Design and Creative Technologies

Dear Rachel

Re Ethics Application: **24/300 Enhancing construction Health and Safety Training using Hand-Held Augmented Reality for Site Safety Protocols in New Zealand.**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 7 November 2027.

Non-Standard Conditions of Approval

1. Please ensure that all photos are de-identified prior to publication (include masking any identifiable features such as tattoos). Currently the Information Sheet suggests that this 'may' happen. Alternatively, allow participants the choice of whether photographs are taken – noting that all images should be routinely de-identified.
2. Ensure the advertisement contains the AUT logo, and AUTEC's approval wording.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

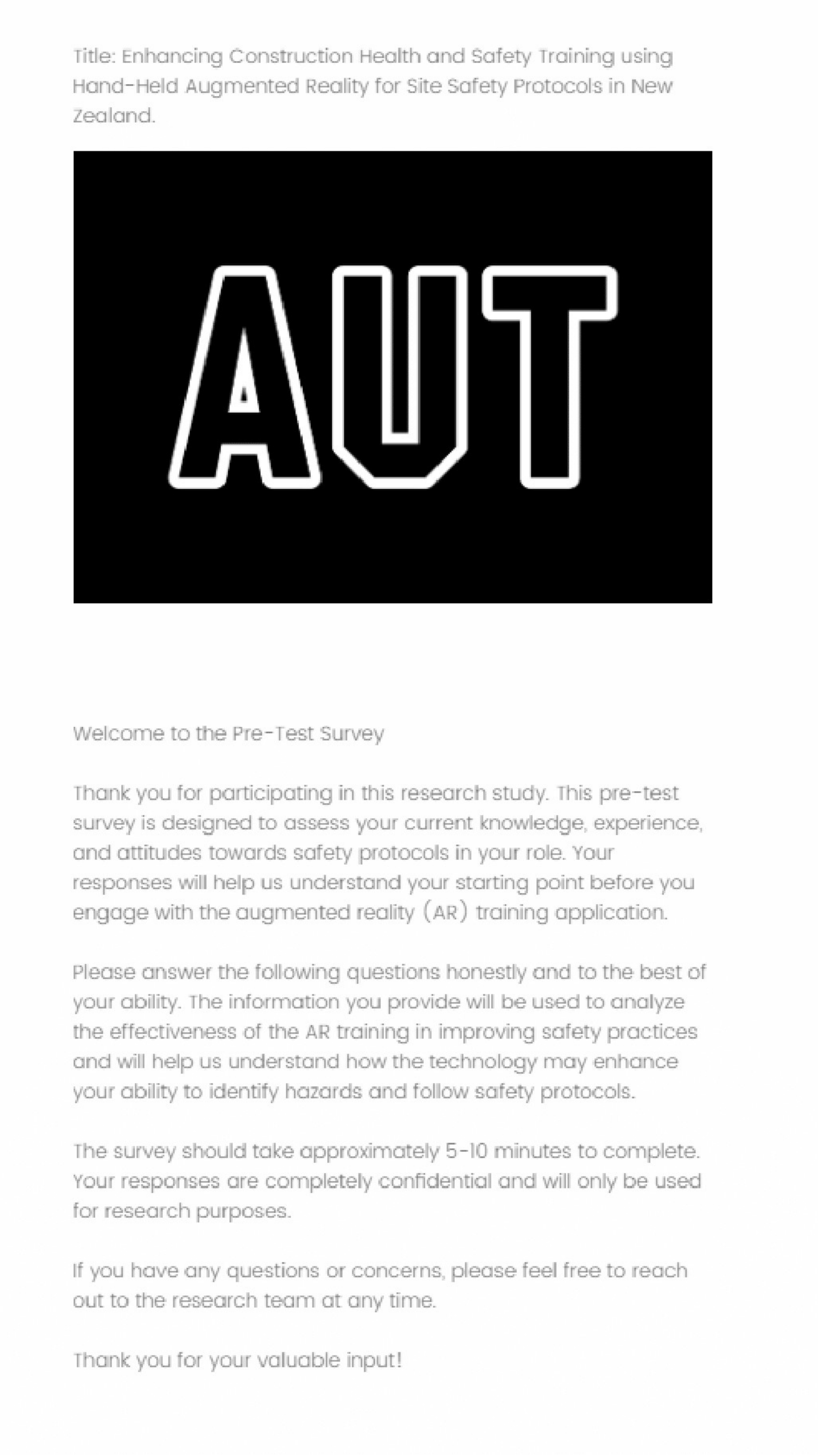
For any enquiries, please contact the Secretariat at ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: Rhp8961@autuni.ac.nz; Stefan Marks

Appendix B *Tools*

a) Surveys



Title: Enhancing Construction Health and Safety Training using Hand-Held Augmented Reality for Site Safety Protocols in New Zealand.

Welcome to the Pre-Test Survey

Thank you for participating in this research study. This pre-test survey is designed to assess your current knowledge, experience, and attitudes towards safety protocols in your role. Your responses will help us understand your starting point before you engage with the augmented reality (AR) training application.

Please answer the following questions honestly and to the best of your ability. The information you provide will be used to analyze the effectiveness of the AR training in improving safety practices and will help us understand how the technology may enhance your ability to identify hazards and follow safety protocols.

The survey should take approximately 5-10 minutes to complete. Your responses are completely confidential and will only be used for research purposes.

If you have any questions or concerns, please feel free to reach out to the research team at any time.

Thank you for your valuable input!

Demographics (General information)

Age:

○ 18-25

○ 26-35

○ 36-45

○ 46+

Gender:

○ Male

○ Female

○ Prefer not to say

Role:

○ Crane Operator

○ Rigger

○ Other (Please specify)

Have you undergone any formal safety training in the past 12 months?

○ Yes

○ No

Education Level:

○ High school diploma or equivalent

○ Trade certificate or apprenticeship

○ Diploma or associate degree

○ Bachelor's Degree

○ Postgraduate degree (e.g., Master's, PhD)

○ Other (please specify)

Ethnicity/Nationality:

○ Māori

○ Pacific Islander

○ Asian

○ European/Pākehā

○ Other (please specify)

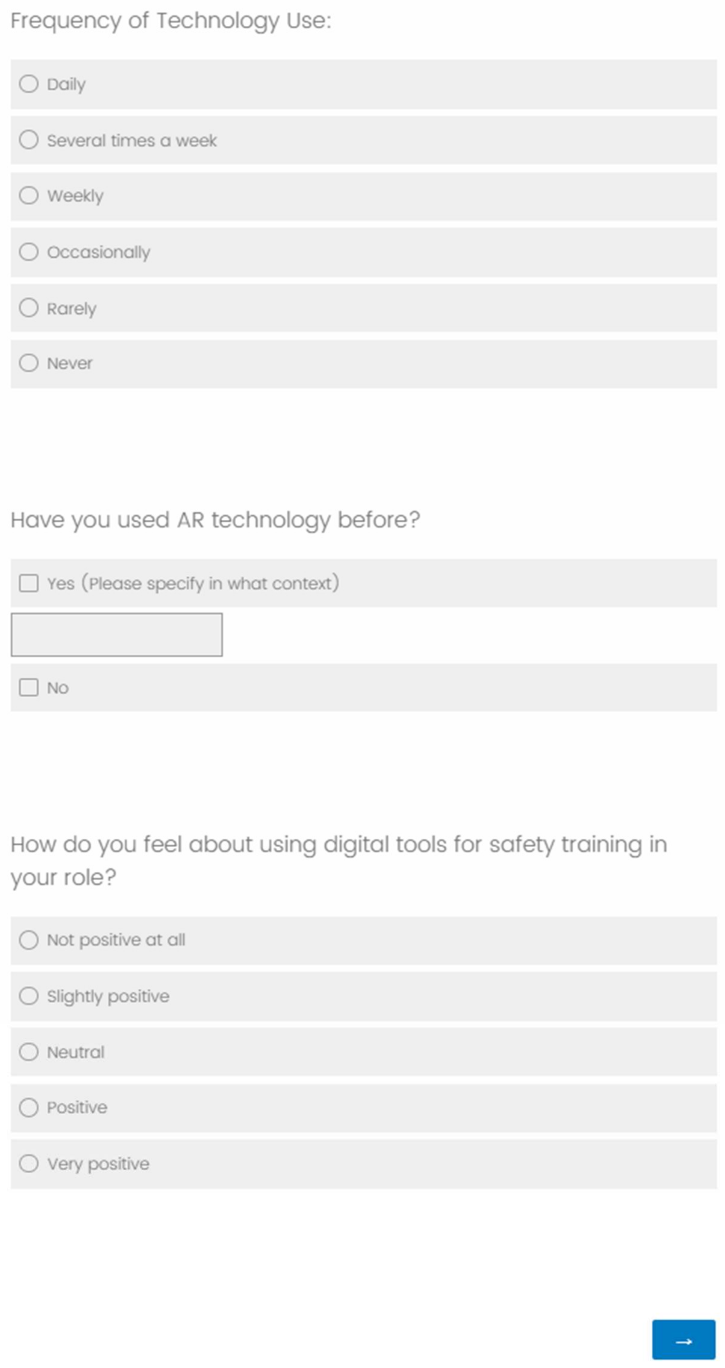
Years of experience in your role:

○ 1-2 years

○ 3-5 years

○ 6-10 years

○ 10+ years



Frequency of Technology Use:

○ Daily

○ Several times a week

○ Weekly

○ Occasionally

○ Rarely

○ Never

Have you used AR technology before?

☐ Yes (Please specify in what context)

☐ No

How do you feel about using digital tools for safety training in your role?

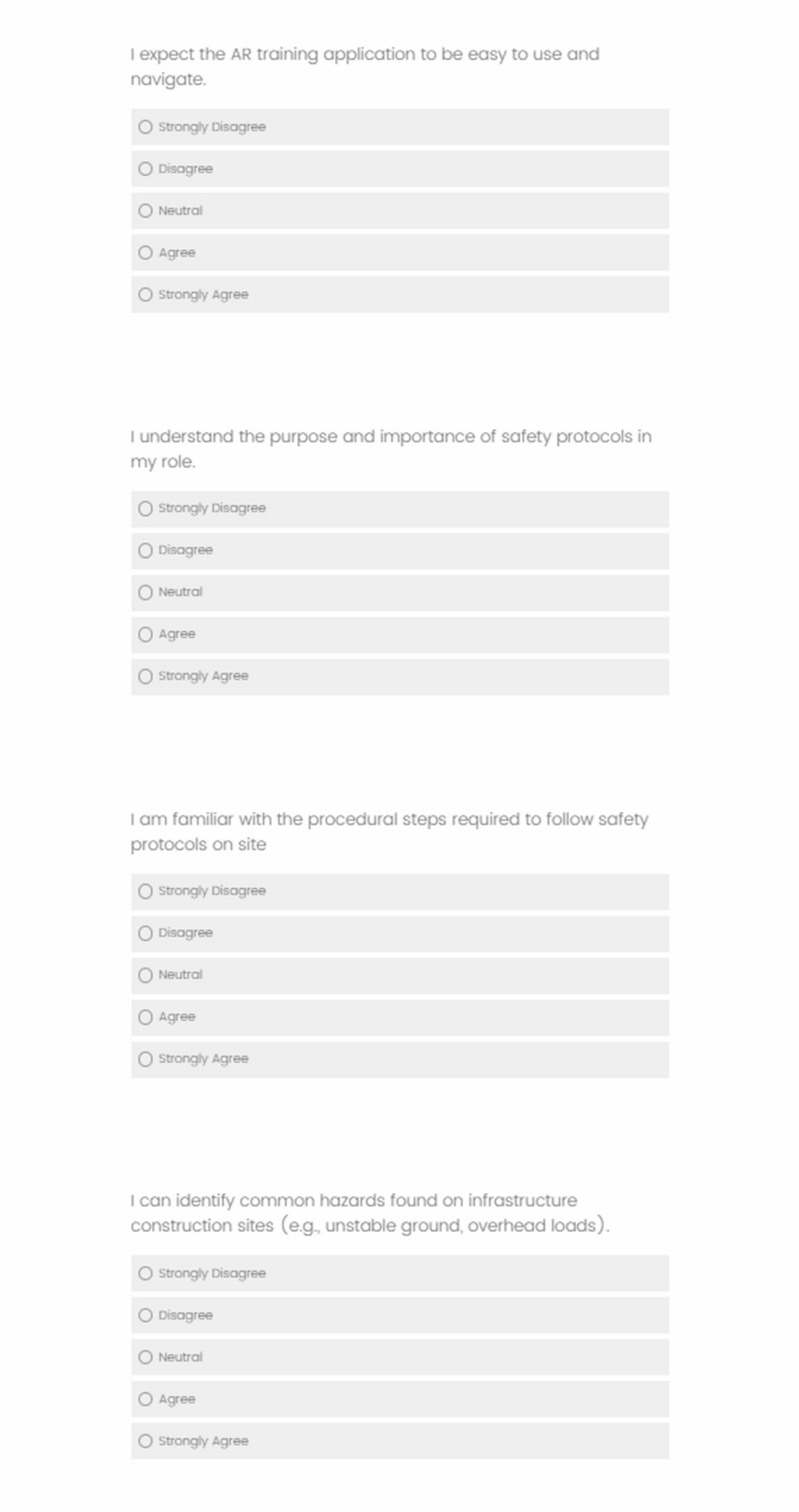
○ Not positive at all

○ Slightly positive

○ Neutral

○ Positive

○ Very positive



I expect the AR training application to be easy to use and navigate.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I understand the purpose and importance of safety protocols in my role.

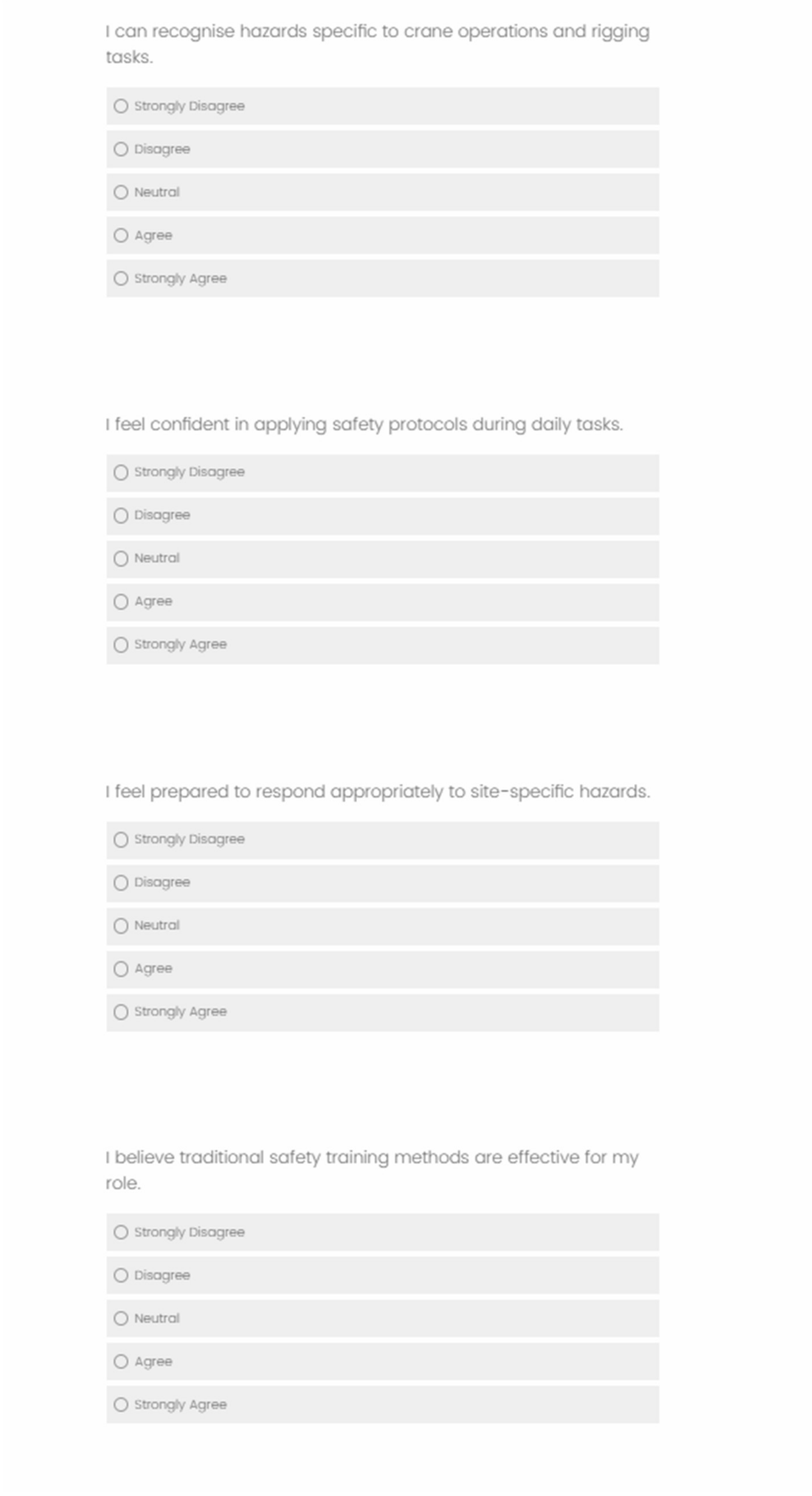
○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I am familiar with the procedural steps required to follow safety protocols on site

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I can identify common hazards found on infrastructure construction sites (e.g., unstable ground, overhead loads).

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree



I can recognise hazards specific to crane operations and rigging tasks.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I feel confident in applying safety protocols during daily tasks.

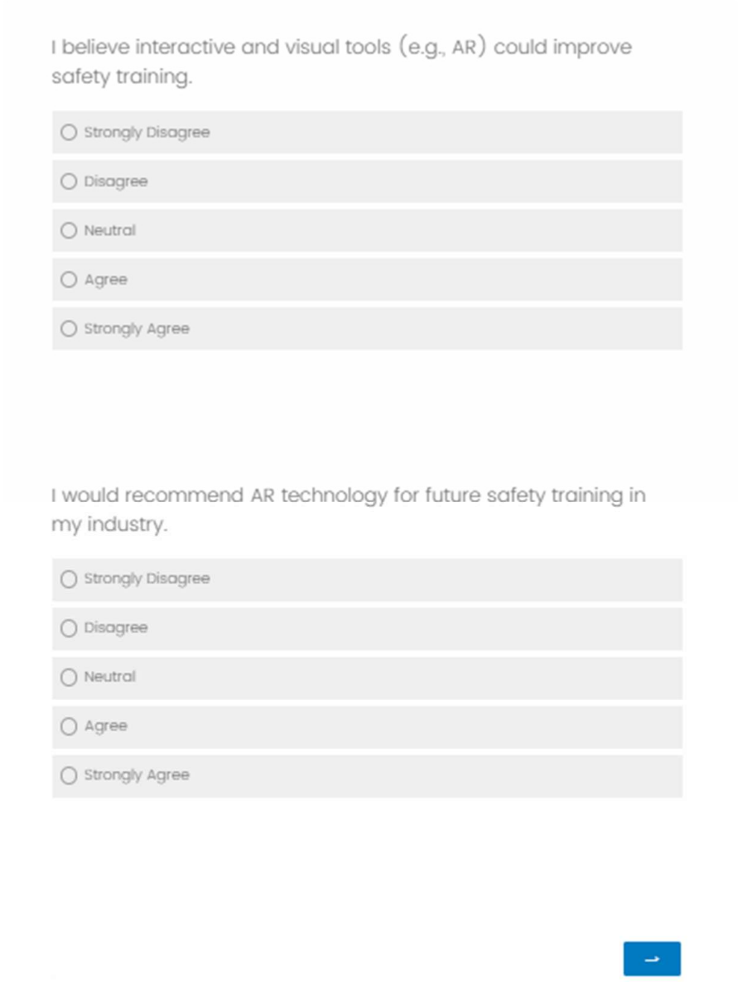
○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I feel prepared to respond appropriately to site-specific hazards.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I believe traditional safety training methods are effective for my role.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

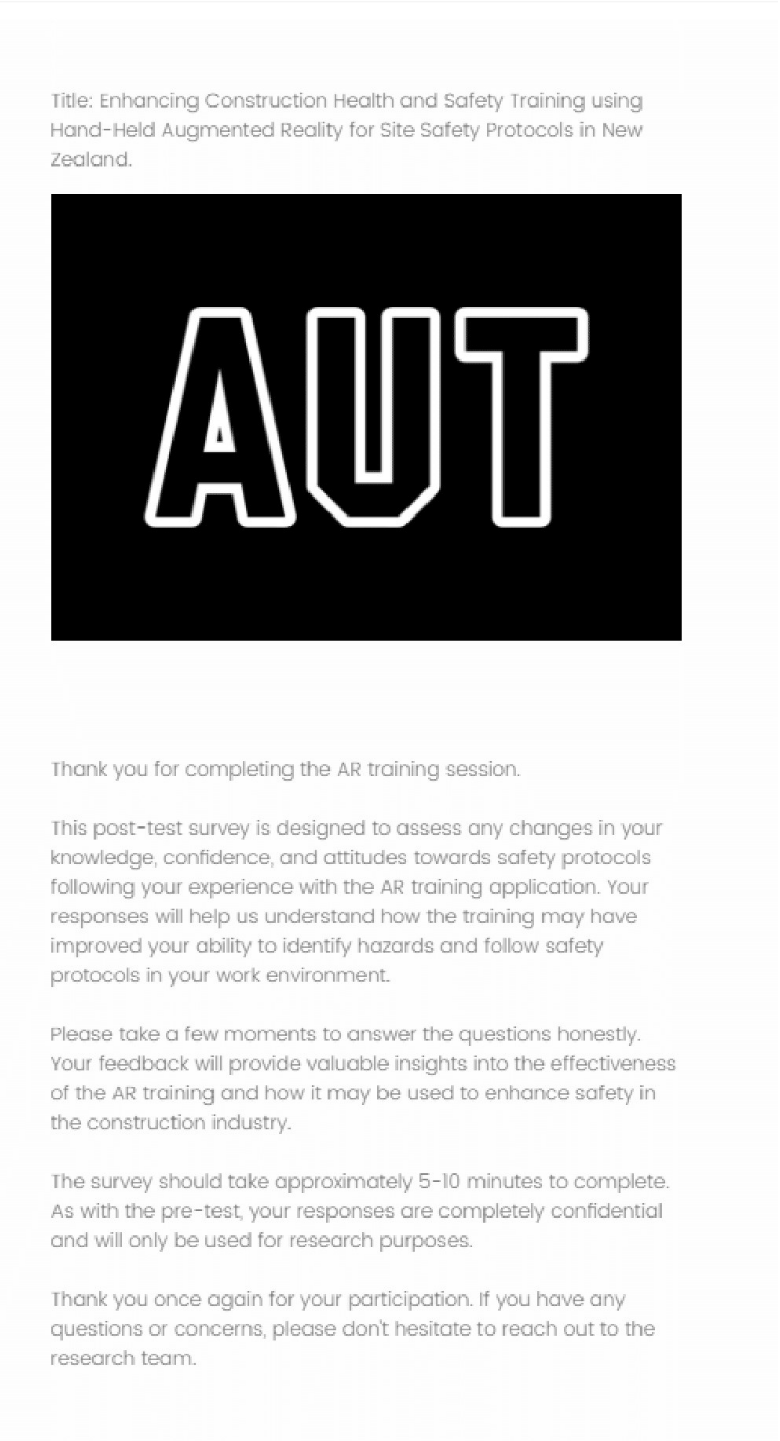


I believe interactive and visual tools (e.g., AR) could improve safety training.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I would recommend AR technology for future safety training in my industry.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree



Title: Enhancing Construction Health and Safety Training using Hand-Held Augmented Reality for Site Safety Protocols in New Zealand.

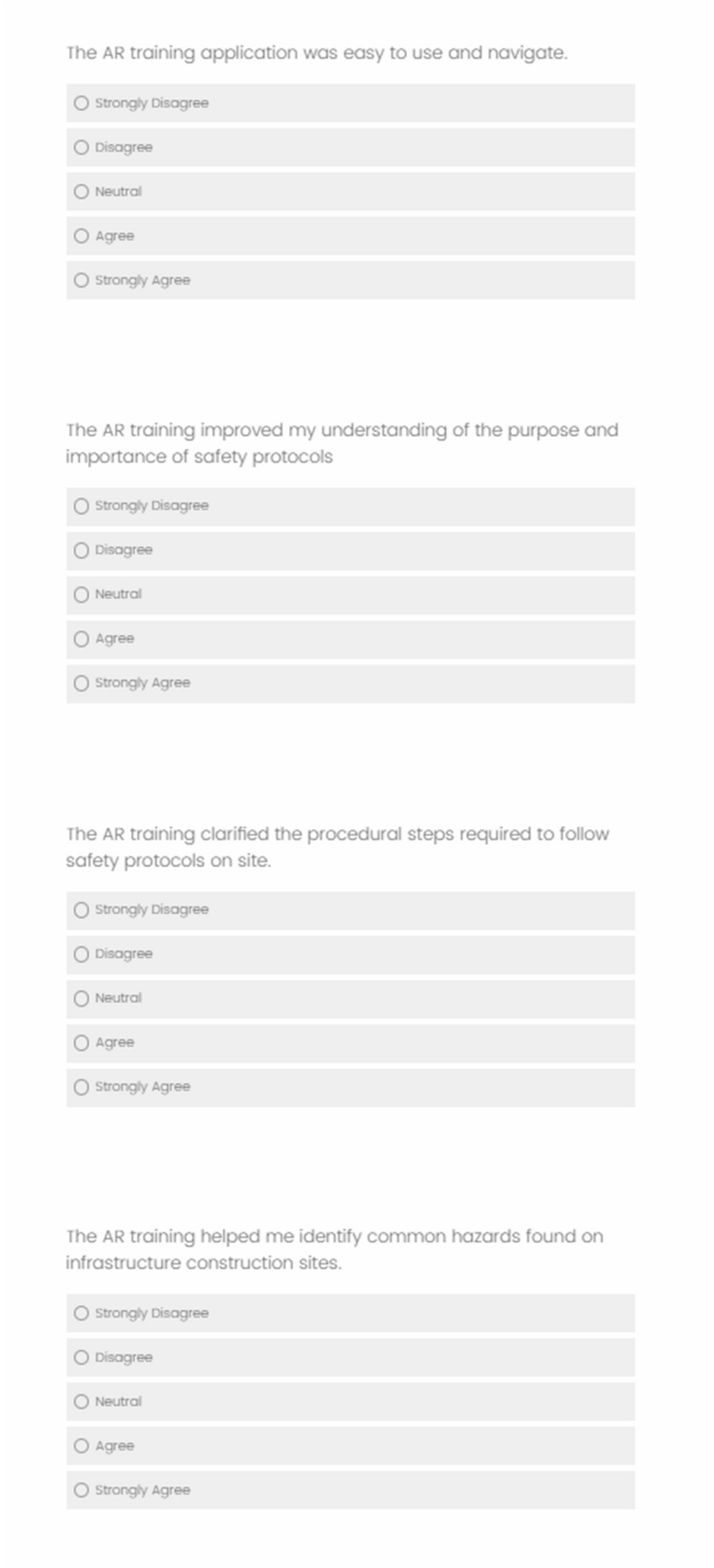
Thank you for completing the AR training session.

This post-test survey is designed to assess any changes in your knowledge, confidence, and attitudes towards safety protocols following your experience with the AR training application. Your responses will help us understand how the training may have improved your ability to identify hazards and follow safety protocols in your work environment.

Please take a few moments to answer the questions honestly. Your feedback will provide valuable insights into the effectiveness of the AR training and how it may be used to enhance safety in the construction industry.

The survey should take approximately 5-10 minutes to complete. As with the pre-test, your responses are completely confidential and will only be used for research purposes.

Thank you once again for your participation. If you have any questions or concerns, please don't hesitate to reach out to the research team.



The AR training application was easy to use and navigate.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

The AR training improved my understanding of the purpose and importance of safety protocols

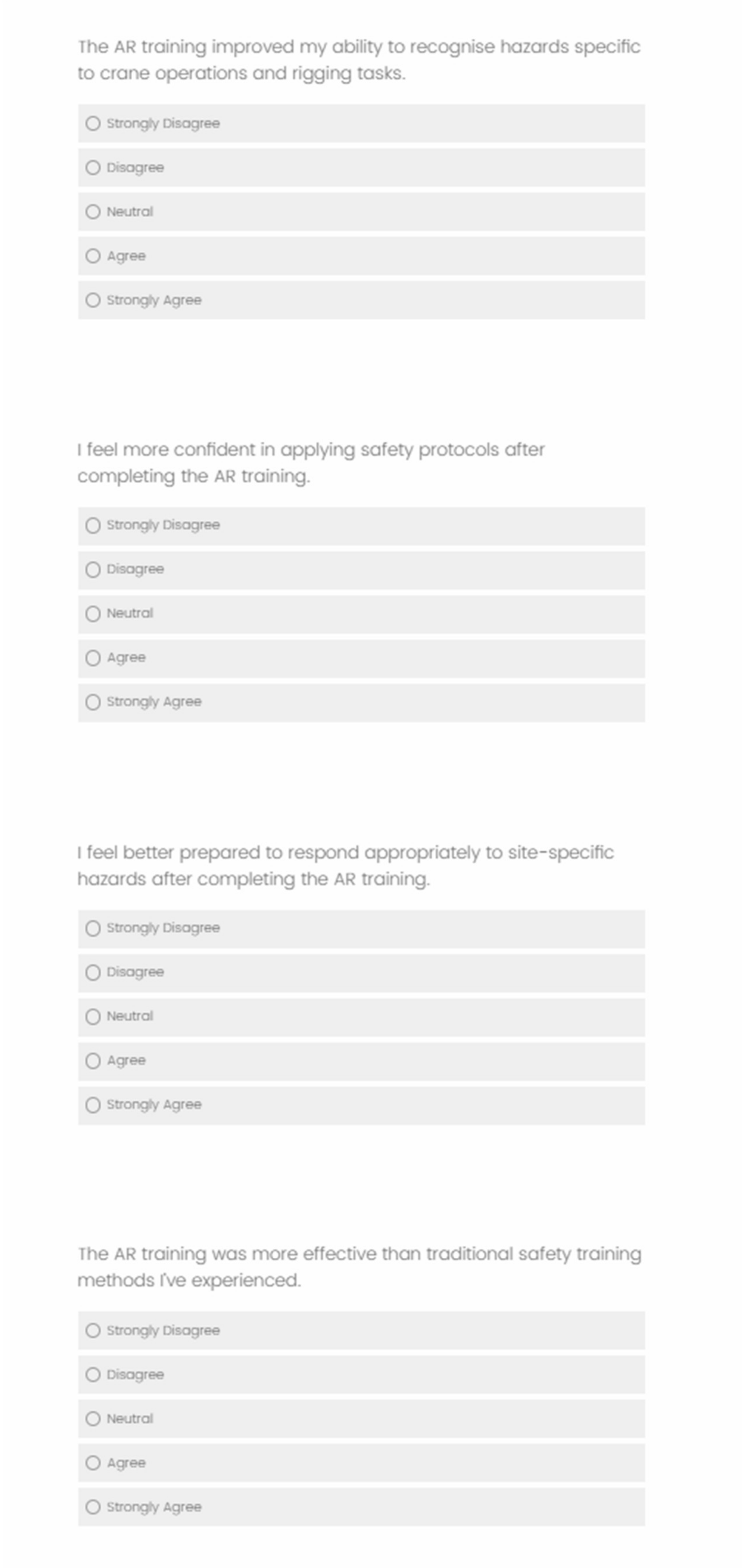
○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

The AR training clarified the procedural steps required to follow safety protocols on site.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

The AR training helped me identify common hazards found on infrastructure construction sites.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree



The AR training improved my ability to recognise hazards specific to crane operations and rigging tasks.

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

I feel more confident in applying safety protocols after completing the AR training.

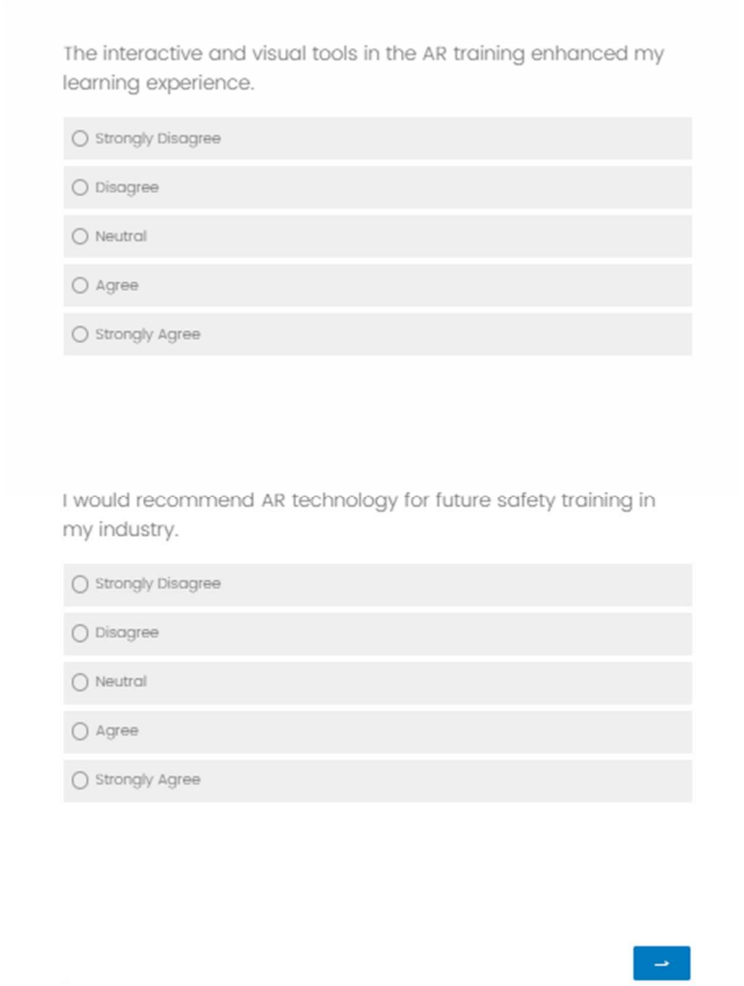
- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

I feel better prepared to respond appropriately to site-specific hazards after completing the AR training.

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

The AR training was more effective than traditional safety training methods I've experienced.

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree



The interactive and visual tools in the AR training enhanced my learning experience.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

I would recommend AR technology for future safety training in my industry.

○ Strongly Disagree
○ Disagree
○ Neutral
○ Agree
○ Strongly Agree

b) Participant Information Sheet

TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Participant Information Sheet

Date Information Sheet Produced:

25 September 2024

Project Title

Enhancing Construction Health and Safety Training using Hand-Held Augmented Reality for Site Safety Protocols in New Zealand.

An Invitation

My name is Ray Hikaka, I am studying a Master of Creative Technologies at AUT University. I wish to invite you to partake in this research on the effective development and adoption of a hand-held AR application designed to enhance specific safety protocols related to crane operations. This research will form the foundations of my Master's thesis. Your participation in this research is voluntary, and you are free to withdraw from this research without any consequences.

What is the purpose of this research?

The purpose of this research is to evaluate the effectiveness and usability of a handheld augmented reality (AR) application designed to enhance safety protocols among crane operators and riggers in New Zealand. By incorporating the Technology Acceptance Model (TAM), this study aims to assess participant's perceptions of the AR technology, particularly its perceived ease of use and perceived usefulness in improving hazard identification and overall safety practices.

The research seeks to understand how AR training influences participant’s knowledge and attitudes toward safety protocols, addressing the persistent challenges of unsafe behaviours and inadequate hazard mitigation in construction environments. Conclusively, this research seeks to contribute valuable insights into the adoption of innovative training methods that can lead to improved safety outcomes and improved operational efficiency in the construction industry.

The findings of this research may be used for academic publications and presentations. This research will also form the basis of my Master of Creative Technologies degree.

How was I identified and why am I being invited to participate in this research?

You were Invited as a potential participant in this research because of your role as a crane operator or rigger at a Site Safe certified company in New Zealand. Your experience and expertise in the construction industry are vital for understanding the effectiveness of the handheld augmented reality application in enhancing safety protocols, specifically in hazard identification. By inviting you to participate, the research aims to gather insights from individuals who directly engage with safety procedures, thereby ensuring that the findings are grounded in real-world experiences and can contribute to improving safety training in the industry. Eligible participants must be over the age of 18, have at least 12 months of experience in their role, have no prior experience with augmented reality safety training, and have not undergone formal safety training in the past 12 months, and be based in Auckland

How do I agree to participate in this research?

You can agree to participate in this research by emailing me and expressing your interest (Ray Hikaka: rhp8961@autuni.ac.nz). Also attached is a consent and release form which I will ask you to sign prior to beginning of the user study session.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

In this research, participants will engage in a session where they will use a handheld augmented reality application designed to enhance safety protocols in crane operations and rigging. Initially, participants will complete a pre-test survey to assess their existing knowledge and attitudes toward safety practices. Following this, they will interact with the AR application, which will guide them through a specific safety scenario related to hazard identification. After the AR training, participants will fill out a post-test survey to evaluate any changes in their knowledge and perceptions regarding safety protocols and to measure their acceptance of the AR technology based on the TAM constructs of perceived ease of use and perceived usefulness. A photo session will capture their engagement with the application (with prior consent). Following this, a focus group will be conducted to collect in-depth feedback on their overall experience with the AR training. This combined approach aims to provide a clearer understanding of the AR training's effectiveness, its acceptance among users and its impact on safety practices in the construction industry.

Participants will engage in the research during work hours, with the organization granting them release from their regular duties to ensure their involvement. The sessions are scheduled to take place at AUT in a large room within the WG building on February 11th and 12th, from 10 AM to 11 PM. These arrangements have been coordinated with management to minimize disruptions to work schedules.

What are the discomforts and risks?

There are little to no risks or discomforts anticipated for participants. The nature of the study involves using a handheld augmented reality application and completing brief surveys, both of which are non-invasive and pose no physical or emotional harm. Participants may experience minor frustration or fatigue while interacting with the technology, but breaks will be provided, and assistance will be available if needed.

How will these discomforts and risks be alleviated?

If you start to experience any discomfort, such as frustration with the AR technology, technical assistance will be available during the session, and you may also take breaks as needed. You are also free to withdraw from the study at any time if you feel uncomfortable

What are the benefits?

This research will contribute to my master's thesis, fulfilling a requirement of the Master of Creative Technology program. The study aims to cultivate a more competent workforce equipped to handle safety challenges effectively. It seeks to enhance safety training outcomes for crane operators, riggers, and construction workers more broadly. Additionally, this research will support valuable insights for policymakers and stakeholders on effective strategies for improving the adoption of AR technology in training within New Zealand's construction industry.

By engaging in the study, participants may gain new skills or enhance existing ones related to safety practices and the use of technology in training. This can increase their competence in their roles and make them more valuable employees. They will also have the opportunity to influence the design and effectiveness of augmented reality safety training programs, which may enhance their own training experiences in the future.

How will my privacy be protected?

Your privacy will be prioritized throughout the session. Participation is entirely voluntary, and the data collected will be anonymized to ensure that no personally identifiable information is linked to your responses. All data will be stored securely and only accessible to the research team. Additionally, any results will be reported in aggregate form to maintain participant anonymity.

Various data collection methods will be employed, including focus groups, photo sessions, pre-test and post-test surveys. Each method has different levels of privacy, and it is essential to clarify how participants' privacy will be protected throughout the study.

Focus Groups:

While focus groups inherently involve group discussion, measures will be taken to ensure confidentiality. Participants will be reminded not to share each other's information outside the group. Transcripts and notes from the focus groups will be anonymized, and identifiers will be removed during data analysis to protect participant identities.

Photo Sessions:

Participants involved in photo sessions will be informed about the purpose of the photos and how they will be used in the research. Consent forms will clearly outline that photos will be used for research purposes only. Identifying features may be blurred or omitted in any public presentations of the data to maintain anonymity.

Surveys:

The pre-test and post-test surveys will be administered in a way that ensures anonymity. Participants will not be required to provide personal identifying information, and responses will be aggregated for analysis. This ensures that individual responses cannot be traced back to specific participants.

Assurance of Privacy Protection:

Participants will be informed about the data handling procedures at the outset of the study. All data will be stored securely, with access limited to the researcher and project supervisor only. Any publication of research outputs will ensure that no individual participant can be identified, maintaining their confidentiality.

What are the costs of participating in this research?

The cost of participating in my research will be the small fraction of your time and energy you give to this user study, approximately 45-50 minutes long.

What opportunity do I have to consider this invitation?

Participants will have a three-week timeframe to carefully consider their invitation to participate in the study. During this period, you are encouraged to ask any questions or seek clarification about the study's purpose, procedures, and potential impacts. After the three weeks, if you choose not to participate, your decision will be respected, and you will not be able to consent to join the study. This allows you ample time to make an informed choice regarding your involvement

Will I receive feedback on the results of this research?

You will have the opportunity to receive feedback on the results of the research. After the study is completed and the findings are analysed, a summary of the results will be shared with all participants who express interest (An option specified in the Consent Form). This feedback will include insights into how the augmented reality application impacted safety training outcomes and any recommendations that emerged from the study. We value your contribution and aim to ensure you are informed about the research outcomes

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor; Dr Rachel Shearer, rachel.shearer@aut.ac.nz, 099219666 ext. 5486.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Ray Hikaka. Faculty of Design & Creative Technologies, School of Future Environments, AUT University. rhp8961@autuni.ac.nz

Project Supervisor Contact Details:

Dr Rachel Shearer. Faculty of & Design Creative Technologies, School of Future Environments. AUT University. rachel.shearer@aut.ac.nz, 099219666 ext. 5486.

Approved by the Auckland University of Technology Ethics Committee on 11/11/2024, AUTEC Reference number 24/300.

c) Consent forms

TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Consent and Release Form

Project Title: Enhancing Construction Health and Safety Training using Hand-Held Augmented Reality for Site Safety Protocols in New Zealand.

Project Supervisors: Dr Rachel Shearer, Dr Stefan Marks

Researcher: Ray Hikaka

○ I have read and understood the information provided about this research project in the Information Sheet dated 25/09/2024.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I understand that the photographs will be used for academic purposes only and will not be published in any form outside of this project without my written permission.

○ I understand that any copyright material created by the photographic sessions is deemed to be owned by Ray Hikaka and that I do not own copyright of any of the photographs.

○ I would like to receive a one-page summary of the findings on this research

○ I understand that identity of my fellow participants and our discussions in the focus group is confidential to the group and I agree to keep this information confidential.

○ I agree to take part in this research.

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 11/11/2024 AUTEC Reference number 24/300

Note: The Participant should retain a copy of this form.

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Permission for researchers to access organisation staff

Project title:	***Enhancing Construction Health and Safety Training using Hand-Held Augmented Reality for Site Safety Protocols in New Zealand.***
Project Supervisor:	***Dr Rachel Shearer, Dr Stefan Marks***
Researcher:	***Ray Hikaka***

○ I have read and understood the information provided about this research project in the Information Sheet dated 25 September 2024.

○ I give permission for the researcher to undertake research within ______________________________________

○ I give permission for the researcher to access the staff / employees of __________________________

CEO's signature: ……………………………………………………………………………………………………

CEO's name: ……………………………………………………………………………………………………

CEO's Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

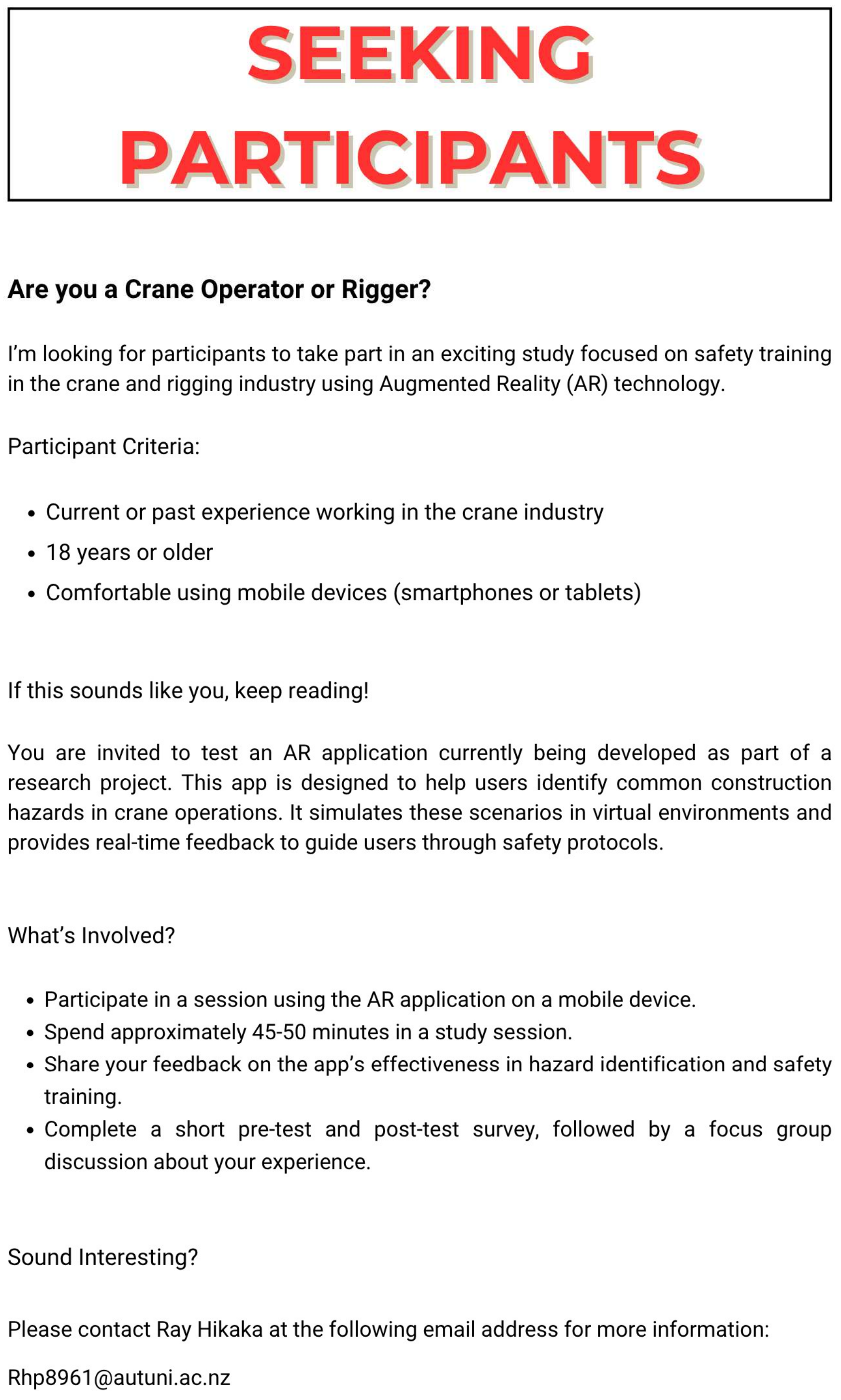
……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 11/11/2024 AUTEC Reference 24/300.

Note: The head of the organisation should retain a copy of this form.

d) Advertisement flyer



SEEKING PARTICIPANTS

Are you a Crane Operator or Rigger?

I'm looking for participants to take part in an exciting study focused on safety training in the crane and rigging industry using Augmented Reality (AR) technology.

Participant Criteria:

- Current or past experience working in the crane industry
- 18 years or older
- Comfortable using mobile devices (smartphones or tablets)

If this sounds like you, keep reading!

You are invited to test an AR application currently being developed as part of a research project. This app is designed to help users identify common construction hazards in crane operations. It simulates these scenarios in virtual environments and provides real-time feedback to guide users through safety protocols.

What's Involved?

- Participate in a session using the AR application on a mobile device.
- Spend approximately 45-50 minutes in a study session.
- Share your feedback on the app's effectiveness in hazard identification and safety training.
- Complete a short pre-test and post-test survey, followed by a focus group discussion about your experience.

Sound Interesting?

Please contact Ray Hikaka at the following email address for more information:

Rhp8961@autuni.ac.nz