VR-Based Safety Training Program for High-Rise Building Construction

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VR-BASED SAFETY TRAINING PROGRAM FOR HIGH-RISE BUILDING CONSTRUCTION

A Thesis submitted to the
Construction Engineering Department

In partial fulfillment of the requirements for
the degree of Master of Science

By

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Fall 2022
DECLARATION OF AUTHORSHIP

I, Sahar Moustafa Bader declare that this thesis titled, “[VR-based Safety Training Program for High-rise Construction Projects]” and the work presented in it are my own. I confirm that:

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Signed:

Sahar Moustafa Bader

Date:

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ABSTRACT

The rates of fatal and non-fatal accidents within the construction industry across the globe are surging despite the massive efforts that are being exerted toward maintaining a safe working environment. In fact, one-fifth of work-related fatalities are attributed to the construction industry. Such fatal accidents are dominant in complex construction projects, such as the construction of high-rise buildings. Past research has proved that the provision of effective safety training programs is a primary course of action that should be taken to minimize construction accidents, fatalities, and both fatal and nonfatal injuries. However, in acknowledging the limitations of traditional safety training programs within the construction industry, several researchers have addressed the urge to incorporate novel training practices that are based on the modern virtual reality (VR) technology to promote “learning by doing” and “experiential learning” in their educational approaches. Nevertheless, there is a lack of incorporating major learning theories as a solid foundation for the design and development of VR-based training programs. Also, there is a lack of comprehensive VR-based safety training programs that specifically address the safety of high-rise building construction.

This research aims to develop a comprehensive, fully immersive, and interactive VR-based safety training program that addresses the hazards and risks pertaining to the construction of high-rise buildings based on major learning theories in an attempt to enhance the learning outcomes of construction workers and safety officers. The developed conceptual framework for conducting VR-based safety training program is based on behaviorism, constructivism, and andragogy principles. The framework validation findings yielded promising results. To start with, it was evident that the introduction of andragogy principles caused group 1 to obtain statistically significant higher hazard identification and accident path scores as compared to other groups. In comparison with group 2 who received the same training without andragogy principles, group 1 had a 36% higher mean hazard identification score than group 2, while a 49% higher accident-path mean score as compared to group 2. Group 1 also scored statistically higher significant scores in risk probability and mitigation measures scores as a result of their enhanced ability to identify more risks and accidents.
Likewise, the introduction of punishments or consequential accidents enhanced trainees’ hazard assessment skills and aided them in overcoming the risk habituation phenomenon, a phenomenon that decreases risk sensitivity because of repeated exposure to hazards without any negative consequence. Therefore, groups 1, 2 and 3 who viewed consequential accidents had statistically significant higher probability impact score than group 4. Excluding group 1 who had much higher scores due to andragogy principles, groups 2 and 3 had 18% and 9% increase in their mean risk probability score as compared to group 4. The case is quite similar in terms of risk impact scores as groups 2 and 3 had 15% and 22% increase in their risk impact scores as compared to group 3.

Finally, it was also evident that the introduction of hazard mitigation measures positively contributed to the trainees’ hazard management skills along with an enhanced selection of the right course of action. Accordingly, groups 2 and 4 who viewed superior safety practices obtained statistically significant higher hazard mitigation scores as compared to group 3 which did not. The increase in the mean of the hazard identification score of groups 2 and 4 as compared to group 3 is 44% and 46% respectively. The comprehensive content of the VR-based safety training for high-rise construction was then further developed into a complete high-rise training program. In total, the developed safety training program includes 7 modules with a total of 76 unique hazards. This research does not only benefit engineers in high-rise buildings, but it also acts as a guide to future researchers and developers to push the limits of their VR training programs and elevate the learning outcomes through the integration of adult learning theories.
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CHAPTER 1: INTRODUCTION

1.1 Background & Overview

The construction industry is often characterized by its unique, dynamic, and fragmented nature where multiple stakeholders are involved while several complex activities are being conducted simultaneously (Le et al., 2014). Therefore, the safety of construction sites has been an issue that has raised several concerns over the past few decades. Recent statistics show that the number of fatalities, accidents, and non-fatal injuries witnessed in the construction industry is still high relative to other industries, despite the increasing level of awareness and the precautionary measures that are being implemented in construction projects. As stated by the International Labor Organization, “The construction industry has a disproportionately high rate of recorded accidents” ("World Statistics", 2021).

According to the latest report published by US Bureau of Labor Statistics (BLS), 1061 fatalities occurred in the construction industry in 2020 with a 5% increase as compared to the statistics of 2007 (BLS, 2020). This is further compounded by the fact that 40 out of 100,000 construction workers encounter fatal work injuries per year, as seen in figure 1 (BLS, 2020). Besides, an average of 200,000 non-fatal injuries are realized in the US construction industry and have been almost constant for the past decade (BLS, 2020).

![Figure 1: Fatal work injuries per 100,000 full-time workers. Source: (BLS, 2020).](image-url)
The case is quite similar in Europe where statistics reveal that about one-fifth of work-related fatalities are attributed to the construction industry (Eurostat, 2021). To further reveal its life-threatening nature, the construction industry has been ranked the first in Europe in 2018, as seen in figure 2, in terms of the number of fatal and non-fatal accidents that occur (Eurostat, 2021); thereby, demonstrating the inherent danger of construction sites and shedding light on the severe implications that could happen to construction workers. In fact, the severity of construction accidents has been acknowledged across the globe causing the industry to be classified as “one of the most dangerous industries to work in”

Figure 2: The construction industry scored the highest rate of fatal injuries across Europe in 2018. Source: (Eurostat, 2021).

The potential safety hazards that are often encountered in general construction projects include being struck by moving vehicles and/or falling objects, falling through penetrations and/or from
heights, slips, trips and falls, handling and lifting injuries, exposure to harmful substances, electrocution, fire and explosions, drowning, etc. (Perlman et al., 2014).

From the aforementioned statistics, it is evident that the construction industry is an industry that is plagued with multiple forms of hazards and risks. It has also been acknowledged that multiple construction fatalities and injuries are attributed to high-rise building construction projects (Martinez et al., 2020) which are on a rise due to land scarcity. The increase in population growth and the need to have more urban cities have been associated with a similar increase in high-rise building constructions to overcome the issue of finite land resources (Deere et al., 2021). Therefore, the demand for high-rise buildings is soaring at unprecedented rates.

In fact, the number of high-rise (200 meters and over) completions have steadily risen over the last decades, with an average of 120+ high-rise buildings being constructed yearly across the globe (Statista, 2022). Examples of high-rises that are currently under construction include Jeddah Tower (Saudi Arabia), Tower M (Malaysia), Merdeka PNB118 (Malaysia), Goldin Finance 117 (China), Evergrande International Financial Center T1 (China), Lakhta Center (Russia), etc. The number of high-rise projects is further projected to double in the future (Deere et al., 2021).

The trend of high-rise construction is also apparent in Egypt with examples of buildings under construction such as the Iconic Tower, Nile Business City Tower 1, Diamond Tower, Infinity Tower, Taj Tower, North Tower, and Oblisco Capitale in New Administrative Capital, and Alamein Iconic Tower, Downtown Towers A, B, C, & D, and The Gate Towers in New Alamein City.

Despite this increase, there is a lack of safety guidelines that dictate best practices when it comes to the construction of high-rise building projects to ensure their safety. This is further supported by the Vice President of Phoenix Mills, a mega-developer who stated that there is a lack of “standardized safety code for high rise buildings for implementation of best practices; developers like us have put in place stringent HSE norms/safety standards to tighten safety for our construction partners and customers.” (Phoenix Mills, 2016).
In recognition of the high mortality rate of work-related accidents in the construction industry, Li et al., (2019) stated that effectively designed safety training programs should be mandated and obligatory for all construction workers. Despite the wide consensus over the benefits of conducting safety training in eliminating potential hazards, there is still a gap when it comes to the investigation of novel safety training methods (Nykänen et al., 2020). It has been acknowledged that most of the existing safety training programs are traditional programs that are based on powerpoint based lectures along with some pictures and videos of the content being taught (Nykänen et al., 2020). The lack of trainees’ engagement in such programs not only risks the lack of knowledge due to the trainees’ emerging sense of exclusion but also risks counterproductive learning (Yardley et al., 2012).

Recently, there has been a wide momentum towards the adoption of new technologies, specifically VR-based technologies, to enhance the outcomes of several educational programs. As stated by Mancuso et al., (2010), “Technology-mediated learning is a relatively new phenomenon in adult learning and is rapidly becoming a vital component of the current and future workplace.” (p. 681). Whereas Zakaria et al., (2020) state that “Gamification has been one of the effective approaches to student-centered learning, it allows students to build skills, acquire knowledge and develop an attitude in a game world specifically created for educational purposes.” (p.325).

Fromm et al., (2021) further state that the opportunity to create learning experiences that were otherwise not possible in real-life is another main driver of the wide utilization of VR technology in education (Fromm et al., 2021). While Zakaria et al., (2020) add that gamification is significantly capable of increasing learners’ engagement, motivation, experience, sense of pride and achievement. Within this context, it has been acknowledged that VR technology has matured enough, receiving increasing popularity as it became relatively cheap and affordable (Wohlgenannt et al., 2019).

The breakthrough in VR and AR is attributed to the magnificent advancement in technologies that enable their use; As stated by Song et al., (2021), “Technological advances have made previously expensive VR HMD devices much more affordable, and a variety of VR applications have been developed.” (p.8). This is further supported by the growing compatibility of the available software
and tools along with the massive reduction in development time (Mora-Serrano et al., 2021). In fact, the VR market in the US alone has increased from $62.1 million in 2014 to $1160 million in 2018 (Wohlgenannt et al., 2019). Its market is further expected to increase to 120.5 billion US dollars in 2026 (Fromm et al., 2021).

Similarly, attention to VR technologies has also increased significantly within the construction industry over the past few years with multiple research papers incorporating VR in safety training (Sacks et al., 2013; Mora-Serrano et al., 2021; Dhalmahapatra et al., 2021; Goulding et al., 2012). The aforementioned research papers have all reflected the potential of VR in enabling the development of a preventative culture; thus, enhancing the learning outcomes of trainees and improving the overall safety performances of construction projects.

Despite the multiple attempts and efforts towards the incorporation of VR technology in educational purposes, these efforts are not based on solid educational foundations, which would have better informed their methodological designs to maximize the learning outcomes for students. In fact, the understanding of adult learning processes is a matter of serious concern for scholars and practitioners advocating any educational reform (Seaman et al., 2017). Accordingly, various research has necessitated the incorporation of learning-theory foundations in game-based learning (Wu et al., 2011).

Accordingly, researchers have been trying to implement learning theories in traditional training for decades to enhance education quality and students’ learning experiences (Svinicki & Dixon, 1987). With the advancements in technology, there have also been similar advocacy for such incorporation in game-based learning (Wohlgenannt et al., 2019). Nevertheless, only a few researchers have shed light on the association between social learning theories and the development of game-based educational programs (Wu et al., 2011; Wohlgenannt et al., 2019; Briese et al., 2020; Fromm et al., 2021).

**1.2 Problem Statement**

From the aforementioned introduction, it is clear that VR has multiple potential benefits when it comes to maintaining safety in construction sites; yet, the applications of the technology are still
limited within the construction industry. Thus, there is a lack of developing comprehensive VR-based safety training programs that fully and conclusively address a specific topic. Besides, there is a lack of considering complex project types such as high-rise construction projects which is one of the project types that is associated with high rates of accidents due to their complexity and unsafe working conditions. These include working at extremely high altitudes, in extreme weather conditions, and using novel construction equipment and method statements. In addition, there is a lack of consideration for major adult learning theories in existing VR-based safety training programs. This could impede further capitalizations on the potential of the technology which could be realized by devising major changes to the ways VR-based safety training programs are being conducted. By considering major learning theories in the training framework, improvements in the learning outcomes could be readily witnessed without incurring any additional costs; thereby, further contributing to the safety of construction sites.

1.3 Research Goal & Objectives
The main goal of this research is to develop a fully comprehensive, immersive, and interactive VR-based safety training program that tackles hazardous aspects of high-rise building construction. The training program would be based on major learning theories further enhance the learning outcomes of construction workers and safety officers; thereby, enhancing the safety performance of high-rise building projects. Accordingly, the research objectives are as follows:

- To identify all potential safety hazards in high-rise building construction.
- To design and validate a conceptual framework for the development and conduction of VR-based safety training programs based on main adult learning theories.
- To design and develop a comprehensive VR-based safety training program for high-rise construction.

1.4 Research Significance
The significance of this research emerges from a wide range of aspects. Firstly, it is practically infeasible to expose construction laborers to actual hazards at construction sites. As stated by Perlman et al., (2014), “Concern for the physical safety of experimental subjects precludes the possibility of asking subjects to tour a real construction site and to identify all of the hazards they
can. In particular, purposefully creating hazardous conditions – such as missing edge protection – would be immoral and unethical.” (p.23). Thus, the provision of a comprehensive safety training program with the aid of VR technology would act as the main substitute for embracing the “learning by doing” and experiential learning approaches.

Secondly, this research works towards the standardization of the developed training program as not only the first comprehensive VR-based training program but also, the first to consider safety training for high-rise construction. This would further be accompanied by the provision of the basis for developing safety guidelines and best practices for high-rise building construction.

Thirdly, this research is considered to be among the few in relation to the incorporation of major learning theories as the main underlying foundation upon which the research’s methodology is designed and built. This research bridges the existing gap in the literature by drawing the attention of those who are interested in developing VR-based training programs to vital aspects that would further complement the strengths of VR technology. Accordingly, it sheds light on crucial factors that should be considered above and beyond the technical aspects of developing VR training models. This would aid researchers in developing a thorough and all-encompassing VR-based safety training program that would tap into the different needs of adult learners through the consideration of major adult learning attributes. Moreover, by following this conceptual framework, researchers could push the limits of their VR training programs and elevate the learning outcomes without incurring additional costs; thereby, aiding in the development of self-actualized individuals who can acquire declarative and procedural knowledge while adopting new problem-solving skills. All of the aforementioned factors would positively contribute to the overall safety of construction sites.

1.5 Thesis Organization
This thesis is organized as follows. Chapter 1 provides an overview of the topic along with the identified gaps, research aims and objectives and research significance. Chapter 2 provides a detailed coverage of the main hazards that are encountered in high-rise construction, the status-quo of the technology along with its different forms of applications, and a coverage of the main learning theories that exist in the educational studies field. Chapter 3 provides a detailed
description of the steps taken to attain the main aims and objectives of this research. Chapter 4 presents the results obtained with reference to each of the objectives along with an analysis of such results. Chapter 5 further discusses these results and compare it against evidence from the literature. Chapter 6 concludes the findings of this research and presents recommendations for future research.
CHAPTER 2: LITERATURE REVIEW

This chapter starts with an introduction into the common types of hazards that are witnessed within the construction of high-rise buildings; this is followed by an introduction of the VR technology along with its benefits, current applications within the construction industry, and how VR-based safety training programs are being conducted. The chapter then concludes by explaining the different learning theories that exist and are acknowledged in the education field.

2.1 High-rise Construction

Craighead, (2009) states that there is no single definition of high-rise buildings; however, The International Conference on Fire-Safety in High-Rise buildings define it as follows “Any structure where the height can have a serious impact on evacuation” (Craighead, 2009). Although the number of floors that constitute a high-rise building is dependent on several factors including the fire and building codes of different countries, it is generally accepted that it is the height that exceeds the maximum reach of existing fire-fighting capability (Craighead, 2009).

Thus, this research defines high-rise buildings as buildings with 20+ storeys. The following paragraphs shed light on the identified literature in relation to the risks and hazards in construction projects in general and in high-rise construction in particular, the use of novel technologies for safety training, existing adult learning theories, and existing VR-based safety training programs that incorporated learning theories in their training frameworks.

It has been well acknowledged that the construction of high-rise buildings imposes multiple challenges on the safety performance of such projects as compared to medium and low-rise buildings (Li et al., 2018). This is primarily attributed to the fact that the majority of work involves working from extremely high altitudes and the excavation of deep foundations, all of which increase the exposure to multiple risks and hazards (Li et al., 2018).

Zaini et al., (2014) further add that high-rise construction is “characterized by continual changes, use of many different resources, poor working conditions, no steady employment, tough environments such as noise, vibration, dust, handling of cargo and expose to stochastic elements such as weather conditions, soil characteristics and road accidents” (p. 255). Another challenging
aspect in the construction of high-rise buildings is the cluttering of floor spaces with building materials, formwork, scaffolding and equipment (Deere et al., 2021). Yet, there is a lack of safety guidelines that encompasses the wide forms of hazards that exist in high-rise construction. For this reason, Zaini et al., (2014) investigated the likelihood and severity of potential hazards in high-rise construction to facilitate the formulation of a high-rise building construction safety and health risk model. The following paragraphs shed light on a few of the severe hazards and risks that are often encountered in the construction of high-rise buildings.

2.1.1 Hazards in High-rise construction

While recognizing the increasing rates of accidents in the construction industry, Goh et al., (2016) identified the causes of accidents in the construction of high-rise buildings along with ways to mitigate such accidents in an attempt to enhance the safety performance of high-rise construction projects. Goh et al., (2016) found that three major forms of accidents occur in high-rise building projects namely, falling from heights, being struck by falling objects and being struck by working vehicles and equipment.

Thus, like typical construction sites, fall hazards remain a leading cause of accidents in high-rise buildings; however, the severity of fall accidents is profound to the extent that they are often linked to fatalities (Melzner et al., 2013). The concern of falling appears to be one of the most dominant factors that lead to increased levels of stress in high-rise buildings (Hsu et al., 2008). Min et al., (2012) found that working on higher scaffolds without safety rails has significantly increased the subjective difficulty in maintaining balance by both expert and novice workers; although, the rate was higher for novice workers. Hence, the significant increase in the subjective difficulty to maintain balance while working on high-rise building projects could easily be inferred. Thereby, indirectly shedding light on the significance of training programs to enhance the expertise of construction workers.

Furthermore, the intrinsic response to the perceived danger of working from elevations, manifested through fear, panic, and shivering, could impair the judgment capacity of construction workers; thereby, increasing their risk of falls (Hsu et al., 2008). Similar results were obtained with regard to cardiovascular stress where workers recorded an increase in their heart rates at higher elevations.
which increased their inability to maintain postural stability (Min et al., 2012). Min et al., (2012) recommended strict adherence to handrail safety regulations and adequate training programs for novice workers.

The risks of working from heights are further magnified due to its impact on postural stability. As stated by Habibnezhad et al., (2020), “Elevation can cause complicating physiological and physical responses due to elevation-induced anxiety and instigating visual mismatch” (p.2). Diemer et al., (2016) found that both acrophobic and healthy people experienced psychological arousal as a result of fear of heights even in virtual environments. These included increasing heartbeats and skin conductance levels. Similarly, Habibnezhad et al., (2020) found that elevation has played a significant role in altering task performance and postural sway in construction workers who are working on activities that require an upright stance.

One of the most beneficial and commonly used preventative measures to fall hazards is the installation of fall protection systems. These systems that are employed in almost any construction type include the installation of guardrails, safety nettings and/or walkable and indisplacable plates in openings and at the edge of buildings (Melzner et al., 2013). Thus, stair, ladder and hatch openings should be guarded by guardrails. Yet, Martinez et al., (2020) acknowledged that there are multiple inspection difficulties in high-rise buildings to ensure the proper installation of fall protection systems; these include the inspection of inaccessible, hard-to-reach and unsafe locations causing safety officers to miss existing safety hazards which often goes unidentified until an accident has already occurred.

Likewise, the construction of high-rise buildings is also associated with using several combustible and flammable materials which increases the risk of fire (Li et al., 2020). As stated by Li et al., (2020), “the fire risks of a high-rise building under construction are relatively large, with many influencing factors and thus high complexity and uncertainty” (p.1). The risk is further compounded by the existence of multiple heat sources and poor fire-fighting capabilities in construction sites. This is since all fire-fighting systems, although already installed, are not yet in use; rather, the full dependence is on temporary fire-fighting facilities during the construction phase (Li et al., 2020).
The case is worsened by the lack of properly constructed refuge routes for escape in fire emergencies (Martinez et al., 2020). The existing routes in high-rise buildings under construction could be regarded as unsafe and insecure. This is because they are often made of wood decking, decking with rebars and narrow and steep ladders connecting between floors during construction (Deere et al., 2021); which could easily shatter from extremely high pressures during evacuations. The severity of these risks further increases by the interconnectivity and transferability of routes that are in constant change throughout the construction process (Deere et al., 2021). Accordingly, Deere et al., (2021) acknowledged that the evacuation of high-rise construction sites is among the most challenging conceivable evacuation scenarios; thereby, further enlarging the associated risks.

Another very likely cause of hazards in high-rise building construction is associated with the massive utilization of tower cranes. Such risks primarily emerge from the weight of objects along with the heights that they are being transferred to; thereby, causing tower crane accidents to be fatal and catastrophic (Shin, 2015). Thus, imposing risks from hazards of moving objects such as struck-by and falling objects (Martinez et al., 2020). Other accidents are also related to the possible collisions as a result of overlapping tower cranes in high-rise building construction. Al Hattab et al., (2018) identified 10 types of possible collisions in overlapping crane operations which are illustrated in the following bullet points.

- Object with Object (OO)- Lifted object of one crane clashing with the object of the other;
- Object with Sling (OS)- Lifted object of one crane clashing with the sling of the other;
- Jib with Sling (JS)- Jib of one crane clashing with the sling of the other;
- Jib with Object (JO)- Jib of one crane clashing with the lifted object of the other;
- Horizontal with Horizontal Movement (HH)- Both cranes moving in horizontal planes;
- Horizontal with Vertical Movements (HV)- One crane is moving in the horizontal plane whereas the other is vertically hoisting;
- Vertical with Vertical Movements (VV)- Both cranes vertically hoisting;
- Horizontal with Loading/Unloading movement (HUL)- One crane is moving in the horizontal plane while the other is in a fixed loading/unloading position;
- Vertical with Loading/Unloading movement (VUL)- One crane is moving in the vertical plane while the other is in a fixed loading/unloading position;
• Loading/Unloading with Loading/Unloading movement (ULUL)- Both cranes are in loading/unloading positions.

While recognizing the severe accidents that are associated with the assembly and dismantling of tower cranes in high-rise building construction, Shin, (2015) investigated the factors that affect work safety that led to accidents during tower crane installation and dismantling. This was done using both surveys and a case study approach. The results of the case study revealed that most tower crane fatal accidents occurred during climbing followed by dismantling and erection respectively; whereas, the majority of non-fatal accidents occurred during installation/dismantling (68.4%) followed by during operations (18.4%) (Shin, 2015).

Furthermore, Hsu et al., (2008) found that multiple safety concerns could arise from strong winds that are often encountered in higher elevations in high-rise buildings projects; thereby, increasing the risks of falling and flying objects (Hsu et al., 2008). Such fall hazards turn into serious risks in high-rise buildings with the lack of guardrails and safety nets around openings, the presence of loose/improperly secured materials at height, the lack of proper Personal Protective Equipment (PPEs) and the lack of safety harnesses (Martinez et al., 2020). Also, unprotected exterior boundaries of slabs and balconies impose multiple threats to the safety of all construction workers on site in high-rise buildings (Martinez et al., 2020).

Hsu et al., (2008) studied the effects of the different environmental variables, that change with the changes in elevation, on the subjective fatigue symptoms and physiological responses of construction workers working in high-rise buildings. The authors found that construction workers performing heavy duties or delicate tasks in high-rise buildings may encounter difficulties in physiological adjustments, specifically in extremely harsh weather conditions (Hsu et al., 2008).

Moreover, the results revealed that temperatures, wind speed and levels of ultraviolet rays increased with the successive increase in elevations; all of which could adversely impact the workers’ physical health. The study also found an increase in the workers’ heart rate which could be attributed to both elevated temperatures and increased stress levels (Hsu et al., 2008); thereby, further expanding the risks to the psychological health of construction workers. Other influencing
factors include but are not limited to the large amount of work involved in high-rise buildings, the long project durations, the complex and variable construction environment, and the existence of mixed and fire-open operations (Li et al., 2020).

2.1.2 Root Causes and Underlying Factors Leading to Hazards

While investigating the major causes of accidents in high-rise building construction, it is apparent that the lack of safety knowledge, ineffective safety training, and careless workers’ attitudes were among the leading causes of accidents in construction sites (Rokooei et al., 2023). In the same vein, it is evident that accidents primarily emerge from unsafe working conditions including the use of defective machinery and equipment, poor housekeeping, and congestion in the worksite, as seen in table 1 (Goh et al., 2016). Furthermore, the lack of adequate training was a leading cause followed by workers’ unsafe acts during work. Goh et al., (2016) attributed such unsafe acts to working without proper qualifications and/or authorizations, operating machinery at unsafe speeds and the improper use of personal protective equipment.

Table 1: Major causes of accidents in high-rise construction projects in Malaysia. Source: (Goh et al., 2016).

<table>
<thead>
<tr>
<th>Question</th>
<th>Perception</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>R6</th>
<th>R7</th>
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<tbody>
<tr>
<td>Major causes of accidents</td>
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<tr>
<td>Unsafe acts (workers’ attitude)</td>
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<td>Unsafe condition (poor housekeeping)</td>
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<tr>
<td>Unskilled workers</td>
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<tr>
<td>Lack of training</td>
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<td>√</td>
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<tr>
<td>Poor site safety management</td>
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<td>√</td>
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<td></td>
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<tr>
<td>Cost saving</td>
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<td></td>
<td></td>
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<tr>
<td>Less awareness of hazardous activity</td>
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</table>

This sheds light on the main critical success factors for the safety management of complex construction projects. In fact, both company-level and project-level practices are crucial for achieving and maintaining safety performance, particularly with regard to large construction projects including high-rise buildings (Hinze & Raboud, 1988). A few of these success factors are management organization, management measures, technical and managerial plan, worker safety quality, safety environment and worker safety behavior (Li et al., 2018). Therefore, Li et al., (2018) found that management organization manifested through the provision of adequate resources,
education and training programs, has a direct impact on the worker safety quality through enhanced competency and skills. Besides, the technical management plan, which includes aspects such as safety training and safety meeting systems, was found to also have a direct effect on the worker's safety behavior.

Certainly, workers’ safety behavior is also amongst the most influential success factors as it is a direct-acting factor that influences construction safety performance in high-rise building projects (Li et al., 2018). In addition, workers safety quality, which includes increased safety talent, awareness, and knowledge, also has a direct impact on worker safety behavior which is considered an underlying cause of misconduct and accidents in construction sites (Li et al., 2018).

Likewise, Ismail et al., (2012) identified the success factors that are crucial for the success of safety management systems and practices of a wide range of construction sites including high-rise buildings, landed houses and infrastructure renovation. In doing so, a comparison was made against five primary factors namely, the resources factor, the management factor, the personal factor, the Human Resource Management (HRM)/incentive factor, and the relationship factor along with 28 other subfactors. Out of the aforementioned factors, the personal factor was found to be the most important success factor for having an effective safety management system, whereas, employees’ safety awareness levels were the most influential sub-factor (Ismail et al., 2012).

The human factor also plays an important role in the safe evacuation from high-rise building construction; to illustrate, aspects such as how fast could workers react to safety alarms, how stable they could be walking over different surfaces in construction sites and most importantly, how they could find their way to the evacuation routes given the available site conditions (Deere et al., 2021).

Other causes are attributed to cost savings from the employer’s side which is one of the main reasons for the insufficiency of safety training and personal protective equipment (Goh et al., 2016). The aforementioned root causes require proactive and in-depth analysis of the Jobsite in high-rise buildings through which relevant data and information could be gathered to aid in
maintaining safety planning and monitoring practices (Martinez et al., 2020); thereby, enhancing the safety performance of high-rise building projects.

2.1.3 List of Identified Hazards
The review of the literature yielded multiple hazards that collectively contribute to a multitude of potential accidents, including but not limited to falls, slips, trips, struck-by-falling objects, struck-by-moving vehicles, alterations in task performance, fatal and non-fatal injuries, chronic disorders, and other project-related accidents such as fire and collapse of structures as the case may be. Besides identifying sources of hazards, the data gathered from the literature review also aided the researcher in getting a sense of the primary causes of accidents, which aided in prioritizing and emphasizing certain hazards over others. Figure 3 shows the themes of the main safety hazards that exist in high-rise construction projects as identified from the literature. While table 4 shows the list of hazards identified from the literature.

![Figure 3: Themes of main safety hazards identified from the literature.](image)

<table>
<thead>
<tr>
<th>Category</th>
<th>Sources of Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of adequate training</td>
<td>Poor judgment capacity</td>
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<td></td>
<td>Slow reaction to emergencies</td>
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<tr>
<td></td>
<td>Wrong reaction to emergencies</td>
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<tr>
<td>Poor working conditions</td>
<td>Cluttering of floor spaces</td>
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<td></td>
<td>Poor housekeeping</td>
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<tr>
<td></td>
<td>Lack of properly constructed refuge routes</td>
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<tr>
<td></td>
<td>Lack of safety instructions/signals</td>
</tr>
<tr>
<td>Poor safety management</td>
<td>Lack of adequate personal protective equipment</td>
</tr>
<tr>
<td></td>
<td>Lack of proper emergency evacuation mechanism</td>
</tr>
<tr>
<td>Lack of adequate safety measures</td>
<td>Lack of guardrails</td>
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<td></td>
<td>Lack of safety nets</td>
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<tr>
<td></td>
<td>Poor firefighting capabilities</td>
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<tr>
<td></td>
<td>Intrinsic responses to elevations</td>
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<tr>
<td>Human acts/behaviors</td>
<td>Inaccurate postures</td>
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<tr>
<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td>Unsafe working behaviors</td>
</tr>
<tr>
<td>Heavy machinery</td>
<td>Concurrent use of tower cranes</td>
</tr>
<tr>
<td>Tough working environment</td>
<td>Altitude/working from extreme elevations</td>
</tr>
<tr>
<td></td>
<td>Extreme weather conditions</td>
</tr>
<tr>
<td></td>
<td>Continual changes in work environment</td>
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<tr>
<td></td>
<td>Unsteady employment</td>
</tr>
<tr>
<td></td>
<td>Noise/dust/vibration</td>
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<tr>
<td></td>
<td>Difficulties in physiological adjustments</td>
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</tbody>
</table>

### 2.2 Safety Training

While recognizing the wide scale and persistent endeavor to promote safety in construction sites, Zhou et al., (2015) conducted an extensive review of the literature to identify the current trends in three main areas namely, the trends in the safety management process, the impact of individual and group characteristics on construction safety and the trends in accident/incident data analysis. Zhou et al., (2015) found an increasing trend towards the proactive management of safety in construction sites which focuses on safety plans, monitoring, knowledge, training, and near-miss management. Thus, the following paragraphs shed light on the significance of safety training along with the different forms of safety training that exist in the construction industry.

#### 2.2.1 Significance of Safety Training

The significance of safety training in the construction industry has been acknowledged by multiple academic researchers throughout the past decades (Min et al., 2012; Li et al., 2018). In fact, safety training emerged to be one of the most significant preventative measures that are utilized to eliminate/prevent the occurrence of accidents in construction sites. This is primarily based on the fact that poor safety awareness could lead to several accidents through acts of omission, errors and misunderstandings (Le et al., 2014).

Demirkesen & Arditi, (2015) identified that effective safety training leads to enhanced hazard recognition and lower accident rates. This is the case specifically with young construction workers; Rauscher et al., (2010) found that the majority of accidents are attributed to unsafe working behaviors from young workers rather than the existence of hazards. Therefore, Shin, (2015) recommended safety training to deter potential hazards and accidents related to workers' incompetency.
Similarly, Li et al., (2018) recommended the adoption of crucial safety measures, including safety training and safety meetings, to enhance the safety awareness and knowledge of construction workers. This is further supported by Rokooei et al., (2023) who state “Continuous yet effective training can present essential safety knowledge to new employees and refresh the comprehension of current employees.”. It has also been revealed that the superintendent’s risk identification capabilities were not related to their work experience, suggesting that little safety training programs could prove sufficient in providing the trainees with the needed skills to maintain safety on construction sites (Perlman et al., 2014).

2.2.2 Existing Forms of Safety Training

Existing safety training in the construction industry is conducted in the most traditional forms while using textbooks, lectures and presentations; furthermore, they are mostly conducted in mere compliance with safety regulations (Mora-Serrano et al., 2021). However, existing safety training programs within the industry have several shortcomings; to illustrate, Bhandari et al., (2019) found that existing training programs rely on “child-focused pedagogical principles when training adult learners, which ignores the wealth of personal experience that adults bring to the learning experience” (p.59).

In some cases, more advanced, yet unrealistic, training frameworks that incorporate cartoons and videos are being utilized (Mora-Serrano et al., 2021). Yet, learning that incorporates enhanced visualization tools, such as videos and other visual aids, is often criticized for its lack of interactivity (Le et al., 2014). As stated by Le et al., (2014), “Interviewing students and civil engineers revealed that the traditional education method does not supply sufficient safety knowledge for performance in construction sites” (p.1). Other challenges that are often encountered during the learning process emerge from the boredom and/or frustration of learners as they perceive the knowledge to be far from acquiring (Mora-Serrano et al., 2021).

2.3 Review of existing learning theories

Merriam & Bierema, (2013) stated that the five main and most commonly referred to learning theories with direct application to adult learning are Behaviorism, Humanism, Cognitivism,
Socialism, and Constructivism. These theories are further complemented by the adult learning principles, also known as the andragogy theory, which address the specific factors to be taken into account while targeting adult learners (Knowles et al., 2005). Yet, there is a lack of incorporating these theories as a basis for conducting VR-based safety training programs.

Rather, most of the available research papers have focused on incorporating learning theories into VR-based education in general. To illustrate, Wu et al., (2011) provided an explanation of how the Game Rules, Game Play, and Game Narratives could be addressed in game-based learning from the perspective of four different learning theories namely, behaviorism, cognitivism, humanism, and constructivism; while Fromm et al., (2021) investigated the applicability of VR technology to the experiential learning theory.

Also, Briese et al., (2020) provided a framework for the application of the ten phases of the transformative learning theory in Simulation-Based Learning (SBL). Similarly, Zakaria et al., (2020) have acknowledged the significance of incorporating the behaviorist learning theory along with the reward/punishment system in gamification for educational purposes. However, as stated by Wohlgenannt et al., (2019), research around VR in education is primarily concerned with the constructivism theory that focuses on the provision of an experiential learning experience to students.

The case is quite similar when it comes to the development of construction safety training using VR technology. In fact, the research by Shi et al., (2019) was the only identified research that incorporated the behaviorist learning theory in VR-based training within the construction industry. However, it is apparent that the social learning behaviors of construction workers in hazardous construction sites were the research’s primary concern. This sheds light on how other crucial influential factors, that are directly addressed in other learning theories, are disregarded. Examples of such factors include motivation, self-direction, problem/life-centeredness, learning orientations, and reflective learning among others. Thus, the following paragraphs shed light on a few of the mostly acknowledged and supported learning theories within the education field.
2.3.1 Behaviorism

To start with, behaviorism is a school of psychology that was founded by John B. Watson in 1913. The theory implies that learning involves a change in behavior that directly results from a particular stimulus in the environment (Alauddin, 2020). Accordingly, the theory is based on the assumption that if a behavior is to be reinforced or rewarded, then it is more likely to be adopted by adult learners; otherwise, the behavior disappears (Wu et al., 2011).

Behaviorism involves two main learning types namely, respondent and operant conditioning (Merriam & Bierema, 2013). Respondent conditioning is derived from natural selection and evolution theories and occurs when conditional reflexes take place as a result of learning. These reflexes act as responses that are elicited by stimuli in a one-to-one causal relationship. On the other hand, operant conditioning/behaviors are triggered by a series of consequences that tend to shape behaviors; therefore, they occur as a result of the interaction of a stimulus and an activity. These consequences are primarily manifested through reinforcements and punishments (Merriam & Bierema, 2013).

Behaviorism is based on quantifiable, systematic, and observable outcomes as markers of learning (Wu et al., 2011), which is among its main strengths. This is because it focuses on the present and facilitates the collection and analysis of data to rectify maladaptive behaviors (Baum, 2017). However, this theory is often criticized for being too deterministic as it focuses on physical aspects while neglecting mental aspects of learning that control human behavior; these include intelligence, talents, feelings, and interests of individuals (Alauddin, 2020). Also, it disregards the genetic and internal influences on human behavior, such as moods and feelings; thereby, neglecting the uniqueness of individuals (Wu et al., 2011).

2.3.2 Cognitivism

Cognitivism, on the other hand, is a general psychology school that is based on “meta-cognition” to understand how thought processes influence learning (Tennyson & Rasch, 1988). It conflicts with the behaviorist theory as it acknowledges that people mentally process the information they receive before responding to a stimulus (Prestine & LeGrand, 1991). Hence, it is primarily derived from the way humans gain knowledge, interpret emotions, and dig into memories (Alauddin,
The theory emphasizes the thinking aspect of humans based on two main assumptions: 1. The crucial role of the memory as an active and organized processor of information; and 2. The crucial role of prior knowledge in shaping behaviors and reactions (Wu et al., 2011).

Among the main strengths of this theory is that it provides a more comprehensive understanding of how the human brain works and processes information; therefore, it is of great importance to practical medical applications (Wu et al., 2011). However, it has been criticized for being purely focused on cognitive processes which cannot be observed and are hard to assess and evaluate (Daniels et al., 2013). This necessitates the conduction of complex experiments to determine cause-and-effect relationships (Prestine & LeGrand, 1991). Also, it disregards biological factors, the environment, and the upbringing of an individual (Daniels et al., 2013).

### 2.3.3 Humanism

Moving on to humanism, this theory is derived from humanistic psychology that was fathered by Abraham Maslow (Alauddin, 2020). Humanism is primarily concerned with the development of a person based on the assumption that human beings have the potential for growth and development (Merriam & Bierema, 2013). Therefore, the theory implies that individuals act with intentionality and values with the main goal of developing themselves as self-actualized individuals (Wu et al., 2011). In its entirety, humanism promotes the notion that human beings should be treated as whole beings while focusing on their subjective awareness and sociative and productive human capacities (Alauddin, 2020).

Accordingly, humanism emphasizes a student-centered approach to learning where teachers facilitate creativity, self-actualization, and self-directed learning (Huitt, 2009). Also, the theory teaches students how to learn, adapt and change to become lifelong learners (Merriam & Bierema, 2013). Among the main strengths of this theory is that it focuses on the entire person along with their values, and self-fulfillment needs (Daniels et al., 2013). It also emphasizes human choices and responsibility which allows for the provision of a person-centered teaching approach (Huitt, 2009). Nonetheless, this theory has been criticized for being the most abstract and obscure of all existing learning theories (Alauddin, 2020). This places a huge burden on teachers to understand
different learning styles. Also, the theory assumes that individuals are intrinsically good and will choose positive paths (Huit, 2009).

### 2.3.4 Socialism

Social cognitive theory draws from both behaviorism and cognitive theories and is mainly considered as a political ideology (Rotter et al., 1972). The theory emphasizes the role of humans as part of the larger society and highlights the idea that human learning occurs within the social context by observing other people. Through observations and imitations, people acquire knowledge, rules, skills, strategies, beliefs, and attitudes (Merriam & Bierema, 2013). Thus, it focuses on social influences and considers the dynamic interactions between the environment, behavior, and individuals.

The theory is based on four basic concepts which are the behavioral potential, expectance, reinforcement value, and psychological situations of individuals (Feather, 1982). Hence, the combination of behavioral, cognitive, and environmental aspects is among the main strengths of this theory (Rotter et al., 1972). However, again, it is often criticized for being loosely structured and for its disregard for biological differences, hormones, emotions, and motivations (Merriam & Bierema, 2013). Moreover, it focuses on what happens in the surrounding environment rather than what the learner actually does (Feather, 1982).

### 2.3.5 Constructivism

Finally, constructivism is primarily concerned with creating meanings from personal experiences as a learning process. The theory departs from the belief that knowledge is a process of formation that continues to develop and evolve (Alauddin, 2020). Thus, according to this theory, knowledge is constructed rather than received (Colliver, 2002). This, therefore, necessitates the active role of students during the learning process through active engagement in activities, discussions, reflections, and hands-on experiences. The theory relates to aspects such as self-directed learning, transformational learning, experiential learning, reflective practice, and problem-solving (Merriam & Bierema, 2013).
One of the main strengths of this theory is that it places mutual emphasis on the skills learned through the learning process as well as the learning outcomes. This is because it intends to stimulate students to be critical thinkers when confronted with new facts (Colliver, 2002). Also, it emphasizes sensory inputs, eliminates the grade-centered approach, puts more emphasis on value, and stimulates self-confidence, critical thinking, and problem-solving by treating students as active participants rather than passive receivers of knowledge (Olusegun, 2015). However, it is criticized for requiring expensive setups, extended preparation times, and varied assessment strategies (Olusegun, 2015). The transformative and experiential learning theories are the main learning theories under the constructivist theory.

2.3.5.1 Transformational learning within the constructivist approach

As stated by Taylor & Cranton, (2013), the transformative learning theory is “based on constructivist assumptions, and the roots of the theory lie in humanism and critical social theory.” (p.5). It is based on the assumption that adults change their perspectives based on the new information they receive by evaluating and critically reflecting on their past experiences and reconciling new information with what they already know in life (Taylor & Cranton, 2013). Therefore, it involves a change in the learners’ frame of reference which consists of associations, concepts, values, and feelings (Gerster-Bentaya et al., 2021). Thus, critical reflections act as a main and integral component of initiating transformational learning (Bass, 2012) followed by critical discourse where learners validate the best judgment.

2.3.5.2 Experiential Learning within the constructivist approach

Experiential learning emphasizes the role of connecting current experiences to previous experiences; based on such connections, possible future implications are derived (Bass, 2012). Accordingly, experiential learning simply means constructing knowledge and meaning from real-life experiences (Seaman et al., 2017). The theory is based on the following assumptions: 1. Learning is a process that entails feedback; 2. The process often includes the unlearning of previous knowledge; 3. Learning is driven by conflicts, disagreements, and differences; 4. Learning is a form of adapting to the environment; 5. Learning results from the assimilation of new experiences with existing ones and vice versa; 6. Based on such assimilations, learners are capable of creating new knowledge (Fromm et al., 2021).
Whereas, Seaman et al., (2017) stated that experiential learning should include both cognitive and emotional processes, action-reflection cycles, and ideals of personal transformation. For this reason, Kolb’s experiential learning theory presents the learning cycle which is based on the difference in preferences in learning styles (Healey & Jenkins, 2000). Kolb’s learning model consists of four primary stages namely, Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AC) (Healey & Jenkins, 2000).

According to the learning model, the cycle begins with the learners’ personal involvement in an experience (Svinicki & Dixon, 1987), which acts as the basis for observations and reflections (Healey & Jenkins, 2000). By drawing logical conclusions, these reflections are then assimilated and distilled into abstract concepts which later act as a basis for future action (Healey & Jenkins, 2000).

2.3.6 Andragogy/ Adult learning principles
Lindeman, (1926) developed four key principles for adult learners. First, adult learners are motivated to learn as long as they perceive the needs and interests that the learning will satisfy. Secondly, adults tend to have a life-centered approach to learning (Knowles et al., 2005). Thirdly, adult learners’ richest resource for learning is experience. Fourthly, they tend to have a tendency towards self-directed learning (Knowles et al., 2005).

Whereas, Knowles et al., (2005) state that there are six main principles to the adult learning theory. To start with, adult learners need to know about the benefits of learning along with the negative consequences of not learning. With regard to self-concept, adult learners need to be treated by others as capable of self-direction; therefore, facilitators need to assist adult learners in transitioning from being dependent to self-directing learners (Knowles et al., 2005).

Concerning learners’ experience, there is a need to emphasize experiential learning instead of transmittal techniques; these include group discussions, simulation exercises, and problem-solving activities. Moving on to the adults’ readiness to learn, adults develop higher levels of readiness when they perceive the benefits that such learning would induce in allowing them to cope with
real-life situations. Regarding adult orientation, it has been acknowledged that adult learners have a problem/task/life-centered approach to learning. Finally, adults need to have both external and internal motivations to learn such as better jobs, promotions, job satisfaction, self-esteem, etc. (Knowles et al., 2005).

2.4 VR Technology in Safety Training
As defined by Akanmu et al., (2020), cyber-physical systems are systems that “strategically employ computational resources such as virtual reality and sensing technologies, for real-time monitoring and understanding of the performance or behavior of learners and provides the training materials needed to achieve the learning or training objectives based on the performance of the learners.” (p.2). However, with the advancement in technology, VR has gained tremendous momentum, specifically when it comes to construction safety training. As stated by Rokooei et al., (2023), “safety training has been one major target area for utilizing this technology as it can realistically simulate high-risk environments”.

There are three main characteristics that distinguish VR technology from traditional training methods. First and foremost, it allows for the creation of realistic scenarios in the virtual environment (Mora-Serrano et al., 2021); thereby, the technology aids in overcoming the challenges associated with physical training, particularly in hazardous locations such as construction sites. Secondly, it facilitates the full immersion of trainees into that environment using several advanced stimuli. Thirdly, it allows for real-time responses and reactions (Mora-Serrano et al., 2021). Thus, emphasizing the “learning by doing” and “experiential learning” concepts. Therefore, the following paragraphs shed light on the uses of VR technology within the context of construction safety training.

2.4.1 Computer-based vs Traditional Safety Training
It is apparent that multiple pieces of research have attempted to incorporate new technologies for training purposes in the construction industry. To start with, Gao et al., (2019) assessed the effectiveness of several computer-based training programs, using user games, computer-generated simulations, virtual and augmented reality, and mixed reality, as compared to the traditional forms of training. In doing so, the following factors were considered: knowledge acquisition, alteration
of unsafe work behaviors, and reduction in injury rates. Gao et al., (2019) concluded that computer-based training is more effective in relation to learning of several technical aspects.

Also, in an attempt to further promote non-traditional learning, Din & Gibson, (2019) have tested the effectiveness of using computer-based games to teach construction, architecture and civil engineering students the Prevention through Design (PtD) approach to be used in the design and pre-construction planning phases. In doing so, the authors compared three forms of learning namely, computer-based serious games, paper-based games and traditional learning. The topics that were included in all training forms included the location and access to construction sites, the storage of different materials, housekeeping, pedestrian routes, personal protection equipment, powerlines, excavation, formwork, and underground utilities (Din & Gibson, 2019).

The game is based on two main components for each hazard. The first is in the form of hazard identification where the hazard is to be identified by the trainees. The second component relates to the identification of a relevant control measure. The results revealed statistically significant differences between the pre-test and post-test scores of students who attended the computer-based game; whereas, no statistically significant differences were found in students who attended the paper-based and traditional training sessions (Din & Gibson, 2019).

In recognition of the significance of safety education to promote a healthful work environment in the construction industry, Le et al., (2014) developed an online and interactive social virtual reality framework to train construction students. The main objective of the framework is to allow students to experience role-playing, dialogic learning and social interaction during the training process. The framework is based on three primary modules. The first is Cooperative Distributed Safety Learning (CDSL) which aids students in understanding the root causes of hazards along with their prevention methods.

The second is Hazard Inspection and Safety Cognition (HISC) which aims at enhancing students’ awareness and hazard identification skills; and the third module is Active Safety Game-based
Learning (ASGL) which is based on 3D virtual reality games to enhance students’ practical capacities (Le et al., 2014). The results revealed that

Sacks et al. (2013) tested the efficiency of VR technologies in enhancing construction workers’ capabilities of identifying and assessing construction safety risks. The training included four main activities related to tower crane operations, general site-safety, and concrete pouring. Their results proved that VR increased participants’ attention and concentration during the training session. However, the research’s setup was based on projectors and XBOX controllers, making it a not fully immersive training.

Pedro et al. (2015) have developed a framework that integrates safety with construction materials and methods education. Their effort was made to overcome the existing inefficiency in the available pedagogical methods for safety trainings within the industry. The training framework involves three sequential modules. The first is an introduction to hazards module; the second is a game where the trainees identify the hazards; and the third is a module that assesses the performance of the students. The results indicate that VR technology is capable of immersing the trainees in a virtual site that accurately presents actual construction sites; thereby, enhancing the students’ learning experience and learning outcomes. Yet, their model is based on a smartphone game which makes it a non-immersive experience to the trainees. Also, the interaction is limited to just selecting proper actions or identifying hazards from pre-set lists on the smartphone.

Isleyen & Duzgun, (2019) investigated the utilization of VR technologies in safety trainings for tunnels and mines. The results revealed that VR training significantly contributed to the trainees focus and attention making them better able to take accurate in a timely manner to maintain a safe working environment during tunnelling operations. This is because the trainees were better able to identify and assess the existing risks. Although their developed model utilized fully immersive VR headsets, it is not clear whether or not the trainees encounter “consequences” for incorrect actions, which is an important aspect of the “learning by doing” concept. Also, no experimental testing was conducted to compare trainees using their model and others who are trained using traditional methods. Their testing depended on the feedback of five experts.
Besides general site-safety training on on-site activities training, VR technologies could also be used to train the operators of heavy equipment on construction sites. Dhalmahapatra et al., (2021) developed a VR-based safety training simulator to train overhead crane operators to increase user engagement, real-time visualization and analysis and knowledge retention capabilities. 19 young and experienced operators participated in the study and the results revealed that the VR-based training was more effective than the desktop-based training. The enhancements of learning outcomes were predominantly evident in the operators’ ability to identify risks and hazardous elements and to identify the appropriate initiative mechanisms.

Similarly, while acknowledging that construction activities could induce several musculoskeletal injuries, Akanmu et al., (2020) developed a cyber-physical postural training program with the aid of virtual reality, wearable sensors and Vive trackers to train workers to use safe postures while constructing wood-frame structures, as seen in figure 4. Awkward postures that was trained for include bending, twisting, overhead work, stooping and squatting (Akanmu et al., 2020).

Shi et al., (2019) used virtual reality technology to investigate two reinforcement theories through which interpersonal learning takes place in construction safety training namely, positive reinforcement and negative reinforcement. The study utilized a multi-user virtual reality system with head-mounted displays accompanied by a motion-tracking system. The users were asked to cross a plant that connects two high-rise buildings (Shi et al., 2019). Research participants were divided into three main groups. The first group did not receive any instructions; the second group
were shown the appropriate walking behavior using an avatar, whereas, the third group was shown an avatar falling off the plank as a consequence of undesired safety behaviors (Shi et al., 2019).

The main factors that were considered include walking patterns which include speed, entropy which refers to the irregularities in the participants’ walking patterns, and head pitch which is considered to be a critical indicator of participants’ risk perceptions. The second factor was walking trends which refers to the changes in the instantaneous walking speed over the course of the experiment and the third factor is walking time (Shi et al., 2019). The results revealed that the positive reinforcement learning theory has resulted in slow and stable walks for most of the participants; on the other hand, the negative reinforcement theory has resulted in unpredictable and irrational behavior which could lead to more unsafe behaviors in hazardous situations. Figure 5 shows snap shots of the experiment conducted.
2.4.2 Advantages of VR-Based Training

Existing research has shown that the utilization of cyber-physical systems, where physical and software components are deeply intertwined, is extremely beneficial in the training of workers. This is because it allows for the assessment of work and the provision of feedback in a safe work environment; thereby, aiding in enhancing the workers’ cognitive and motor skills (Akanmu et al., 2020). The case is quite similar when it comes to the use of VR technology.

From an extensive review of the literature, multiple benefits of using VR technology in safety training emerged; thereby, indicating the huge potential of this technology in eliminating accidents and fatalities in construction sites. This is since the use of Virtual Reality tools could aid in the establishment of a culture of prevention, where major changes are introduced to the unsafe working behaviors of construction labors (Mora-Serrano et al., 2021).

In addition, Le et al., (2014) concluded that the use of VR has proved beneficial in enhancing students’ and trainees’ knowledge and practical skills. Furthermore, the researchers found that the learning environment has a huge potential in enhancing collaborative work while identifying safety hazards in complex environments (Le et al., 2014). Besides, these tools are also capable of promoting the transfer of knowledge through continuous awareness and learning of construction workers (Mora-Serrano et al., 2021). As stated by Din & Gibson, (2019), “Well-designed serious games have the potential to turn the learning experience into a fun challenge through the right blend of instructive and entertaining elements” (p.186).

The benefits of VR technology in relation to hazard identification and detection skills have also been established in the literature. To illustrate, Martinez et al., (2020) proved that visual exposure to safety hazards is beneficial in enhancing both the identification and rating capabilities of safety managers/officers in high-rise buildings; thereby, enhancing the safety outcomes.
Similarly, Perlman et al., (2014) indicated that the participants who attended the VR hazard identification session were more capable of identifying hazards as compared to participants who attended the traditional hazard identification session; such an increase was primarily attributed to the identification of risks that are directly related to moving objects. Also, the use of such technologies aided safety managers in completing their safety inspections at a much less time as compared to their physical inspection (Martinez et al., 2020).

In addition to the identification of hazards, decision-making capabilities are also vital to ensure safety in construction sites. As stated by Woodcock, (2014), “The inspector must not only recognize indicators of defects but often must also be able to legitimize a decision based on risk.” (p.146). There is evidence that VR technology could enhance the decision-making capabilities of safety officers to mitigate the risks associated with the identified hazards (Woodcock, 2014).

Also, VR technology has proved beneficial for the assessment of construction workers and safety officers. The results of Li et al., (2012) concluded that computer technology is more effective than traditional means of assessments as it provided workers with more details that required higher levels of thinking. Furthermore, it was evident that this assessment method had identified the areas of weaknesses in workers’ knowledge (Li et al., 2012). Thereby, allowing for the design of specific training curricula that target and rectifies such areas of deficiencies.

Likewise, the results of Akanmu et al., (2020) revealed that the developed training using VR technology was extremely beneficial in providing understandable feedback on the risks associated with undesired work postures. In addition, the use of VR tools in the learning process of construction workers is considered to be a major step towards the digitalization of the industry; thereby, positivity contributing to the attractiveness of the industry to young workers (Mora-Serrano et al., 2021).

Finally, the use of VR technology is also accompanied by multiple financial gains. As stated by Su et al., (2013), “Training on a simulator avoids expenses for fuel, equipment rental, site, and more importantly, the risks from real site operation hazards.” (p.339). Thus, the use of virtual
environments could allow construction workers to be trained on different tasks repeatedly while ensuring their safety and the safety of the machine used and saving costs (Su et al., 2013).

2.4.3 Review of existing VR-training mechanisms in the construction industry

From an extensive review of the literature, it was apparent that there is a lack of providing trainees with a fully comprehensive training experience that considers the trainees’ motivation to learn, exposes them to adverse accidents/consequences, and introduces them to superior safety practices and measures that should be maintained on-site. This is further acknowledged by Hoang et al., (2021) who stated that existing VR training has focused on hazard identification and the demonstration of superior safety practices only; thereby, creating a gap in having a scientifically proven training approach that combines hazard identification, exposure to accidents, and exposure to the right course of action.

The following paragraphs shed light on the existing research that developed VR-based safety training programs. This review is not concerned with the topic/material that was being taught in the developed programs nor their end results but rather, with the procedure of the training itself. In doing so, the following review focuses on the methodological aspects of conducting VR-based training. It is worth noting that the review focused on immersive VR-based training developed in relation to the construction sector. Also, the review focused on research papers that could be considered somehow general, included elements of hazard identification and inspection, and was not purely performance/task-based training.

2.4.3.1 Hazard Identification Training

To start with, Dhalmahapatra et al., (2021) developed a training simulator for overhead crane operations. The training is conducted in three phases; the first phase is a practice phase where the users get introduced to VR headsets and navigation and control in the virtual environment. The second phase is a familiarization phase where the trainees get introduced to the equipment/crane cabin and its functionalities. The third phase entails training for the actual crane operations in the virtual environment.
When the trainees enter the cabin, they were asked to perform the safety checks and were then instructed to perform five main tasks namely, lifting and lowering of crane hoist, picking the ladle containing molten metal from the loco, placing the ladle at the turret, picking up the empty ladle from the turret, and pouring the molten slag by tilting the ladle (Dhalmahapatra et al., 2021). They were then asked to identify the associated hazards after the training program. This training methodology does not expose the trainees to the consequences of the hazards or any potential accidents nor does it show the trainees how such hazards could have been prevented, eliminated, or mitigated.

Thus, defying the behaviorist theory that necessitates the exposure to elements of punishment or reinforcement to effectively introduce positive behavioral changes. Similarly, from the constructivist approach, the confrontation of real-life problems, resembling accidents, along with the trainees' ability to solve them, in the form of having the right safety measures in place, are crucial factors for the effective learning of adult learners. Accordingly, neglecting these crucial factors might affect the trainees’ learning outcomes in terms of their hazard assessment and hazard management skills and competencies.

Han et al., (2022) used the theory of embodied cognition to test the effectiveness of digital 3D/VR safety training as compared to the traditional means of training. This was done by collecting data in four primary dimensions namely, self-evaluation of the learning process, end-point evaluation of learning impacts, physiological reactions, and learning performance. The changes in learning performance, as usual, were tested by measuring the difference between the trainees’ hazard identification capabilities prior to and post the VR training using two indicators which are accuracy and time taken to identify the safety hazards. Figure 6 shows the workflow of the conducted training.

With regards to the training method itself, it consisted of a virtual tour of a construction site where trainees were asked to tour the site and identify/press on the hazards as they were being identified. When the hazard is accurately identified, two multiple-choice follow-up questions emerge. The first relates to the analysis of the identified hazard by asking the trainees to determine the danger
level of the hazards; whereas, the second relates to the evaluation of the type of accidents that could take place as a result of this hazard.

Based on these, the trainees decide on the course of action that needs to be taken. The authors mentioned that the trainees’ performance is calculated, and feedback is given “afterwards” based on such performance. However, nothing is mentioned with regard to the type of feedback given, how it is provided to the trainees, nor when exactly. Again, this sheds light on the fact that trainees are not exposed to any consequences from the hazards that they found nor the right safety measures or practices that should be maintained to mitigate the adverse effects of such hazards. The fact that they were asked to assess the hazard and respond with the right course of action without actually experiencing any of the potential accidents or the appropriate measures acts as a limiting factor to the learning potential of the VR technology.

![Workflow of VR-based construction safety training](image)

**Figure 6**: VR-based construction safety training. Source: (Han et al., 2022).

Similarly, Nykänen et al., (2020) tested the efficacy of VR-based safety training programs and the human-factors training method in comparison to the traditional training methods. In their VR model, the participants mainly practised safety-related actions such as visually searching for hazards, removing hazards, inspecting equipment and machinery for any defects, walking safely around or through a work area, and communicating with construction vehicle drivers. This was followed by the provision of both visual and auditory feedback and information to the trainees; however, the authors did not specify when exactly the feedback is presented, the type of feedback,
and whether the feedback is presented by the research team automatically in the developed model. Again, the trainees were not exposed to any form of accidents or superior safety management practices that should be maintained on-site.

Likewise, Joshi et al., (2021) developed a program that introduces trainees to the safety protocols that should be maintained in a concrete prestressing/precasting plant. In doing so, the trainees were required to navigate the site while watching informative videos on suspended loads, the stressing process, and overall plant safety. In the case of doing an unsafe act/behavior, the module restarts indicating the trainees’ failure in maintaining appropriate safety practices. Figure 7 shows the training sequence that was adopted by the researchers. However, again, the trainees were not exposed to the accidents that might occur as a result of their wrongdoing or unsafe behaviors nor were they exposed to superior safety management practices. Subsequently, they were asked to respond to a certain set of questions in the virtual environment. Again, no details on the consequences of wrongly answering these questions were provided by the researchers.

Figure 7: Activities that should be performed by trainees during their VR-based training. Source: (Joshi et al., 2021).

2.4.3.2 Hazard Identification & Exposure to Superior Safety Management Practices Training

In the same vein, Wolf et al., (2022) developed an Augmented Virtuality (AV) model that integrates both VR and real-world elements that are modelled and tracked in the virtual environment. These real-world elements act as input devices to strengthen data collection for a better evaluation of the trainees’ performance and the customization of their feedback. Similar to other VR prototypes, participants were asked to perform a specific task and are guided through specific instructions that appeared to them in the virtual environment.
As they navigate the site, they are asked to identify the sources of hazards which, upon the trainees' interaction with them, turn into the safe and accurate measures that should be maintained in the specific worksite. The trainees are not allowed to perform the task, or the cutting process unless all hazards are identified. After performing the task, the trainees were presented with customized feedback with hits and misses regarding the hazards. Yet, it could be evident that no direct feedback was given to the trainees during the training session; this increases the possibility that trainees might have interacted with the hazards coincidently or are not fully aware of all the dangers contributing to a specific hazard. Also, the lack of any form of consequence upon the trainees' failure to identify all hazards might limit their ability to visualize and appreciate the severity of the risks associated with this hazard.

Isleyen & Duzgun, (2019) developed a VR-based safety training program to train construction workers to identify potential hazards in tunnels along with the necessary measures that should be taken to mitigate the associated risks. For their training procedure, the trainees were asked to walk around the site and identify all potential hazards in the tunnel. Subsequently, the trainees were asked to identify the probable tunnel failure mode based on the identified hazards. Upon the right response, the trainees are then allowed to take the necessary measures to prevent failure. This shows that the trainees were only exposed to the right measures that maintained the stability of the tunnel; however, they were not exposed to the tunnel failure itself such as tunnel failure or changes in its geometry.

2.4.3.3 Hazard Identification & Exposure to Accidents Training

Jeelani et al., (2020) aimed to compare the effectiveness of virtual reality and stereo-panoramic environments in construction safety training. The training protocol of their VR-based training starts by conducting a baseline performance evaluation where the trainees were asked to navigate a scene and verbally identify all potential hazards using their VR headsets. They were also asked to provide mitigation strategies for the identified hazards. Subsequently, personalized feedback was provided to the trainees; this feedback included performance feedback on the hazards that were not identified by the trainees along with process feedback that communicated their weaknesses in the hazard-searching process.
Then, the trainees had undergone hazard management training, which was conducted with the use of presentations explained by an instructor, followed by a hazard management feedback session where the trainees had to reassess the hazard mitigation strategies, that they chose in the baseline performance evaluation, against what they would choose after the hazard management training. Then, the trainees took their VR-based training where they were shown visual cues that aided them in conducting a proper and systematic search for hazards in the virtual environment. This was coupled with multiple accident simulations; however, these accidents did not particularly emerge as a direct consequence of wrong acts or behaviors from the trainees nor their inability to accurately identify all the hazards at the scene.

Not only would having sudden accidents defy realism, which is a crucial element in developing effective VR-based training, but also, this type of training might impair the trainees’ ability to deeply understand accident paths based on a true likelihood and impact assessment of the existing hazard along with the associated risk initiators and the corresponding type of accident. Similar to other developed VR training software, the trainees were also not exposed to the right safety measures in the virtual environment.

Similarly, Hoang et al., (2021) developed a VR-based safety training for safety training of construction workers using the fear arousal approach where they get exposed to workplace accidents. This is based on the hypothesis that raising fear raises the safety awareness of construction workers and improves their overall safety attitudes. Their VR training included 3 scenarios/tasks where different accidents were programmed to appear to the trainees. Such accidents appeared to the trainees without them having to have conducted any faults or unsafe practices; thereby, the trainees were not given the choice to avoid such accidents. As discussed earlier, this training methodology might affect the trainees’ ability to have a deep understanding of accident paths. Further, the trainees might be at greater risk of attributing such accidents to wrong hazards; thereby, weakening their ability to accurately attribute accident types to specific hazards based on not only their severity but also, other triggering factors in the working environment.
Likewise, Adami et al., (2021) developed a VR-based training program to train construction workers on the safe use of demolition robots. During the training process, the trainees are presented with a warning message for any unsafe behavior that was performed by the trainees. Subsequently, the trainees get exposed to the consequences of their unsafe behaviors during the training. While this training methodology maintains accident paths and builds on the trainees’ ability to assess existing hazards along with the associated potential accidents, again, it does not serve towards enhancing their hazard management skills and taking the right preventive/mitigative measures on-site.

2.5 Research Gap

From an extensive review of the literature, the following gaps emerged. First and foremost, there is a lack of standardized safety guidelines that dictate the best practice in relation to maintaining safety during the construction of high-rise buildings. On the contrary, most of the guidelines are rather concerned with the safe design of such buildings along with the safety of residents with little consideration for the safety of construction workers and laborers.

The gap in having appropriate safety and risk models that specifically target high-rise building construction not only lacks from the industry but also, the construction safety training curricula. These findings are supported by Le et al., (2014) who indicated the gap that exists in the construction curricula in relation to safety education. Thus, it was evident that none of the existing traditional training programs, including the OSHA, IOSH and NEBOSH, have dedicated sections/programs that address the multiple hazards that emerge during the construction of high-rise buildings. Besides, there is a lack in the literature when it comes to the identification and categorization of all unique hazards pertaining to the construction of high-rise projects. This further hinders the development of safety guidelines for high-rise construction (Zaini et al., 2014).

Secondly, despite the few, yet beneficial, attempts that have been conducted within the construction towards the incorporation of VR for educational and training purposes, the developed models were primarily built on a few hazards in relation to the targeted hazard category or topic. Thus, there is a lack of designing a fully comprehensive VR-based training program that tackles
construction projects as a whole in general and high-rise building construction in specific. With the context of the industry, it is evident that the utilization of such technologies are primarily conducted as a marketing tool rather than to actually capitalize on the potential of the technology.

Thirdly, from all the identified literature that used VR technology as a basis for their safety training within the industry, only a few were found to base their methodology and model development on existing crucial learning theories (Wu et al., 2011; Fromm et al., 2021; Zakaria et al., 2020; Briese et al., 2020; Wohlgenannt et al., 2019). Thus, it could be concluded that there is a general lack of discussion when it comes to the incorporation of learning theories into VR applications within educational contexts.

Rather, most of the papers discussing potential improvements to the outcomes of VR-based learning were concerned with the quality of the development of the prototype itself; these include the rendering quality, user/learner immersion, and interaction levels (Wohlgenannt et al., 2019; Fromm et al., 2021). In addition, the few research papers that addressed the issue were primarily focused on one general theory; thereby, disregarding the possibility of integrating several theories together.

Not only does this diminish the value that could be obtained from the simultaneous capitalization of the strengths of different theories but also, ignores the fact that each theory independently taps into the different needs of adult learners. Moreover, none of the previous attempts had provided a conceptual framework that could be utilized as a basis for the development of VR-based educational programs. Hence, there is a general lack of practical guidance for researchers willing to develop their training programs on solid and scientifically proven foundations. The case is quite similar when it comes to the development of construction safety training using VR technology. In fact, the research by Shi et al., (2019) was the only identified research that incorporated the behaviorist learning theory in VR-based training within the construction industry.

Lastly, existing research papers are small-scale studies with a few subject trainees. Accordingly, Gao et al., (2019) recommended the conduction of more studies that would prove the effectiveness of computer-based training methods in driving positive behavioral changes and reducing injury
rates within the construction industry. The authors further argued for the need to have large-scale tests with adequate samples to ensure the validity of the results (Gao et al., 2019).

2.6 Chapter Summary

To conclude, it was evident that high-rise construction sites, similar to other complex construction projects, have a wide range of hazards. However, the hazards covered in the literature were somehow generic; thereby, confirming the fact that there is a lack of safety guidelines that present potential hazards in depth. In further reviewing the literature, it was apparent that lack of effective safety management along with lack of safety knowledge and unsafe working behaviors are among the root causes of hazards in high-rise construction. This shed light on the significance of safety training. However, the lack of safety training programs that target high-rise construction was also evident.

A review of existing literature also revealed that existing forms of safety training are widely criticized for their lack of effectiveness. Accordingly, the wide momentum towards novel training approaches has been apparent. Among such novel approaches is the use of VR technology. The technology has proved a huge potential in enhancing the learning outcomes of trainees. Nevertheless, existing VR-based training programs seemed to lack a comprehensive framework for conducting training. Thus, existing VR-based safety training programs follow one of the following training procedures: 1. Exposing trainees to hazards; 2. Exposing trainees to hazards and consequential accidents; or 3. Exposing trainees to hazards and applicable safety mitigation measures.

A review of existing learning theories and adults' learning principles was then made to have a better understanding of the theoretical foundations of adult learning processes and mechanisms. In doing so, it was evident that there is a lack of VR-based training that is based on solid foundations that consider learning theories and adult learning principles to enhance the learning outcomes of the trainees.
CHAPTER 3: METHODOLOGY

As mentioned earlier, this research has three main objectives. Figure 8 provides an overview of the adopted methodology.

Figure 8: Overview of the research methodology.
3.1 Step 1: To Identify Potential Safety Hazards in High-rise Construction.

The first step of this research is to obtain a comprehensive understanding and coverage of the safety hazards that could be encountered in high-rise construction; this step is crucial for the design and development of an all-encompassing safety training program that would be of benefit to the industry and would positively impact and lower the rate of accidents, fatalities, and injuries within the high-rise construction sector. For this reason, a multi-approach, encompassing an extensive review of the literature, conducting interviews with safety managers, and site visits were used. The following paragraphs provide an overview of the adopted steps to gather the needed information.

To further enrich the findings of this research, the researcher decided to include primary data as well. As stated by Madsen, (2018), primary data is first-hand raw data that is directly collected by the researcher. Thus, the gathering of primary data allows for the gathering of data that is specifically tailored to meet the main objectives of the research. There are multiple primary data collection techniques including interviews, surveys, observations, questionnaires, etc (Madsen, 2018). However, interviews and observations are the most relevant in cases where high-quality qualitative data is needed in a highly technical and specialized field. Therefore, both expert interviews and site visits were chosen as the primary means of data collection in this research.

3.1.1. Interviews with safety managers

Interviews allow for the interaction between the researcher and research participants throughout the interview (Gideon, 2016); thereby allowing for further discussion and clarifications on important topics. Data gathered from these interviews included the wide form of hazards that exist within high-rise construction; besides potential sources of hazards, other data, such as all possible hazard initiators, severity and all probable consequences, were also gathered. In addition, data gathered from experts also included a detailed insight into the role and job responsibilities of safety officers, and the appropriate mechanism for conducting site inspections and walkthroughs.

The type of conducted interviews were semi-structured open-ended interviews; this allowed for more flexibility in asking exploratory questions as the case needed (Doyle, 2022). It also allowed the researcher to gain more explanations and clarifications on highly technical questions. This positively contributed to the richness of the gathered data as it allowed the researcher to investigate
different facets of the research question (Doyle, 2022). A list of the prepared set of interview questions is provided in the appendix. The sampling technique used in this research is purposive sampling where interviewees who play key roles in managing the safety of high-rise buildings were chosen. This was accompanied by the snowball sampling technique where interviewees were asked to refer us to other safety managers.

3.1.2 Site visits
Similarly, site visits were viewed as crucial as they would allow the researcher to have deeper knowledge and vision of all the safety measures that should be taken in high-rise construction during the different phases of construction. Not only would this aid in the design and formulation of the relevant prevention and mitigation measures to be taught in the training program, but also would aid the researcher in developing a realistic construction site in the virtual environment. As will be discussed later on in this chapter, realism and having realistic scenarios are crucial components for designing an acceptable, usable, and functional safety training program (Stachoň et al., 2018).

3.2 Step 2: To Design a Conceptual Framework for the Conduction of VR-based Safety Training Programs Based on Learning Theories
The design of the VR-based safety training program was a multi-step sequential process that included the consideration of multiple factors, as seen in figure 9. This was done to ensure the development of an effective and efficient safety training program that meets international standards and is successfully capable of lowering accident rates in high-rise construction projects. The following paragraphs provide detailed descriptions of the steps taken during the design of the training program.
3.2.1 Targeted Outcomes/competencies

To start with, the significance of having an outcome-based/competency-based training program has been established. This is because it represents a shift in focus from the traditional objective-based approach to include targeting intangible behaviors and soft skills, besides technical skills (Weobong, 2020). Accordingly, training outcomes or competencies could be defined as the actions a learner should be able to perform, and the level of skill that the learner must be able to demonstrate when performing that action, in order for the learner to be considered fully trained (Svendsen, 2012). These outcomes could then easily be converted to learning objectives that could efficiently be designed and measured through the training program.

Wohlgenannt et al., (2019) revealed that four primary competencies are targeted in higher education namely, declarative knowledge, procedural knowledge, problem-solving skills, and
communication skills. Declarative knowledge is based on the learning of facts, abstract concepts, and scientific principles. Procedural knowledge includes the learning of tasks that foster the conduction of processes. Problem-solving skills include complex decision-making such as risk assessment. Finally, communication skills include interactivity and collaboration (Wohlgenannt et al., 2019).

In reviewing the literature, it was apparent that multiple safety management inspection competencies are vital for the proficient conduction of oversight activities and duties. These include but are not limited to understanding safety management systems, applicable regulatory frameworks and legal requirements, understanding different site oversight techniques, understanding organization safety performance indicators and frameworks, understanding risk, demonstrating system thinking, and possessing excellent analytical, decision-making, and analytical skills, and understanding human performance and limitations (SMICG, 2013).

Although such competencies should be particularly highly possessed by safety managers or inspectors, the existence of such competencies in other workers is also of great significance (SMICG, 2013). This is due to the fact that it is impractical for safety inspectors to perpetually supervise or oversee employees. This is specifically true when it comes to high-rise construction as each inspector could be assigned multiple storeys to oversee. Therefore, the training of workers could aid in the prompt identification, analysis, reporting, and mitigation of the identified hazards which will positively affect the overall safety of the project and lower the rate of potential accidents, injuries, and fatalities.

Accordingly, the outcomes identified in this research are relatively general outcomes and competencies that should be possessed by all workers on site, albeit to different extents. Therefore, the chosen outcomes are mainly directed toward understanding risk, system thinking, analytical, and decision-making skills. Therefore, trainees should be capable of anticipating, recognizing, evaluating, and controlling hazardous conditions and practices affecting people, property, and the environment. In addition, training programs should enable the trainees to work individually or on a team to critically analyze, interpret, and provide leadership to address and manage problems in occupational safety and health.
As stated by Tappura & Jääskeläinen, (2020), effective safety training programs should be capable of enhancing safety knowledge, safety attitudes, beliefs, motivation, safety behaviors, and safety performance. It is clear that the aforementioned outcomes are purely directed toward safety knowledge, attitudes, and performance; however, besides safety awareness and knowledge, it has been acknowledged that workers have a vital role to play in maintaining safety on site. This is done through the enhancement of their safety perception which in return enables them to positively change job-related behaviors (Cavazza & Serpe, 2010).

Accordingly, safety training should not merely target to enhance workers' knowledge and competencies to maintain site safety but also, they should target workers’ cognitive levels and psychological orientations to introduce behavioral changes (Cavazza & Serpe, 2010). In fact, Cavazza & Serpe, (2010) found that training programs, if designed effectively, could introduce positive attitudes through changes in beliefs and emotions towards a better safety climate. Based on these factors, the targeted competencies/outcomes are as follows (also in Figure 10):

1. Enhanced safety culture motivation and perception
2. Enhanced hazard recognition & identification
3. Enhance identification of hazard initiators & consequences of hazards.
4. Improved risk assessment skills (Likelihood & Impact)
5. Enhanced awareness of preventative & mitigative measures
6. Enhanced selection of the right course of action based on practicality and affordability

Figure 10: Identification of targeted learning outcomes from the training program.
3.2.2 Design of the Conceptual Framework for Conducting VR-based Safety Training

The understanding of adult learning processes is a matter of serious concern for scholars and practitioners advocating any educational reforms (Seaman et al., 2017). The following paragraphs explain the methodology through which the framework was developed. To start with, two main types of research exist namely, primary and secondary research. Primary research entails the gathering of first-hand data that meet the specific aims of the research; whereas, secondary research entails the gathering of data that was originally published for other purposes (Gideon, 2012). To have a deeper understanding of the learning process and the factors that should be considered for the effective delivery of information to students, this research opted for a mixed-strategy approach where both primary and secondary data were used for the development of the conceptual framework.

Accordingly, secondary data was gathered from an extensive review of books and peer-reviewed journal articles related to the different learning theories along with their integration into VR-based learning models. Whereas, case studies, interviews, and focus groups could be used to gather qualitative data (Saunders et al., 2017). However, due to the lack of practical application of learning theories in VR-based educational contexts, the case study method is not applicable. Interviews, on the other hand, are regarded as an excellent one-to-one means for gathering in-depth qualitative data (Saunders et al., 2017). Similarly, focus group discussions allow for the gathering of rich information based on a moderated interaction among a group of experts (Gideon, 2012).

Since this research aims to integrate the opinions of experts from two different fields namely, educational studies and construction engineering, the focus group method was found to be the most suitable for the gathering of differing perspectives. Accordingly, the purposive sampling technique was deployed in this research, where the research’s experts were chosen based on their characteristics and the research’s objectives (Gideon, 2012). Again, the adopted research is a multi-step process that includes the identification of the research design, choosing the research participants, conducting the focus group discussion, data analysis, and the development of the final conceptual framework as seen in figure 11.
Figure 11: Research method used for the development of the conceptual framework for the VR-based training program.

3.2.2.1 Focus Group Demographics

In total, 5 experts with educational studies backgrounds and 2 experts with construction management backgrounds were selected and recruited. Years of experience ranged from 10 to 25+ years within their respective fields. It is worth noting that all educational studies experts have research interests related to the adoption of new technologies, including VR, in higher education. Table 3 presents background information of the experts who participated in the focus group discussion.

Table 3: Demographics of focus group experts.

<table>
<thead>
<tr>
<th>Experts</th>
<th>Background</th>
<th>Position</th>
<th>Years of Experience</th>
<th>Research Interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Construction Management</td>
<td>Professor</td>
<td>25+</td>
<td>A wide range of interests in the use of technologies such as artificial intelligence and digital technologies in the project management field with a specific focus on the use of novel technologies for safety training in construction sites.</td>
</tr>
<tr>
<td>2</td>
<td>Construction Management</td>
<td>Assistant Professor</td>
<td>8</td>
<td>A wide range of interests in construction engineering and management with a current focus on the use of Virtual Reality (VR) and Augmented Reality (AR) in the safety of construction sites.</td>
</tr>
<tr>
<td>3</td>
<td>Educational Studies/ Science Education</td>
<td>Professor</td>
<td>25+</td>
<td>The provision of quality education within the STEM/STEAM areas, with a focus on the use of novel educational technologies.</td>
</tr>
<tr>
<td>4</td>
<td>Educational Studies</td>
<td>Professor</td>
<td>13</td>
<td>Educational reforms and learners’ development theories with particular emphasis on modern teaching approaches.</td>
</tr>
<tr>
<td>5</td>
<td>Educational Studies</td>
<td>Associate Professor</td>
<td>15</td>
<td>International and comparative higher education with a specific interest in the use of digital technologies in teaching and learning.</td>
</tr>
<tr>
<td>6</td>
<td>Educational Studies</td>
<td>Assistant Professor</td>
<td>10</td>
<td>Curriculum and instruction through innovative learning solutions with a particular focus on educational technology and teaching methodology.</td>
</tr>
<tr>
<td>7</td>
<td>Educational Studies/ Science Education</td>
<td>Assistant Professor</td>
<td>7</td>
<td>Educational Administration, Supervision, Planning, and Economics; Sustainability of educational reforms with a specific focus on organizational behaviors.</td>
</tr>
</tbody>
</table>
3.2.2.2 Focus Group Discussion

The focus group discussion was divided into two phases. In the former phase, the research experts were introduced to the research topic along with its main aims and objectives. This was followed by some ethical considerations in which experts consented to participate. The second phase entailed the actual conduction of the moderated discussion in a semi-structured format. The discussion was divided into three phases; the first phase entailed discussing the different existing theories, as identified from the literature, along with their applicability to the research’s aims and objectives. The second phase entailed discussing all crucial influential factors that would have a positive impact on both the learner and the learning process. The third phase entailed discussing the most productive combination of learning theories that would aid in maximizing the learning outcomes of VR-based learning.

3.2.2.3 Focus Group Data Analysis

The content analysis technique was used for the analysis of the transcribed data gathered from the focus group discussion. This technique allowed for the identification of patterns and trends that acted as the main basis for the development of the conceptual framework. During the analysis, the following factors were considered to support the qualitative analysis of the gathered data: the order of the discussed topics, the presence and absence of certain topics from the discussion, the time spent discussing each topic, the intensity of expressions in relation to the topics being discussed, the reasons and reactions of experts to each topic, and the consensus over the topic being discussed.

3.3 Step 3: To Validate the Developed Framework Through a Pilot Study

In previous reviews of the literature, it was apparent that there is a lack of incorporating learning theories in the design of VR-based safety training programs within the industry. This was the primary reason that prompted the development of the training framework based on scientifically proven foundations. Yet, the developed framework is different from existing VR-based training programs since it incorporates different learning theories, which is a novel approach: thereby, necessitating the validation of this framework for its efficiency and effectiveness in meeting the targeted outcomes of the research’s training program. To validate the developed framework, it was necessary to have a deeper understanding of how existing VR-based training programs are being conducted within the construction industry.
3.3.1 Framework Validation Strategy.

From the aforementioned review of the literature, it is apparent that most of the available studies have validated the effectiveness of incorporating major elements of the constructivism learning theory through the design and development of VR-based safety training programs; yet, other crucial aspects that were incorporated in the developed training framework were clearly neglected in the literature. Accordingly, this research paid more attention to validating the effectiveness of such other crucial elements on the learning outcomes of the trainees. The following paragraphs explain the vital training pillars that lacked in the literature followed by an explanation of how they are going to be assessed and validated.

To start with, none of the existing research has considered the trainees’ motivation to learn. Similarly, none of the existing research has paid attention to enhancing trainees’ need to learn before training by showing them the benefits of learning and the consequences of not learning. Yet, such elements were found to be of significant importance, particularly with adults, according to andragogy and adult learning principles. Therefore, the validation of considering such aspects in VR-based training is vital. Since the majority of existing VR-based training included elements of constructivism and behaviorism, it was necessary to independently validate the effectiveness of considering the learners’ needs to learn and motivation to learn with regard to their learning outcomes/competencies. This is done in an attempt to separately quantify the effects of such inclusion on trainees learning outcomes.

Similarly, in reviewing the literature on VR safety programs that have been developed to train construction workers, it was apparent that all the developed training programs were either task-performance training or awareness-raising training programs. Since task-performance training is usually directed to specific trades, their methodologies were found to be irrelevant to this research. On the other hand, it was also evident that the training programs that included elements of inspection or awareness training are divided into three main types namely, purely hazard identification training, hazard identification training with adverse consequences and accidents, and hazard identification training with hazard prevention/mitigation measures. Therefore, the
validation of the developed framework is performed by comparing the results against such types of training. Figure 12 shows the procedure adopted for validating the conceptual framework.

Thus, the validation procedure included four groups of trainees. The first group received the VR training using the developed conceptual framework; hence, they first received an introduction that established their need to learn. This is done by explaining and showing them the benefits of learning the scenarios to be taught in this training and the consequences of not learning. This is further reinforced by external and internal motivators to drive their readiness to learn before they undertook the actual training. Then, they were allowed to set their own goals in relation to their desired and targeted enhancements in knowledge after the training.
Subsequently, they were trained on the four scenarios using the developed conceptual framework where they were allowed to navigate the site and identify all existing hazards. If the trainees failed to identify all the hazards in each scenario, they were exposed to an accident that resembled an adverse impact of their failure. They were then provided with auditory feedback and allowed to re-identify the hazards; when they accurately identified all hazards, they were exposed to superior safety management performance along with all the hazard mitigation and prevention measures that should be implemented. This was further reinforced by auditory feedback that explained this superior performance. It is worth noting that all groups received the same exact feedback upon their wrong and right identification of existing hazards.

The second group of trainees also took the same training using the conceptual framework; however, the training did not include andragogy principles; therefore, the trainees were directly trained for the three scenarios in the virtual environment without being introduced to any types of motivational drivers. As mentioned earlier, the aim of this step was to compare the learning outcomes of group 1 and group 2 to be able to independently assess the contribution of considering a few of the main andragogy principles on the learning outcomes of the trainees in VR-based training. Hence, any difference in the learning outcomes between groups 1 and 2 could be safely attributed to the introductory training that set the motivational basis for learning and acquiring the knowledge taught in the three scenarios. This yielded the following hypothesis:

**H1:** It is predicted that the use of andragogy principles in VR-based training positively contributes to the learning outcomes of trainees.

Group 3 also took training on the same four scenarios; however, without being exposed to superior safety management practices that should be implemented. Thus, the trainees were asked to navigate the site and identify all existing hazards. If they failed to accurately identify all hazards, they were exposed to an accident which acted as an adverse impact of their failure to detect all hazards. Then, they were provided with the same auditory feedback and were allowed to re-identify the hazards. Upon their identification of all hazards, auditory feedback was played to them explaining superior performance. This yielded the following hypothesis:
**H2:** It is predicted that exposing trainees to consequential accidents enhances their accident-path identification skills.

**H3:** It is predicted that exposing trainees to consequential accidents enhances their ability to assess the probability of risks that are attributable to the identified hazards.

**H4:** It is predicted that exposing trainees to consequential accidents enhances their ability to assess the impact of risks that are attributable to the identified hazards.

Group 4 undertook training on the same four scenarios; however, they were only exposed to superior safety management practices. Thus, the trainees were first allowed to navigate the site and identify all existing hazards in each scenario. If they failed to accurately identify all the hazards, auditory feedback was provided to the trainees; nevertheless, they were not exposed to any accidents in the virtual environment. They were then allowed to re-identify the hazards in the given scenario and upon their right response, the trainees were exposed to the right course of action and all the safety measures and practices that should be implemented to prevent/mitigate these hazards. This was further reinforced by feedback that explains superior performance. This yielded the following hypothesis:

**H5:** It is predicted that exposing trainees to the right course of action enhances the trainees’ safety management and hazard mitigation skills.

### 3.3.2 Research Participants of the Pilot Study

In order to obtain the right number of research participants, it was necessary to review the literature on the number of participants that are normally deployed in VR-based training. This is based on the fact that it is usually impractical to choose a sample size that represents the whole population. In addition, the limitations in the available number of VR headsets, the individuality of the training process, and its relatively long duration limit the number of participants. Therefore, this review was essential to ensure that the research has deployed just the appropriate number of participants to gain statistically significant results while maintaining time, cost, and effort efficiency. Table 4
presents the number of research participants as used in the tests of VR-based training programs in the literature.

Table 4: Review of the number of research participants used in the tests of VR-based training.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Research Brief</th>
<th>No. of participants in VR training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Han et al., (2022)</td>
<td>Comparison between traditional training and VR-based training.</td>
<td>25 each</td>
</tr>
<tr>
<td>(Kim et al., 2021)</td>
<td>To train workers to be attentive to struck-by hazards.</td>
<td>32</td>
</tr>
<tr>
<td>(Wolf et al., 2022)</td>
<td>The authors developed a new framework for the collection and analysis of trainees’ data in the virtual environment to provide them with personalized feedback based on their hazard identification performance.</td>
<td>30</td>
</tr>
<tr>
<td>(Joshi et al., 2021)</td>
<td>The authors developed a Virtual Reality module to train safety protocols in the prestressed/precast concrete industry. The comparison was made between 2 groups; the first took VR training and the second took traditional video training.</td>
<td>16 each</td>
</tr>
<tr>
<td>(Adami et al., 2021)</td>
<td>The authors developed a VR-based training to train construction workers on how to use demolition robots.</td>
<td>25</td>
</tr>
<tr>
<td>(Shi et al., 2020)</td>
<td>The authors tested the effects of information formatting on the working memory of construction workers. The comparison was made against four formats namely, 2D isometric drawing, 2D isometric drawing with rich-text operational instruction, an interactive 3D model, and an immersive Virtual Reality (VR).</td>
<td>30 each</td>
</tr>
<tr>
<td>(Jacobsen et al., 2021)</td>
<td>The authors developed a framework that provides construction trainees with personalized feedback in the virtual environment using VR-enabled data gathering and analysis</td>
<td>9</td>
</tr>
<tr>
<td>(Li et al., 2022)</td>
<td>The authors developed an optimized VR training for construction workers that trains workers based on their preferences. To validate their methodology, comparisons were made between three groups who undertook personalized guidance VR training, free exploration VR training, and traditional slide training.</td>
<td>15 each</td>
</tr>
<tr>
<td>(Cyma-Wejchenig et al., 2020)</td>
<td>The authors tested the influence of VR training in maintaining the postural stability of construction workers working at height. Comparisons were made against a control group who did not take any training.</td>
<td>10</td>
</tr>
<tr>
<td>(Lu &amp; Davis, 2018)</td>
<td>The authors tested the influence of priming factors on risk perception in VŔ-based safety training for construction workers. The comparison was made against four groups who took training with and without sound and with and without priming factors.</td>
<td>13 each</td>
</tr>
</tbody>
</table>

The average number of participants from the reviewed papers is 20.5; therefore, this research included a total of 80 participants, 20 in each training group. As stated by the benefits of recruiting construction/civil engineering students in VR-based safety training programs emerge from their low site experience. Thus, this would prevent wide variations and disparities in the obtained results as the effects of site experience and job roles are eliminated. Similarly, Han et al., (2022) have deployed university students to eliminate the effect of personal traits, such as age, experience, prior knowledge, and computer & new technology skills, on the results of the research. Therefore, the
research participants were a mix of junior, sophomore, and senior construction students who were randomly assigned to the different training groups.

3.3.3 Pilot Study-Evaluation of results
Comparisons is often conducted between the mean values using multiple statistical tests to compare variances in research data. Figure 13 shows the adopted evaluation methodology. Following is a detailed description of the rationale behind such choices.

T-tests are tests used to identify the difference in means between two independent groups; in the case of having more than two independent groups, then ANOVA tests are used (Harper, 2000). Since this research aims to identify whether there is a difference in the means of four groups of trainees who took part in four different training methodologies, the ANOVA test was chosen.

There are two forms of ANOVA tests namely, one-way ANOVA and two-way ANOVA tests. Simply stated, one-way ANOVA tests are beneficial in detecting the effect of a single variable whereas, two-way ANOVA are beneficial in detecting the effects of more than one variable
(Sprinthall, 2014). Since this research has one main independent variable, which is measuring the learning outcome of the trainees, and one main dependent variable, which is the training methodology used, a one-way ANOVA test was chosen.

However, as stated by Goos & Meintrup, (2016), three main assumptions need to be met to be able to conduct ANOVA analysis namely, that the samples are independent, are normally distributed, and have equal variances. Since the data was gathered from 80 different students to conduct the analysis, it is considered independent data; thereby, meeting the first assumption of the ANOVA test. To ensure the normality of data and equality of variances, the following test procedures were adopted.

To start with, with regard to the normality assumption, the Shapiro-Wilk test was initially conducted to ensure that the gathered data are normally distributed. The significance level used was 0.05 and the null hypothesis was “The variable from which the sample was extracted follows a normal distribution”; hence, in cases where the obtained P-value was greater than the significance level of 0.05, the null hypothesis cannot be rejected, and the data was assumed to be normally distributed.

If the data of all four groups were found to be normally distributed, then Levene’s F-test was conducted to ensure the equality of variances. The null hypothesis used is H0: The variances are identical; whereas, the alternative hypothesis is Ha: At least one of the variances is different from another. The significance level is 0.05; therefore, if the p-value obtained is greater than 0.05, the null hypothesis is rejected, and the data is considered to be of equal variance. Then, a traditional ANOVA test was conducted. This was done separately for each of the score groups that were explained earlier, namely, hazard identification, accident path, probability, impact, and hazard mitigation scores. The analysis was conducted using Microsoft Excel data analysis add-in. A p-value of 0.05, as suggested by Sprinthall, (2014), is used to indicate the existence of a statistically significant difference.

In the case of finding a statistically significant difference, a post hoc test, using the Bonferroni correction as suggested by Sprinthall, (2014), is conducted to exactly pinpoint where the group
differences lie. As stated by Armstrong, (2014), “Bonferroni is used as a post-hoc procedure to correct the family-wise error rate following analysis of variance (ANOVA).” The Bonferroni correction was proposed to count for type I error to be better able to accurately identify whether a significant difference exists.

In the case of having a true null hypothesis (Ho), a significant difference will be observed by chance one in 20 trials. Accordingly, a minimum of a single test will have statistically significant difference at a P-value of 0.64. Hence, the Bonferroni correction is applied to the p values associated with each individual test to maintain the α level over all tests at 0.05. In doing so, the Bonferroni correction was performed using a two-tailed t-test with equal variances.

However, if the variances between groups were found to be unequal, the Welch Test or Welch ANOVA test (Welch, 1951) was conducted. The Welch test adjusts the F ratio formula, while the data is heterogeneous, to have a similar numerator in the case of having a true null hypothesis. The p-value can be interpreted in the same manner as in the analysis of the variance. The Brown-Forsythe test or Brown-Forsythe F-ratio (1974) test uses a different denominator for the formula of F in the ANOVA. The p-value can be interpreted in the same manner as in the analysis of the variance table.

On the other hand, if the data were found to be not normally distributed, the Kruskal-Wallis test was conducted. This test is the nonparametric equivalent of the one-way ANOVA and is typically used when the normality assumption is violated (Julien, 2019). It is beneficial as it allows for testing the normality of data between more than two groups. The null hypothesis of the Kruskal-Wallis’s test is that the mean ranks of the groups are the same. The Kruskal-Wallis test is the equivalent of the one-way ANOVA test for nonparametric data (Julien, 2019).

3.4 Step 4: To Design a Comprehensive VR-based Safety Training Program for High-rise Construction

As stated by Dannewitz, (2022), extensive project planning is extremely important when it comes to the development of an effective VR training program. This is because it allows the developers to deeply brainstorm the scenarios to be included, the training environment, ambient sounds, and
user interactions. The following paragraphs show the adopted methodology for the design and development of the content of the VR-based safety training program for high-rise construction.

3.4.1 Module Development
As defined by Colman, (2022), a training module is “a component of a course that focuses on a specific objective and is designed to teach on a specific topic.”. They act as book chapters in a large course that covers a specific knowledge area, and normally have a particular sequence that builds knowledge step by step while covering specific learning content from simple to more complex topics. The following paragraphs shed light on the module development process.

3.4.1.1 Training Modules
The first step of designing the training program includes defining its basic modules. This was done by categorizing the hazards identified from the literature review, site visits, and expert interviews. Thus, an extensive review and organization of the gathered data were done based on thematic analysis where common topics, ideas, and patterns in the gathered hazards were identified.

Based on such analysis, common themes were extracted as the main modules of the training. This was based on a deductive approach where the data was approached with some preconceived themes that are present in existing safety training programs. The identified themes were then given appropriate names that would indicate their overarching goals and content. Since the thematic analysis conducted is purely subjective and relies on the researchers’ judgments, it is acknowledged that following another procedure could yield different modules for the training program.

3.4.1.2 Units/Chapters of the Training Modules
Subsequently, each module was further divided into units/chapters that address more specific topics along with the associated hazards. Again, thematic analysis was used to identify and categorize the identified hazards into different chapters based on their correlation, relevance, and relatedness. After identifying the theme of the chapters under each module, the exact content of each chapter was then designed.
3.4.1.3 Content of Chapters/Units

Although the extensive primary data gathered in this research was rich and informative enough to create the content of the training program, they were mainly limited to the context of the Egyptian construction industry. With the aim of expanding the applicability of this training program across the globe, it was necessary to rely on additional external sources. Therefore, another review of the literature was conducted to gather further knowledge and information on the general hazards associated with each chapter and the most appropriate safety measures that should be maintained to eliminate all potential risks and adverse consequences.

In doing so, safety reports from major occupational health and safety organizations, including but not limited to the Occupational Safety and Health Administration (OSHA), the Institute of Occupational Safety and Health (IOSH), The National Examination Board in Occupational Safety and Health (NEBOSH), Health and Safety Authority (HSA), Division of Occupational Safety and Health (DOSH), Health and safety executives (HSE), International Labour Office (ILO), National Safety Council, and United States Department of Labor.

In addition, industry reports from major contractors illustrating their method statements, major manufacturers along with their safety manuals, and other governmental occupational safety reports were also reviewed to gather all the needed information on relevant chapters/units. Also, peer-reviewed journal articles and conference papers discussing safety measures that should be implemented in relation to the program’s chapters and units were also reviewed. A list of all the additional references that were used for the development of the chapters’ content is provided separately in Appendix. Subsequently, the content of each chapter/unit was refined and organized to be used in the development of the training scenarios.

3.4.2 Design of Training Scenarios

After creating the exact content of the different chapters of the VR-based safety training program, it was then crucial to select the appropriate scenarios through which the content of each chapter could be taught to the trainees. The following paragraphs show how the scenarios were chosen along with the sequence through which they are to be taught.
3.4.2.1 Chosen Scenarios

As stated earlier, one of the main andragogy principles that have been considered in the developed framework for conducting the training is having a real-life problem-solving approach to learning. Therefore, it was crucial to incorporate realistic scenarios with real-life accidents. Thus, a review of accident investigation reports, conducted by multiple health and safety organizations, was conducted. These primarily included investigation reports published by OSHA and NEBOSH. Besides, accident cases that were identified by safety experts during the interviews and site visits were also included. This was further complemented by reviewing news articles that covered real-construction accidents with sufficient evidence or details of the root causes of such accidents along with enough details on the context of the accident. Based on this, the accidents that were found to be highly related to the contents of the different chapters were chosen.

3.4.2.2 Scenario Sequence

Curriculum sequencing is a vital aspect that has drawn the attention of researchers and academic scholars. This is based on the fact that curriculum is considered a narrative or a journey that a learner undertakes; therefore, it should allow for the development of meaning over time. As stated by Ashbee, (2021), “A curriculum should be crafted as a whole, so that it has coherence: knowledge should build and speak to other knowledge across the curriculum in a thorough and orderly way.” (p.55). Therefore, considerable attention has been given to the sequence of scenarios in this training.

Several sequencing types exist when it comes to sequencing training curricula which are discussed hereunder. To start with, job performance order arranges the content of the curriculum based on the sequence of the related job tasks; simple to complex arranges the content of a curriculum based on the complexity of each content starting with the least complex and moving towards the most complex ones (Enser, 2021). Critical sequencing, on the other hand, sequences content based on their relative importance or criticality within the training, whereas, known-to-unknown sequencing entails starting with known topics and building upon them by slowly revealing unfamiliar topics. Another type of sequencing is dependent sequencing which is used when a certain topic requires prior mastery and knowledge of another. The Narrative is the last sequencing technique that entails the unfolding of the curriculum in a story format (Ashbee, 2021).
This research integrated two sequencing types namely, simple-to-complex sequencing and narrative sequencing. Simple to complex sequencing was used to sequence the modules of the training starting with the least complex modules that provide the trainees with basic and general knowledge to more complex ones that provide highly technical details in relation to the safety of high-rise construction. On the other hand, narrative sequencing was used within each module where the module chapters are being taught based on a story whose sequences are revealed as the trainee progresses in the chapters of this specific module.

3.5 Step 5: To Develop the Comprehensive VR-based Safety Training Program for High-rise Construction

The development of the comprehensive VR-based training program was commenced subsequent to the completion of the design phase that yielded the modules of the training along with their respective chapters and scenarios through which the content of the training will be taught to the trainees. The following paragraphs illustrate the development of the training.

3.5.1 Software & hardware used

The software used in this research is Unity2019. It was selected because it allows for building 3D models, virtual reality, and augmented reality games. It allows for drag and drops functionality from different other software like Sketch Up & Revit. In addition, the main engine scripting in Unity is C#. The main hardware component used is the Meta Quest 2 (initially sold as Oculus Quest 2).

3.5.2 VR Environment

Dannewitz, (2022) states that presence and engagement are the most significant elements in designing the virtual environment. While designing the module, several factors were considered namely, immersion, presence, and embodiment. These factors are discussed hereunder.

3.5.2.1 Immersion

The storyboard shall ensure a fully immersive experience as such immersion is the main essence of providing realistic safety training. Accordingly, three main types of immersion, as stated by
Adams, (2021) would be considered while developing the storyboard and scenarios of the safety training modules:

a. **Tactical Immersion:** Tactical immersion is “immersion in the moment-by-moment act of playing the game” (Adams, 2021). Thus, it is often based on the design of simple challenges that could be solved by the trainees in a fraction of the time. To be able to provide trainees with tactical immersion, the design phase should plan for the development of a flawless user interface providing zero struggles with speed and control disruptions.

b. **Strategic Immersion:** Strategic immersion is the form of immersion that allows trainees to observe, calculate, and deduce the needed actions to achieve victory (Adams, 2021). Hence, strategic immersion could be achieved through the design of enjoyable mental challenges that are based on logical paths and routes with minimum randomness.

c. **Narrative Immersion:** Narrative immersion is primarily achieved based on the effectiveness of the storylines (Adams, 2021). Therefore, the stories formed should be encouraging to trainees to invest in and get immersed in the narrative to find out the ending.

### 3.5.2.2 Presence

Having a realistic and authentic sense of presence is vital in VR-based training modules as it allows trainees to react to the virtual environment as they would in real encounters. Therefore, the development of the model would focus on providing trainees with a wide field of experience with vividly clear images and no visual anomalies. As found by Slater, (2009), the notion of presence has long been considered central to virtual environments, for evaluation of their effectiveness as well as their quality.

Therefore, considerable attention has been given to maximizing the trainees’ sense of presence in VR-based training. To start with, three main types of presence should be ensured in the virtual environment namely, spatial presence, self-presence, and social presence (Dannewitz, 2022). Spatial presence relates to the VR’s ability to completely isolate the user/trainee from the external environment; thereby, allowing the user to believe that they are in the real world. This is done through the right combination of lighting, audio, and the positioning of users and surrounding objects (Dannewitz, 2022).
Self-presence relates to the users’ ability to cause an impact in the virtual environment through their interaction with the surrounding environment. Finally, social presence relates to the fact that the users are not left alone in the virtual environment; rather, they are perpetually surrounded by avatars that represent actual people in their movements and actions (Dannewitz, 2022).

3.5.2.3 Digital Assets

All the digital assets used within the training program are either purchased from Unity store or TurboSquid. In certain specific cases where sophisticated assets were not found, they were manually created using Revit. In obtaining these assets, considerable attention was given to the quality, resolution, and realism of these assets.

3.5.2.4 Animations

As stated by Gisbergen et al., (2019), realism is not realized by VR users/trainees by the mere consideration of the realism of the environment but also, but considerable attention should be given to the level of realism of the surrounding characters. Despite having assets that are extremely high quality, animations were crucial to further enhance the realism of the model. In fact, animations were used for two primary purposes. First, they were as a background effect where other animated workers surround the trainees. These workers tend to perform tasks that are relevant to the scenario or topic at hand. They could also be doing other jobs that relate to their location on-site such as cleaning, sweeping, etc. The main goal is to have a dynamic environment where the trainees can feel immersed and surrounded by real individuals. The second aim of using animations was to enhance the realism of the accidents that are to be witnessed by the trainees. Thus, this type of animation is aimed at simulating fire accidents, equipment failure, exposures, workers falling from a height, etc.

3.5.2.5 Background effects

Lu & Davis, (2016) found that adding background sound to a construction virtual environment enhances the trainees’ sense of presence. This is particularly true specifically when the inserted sounds are aligned with the animated workers; thereby, enhancing the sense of familiarity and presence further (Lu & Davis, 2016). A wide form of background effects was used in the training program. This includes but is not limited to the noise of the construction site, the noise of nearby construction workers, sound effects of existing wind or by-passing equipment, etc.
CHAPTER 4: RESULTS & ANALYSIS

This chapter provides a detailed description of the results obtained in relation to each of the main objectives of this research along with an analysis of such results.

4.1 Identified Hazards in High-rise Building Construction

4.1.1 Interviews with safety managers

4.1.1.1 Interviewees' background information

Four interviews were conducted with safety managers supervising different high-rise building construction projects in Egypt with years of experience ranging from 15 to 27 years. To start with, the interviewees were first asked about their educational backgrounds. Different educational backgrounds emerged as follows: communications engineering, agriculture engineering, law, and business administration.

When the participants were asked about their accreditations, all of the interviewees stated that they have the OSHA’s 30-hour General Industry and Construction accreditations along with the NEBOSH international construction certification. The majority of the interviewees have also acquired IOSH construction health and safety certificates. Other accreditations acquired by the interviewees included scaffold erection and dismantling, rigging and rifting, lifting, safe driving, and safe work analysis. Two of the interviewees are accredited lecturers and Trainers of Trainers (ToT). Their accreditations were from institutes such as the Lifting Equipment Engineering Association LEEA in England, the Institute of Occupational Safety and Health (IOSH), SMART university, and Omrania university.

The participants were then asked about the number of high-rise construction sites that they have managed throughout their professional careers. Only one of the interviewees indicated that he managed 6 high-rise building projects both in and outside Egypt. Interviewee 2 indicated that he had managed 3 high-rise buildings outside Egypt, specifically in the Gulf area, with the current project being his fourth high-rise project and the first in Egypt. Interviewees 3 and 4 indicated that this is his second project. All background information is summarized in table 5.
Table 5: Summary of experts’ background information & accreditation

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Educational background</th>
<th>Years of experience</th>
<th>No. of high-rise buildings managed</th>
<th>ToT</th>
<th>OSHA General</th>
<th>OSHA Construction</th>
<th>NEBOSH</th>
<th>IOSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee #1</td>
<td>Communication engineering</td>
<td>22</td>
<td>6</td>
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<td>✔</td>
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</tr>
<tr>
<td>Interviewee #2</td>
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<td>✔</td>
<td>✔</td>
</tr>
<tr>
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<td>✔</td>
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</tr>
<tr>
<td>Interviewee #4</td>
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<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
4.1.1.2 Interviewees’ Authority & Job Responsibilities

Subsequently, the interviewees were asked about their job roles and responsibilities as HSE managers. There was a consensus from all participants that their jobs revolved around everything concerning the health and safety of workers on-site including but not limited to inspection, auditing, reporting, coaching, training, and risk assessments. These efforts are primarily exerted to preserve the health and safety of all workers on site while eliminating schedule delays and cost overruns. Thus, from their responses, it was apparent that the management process adopted is similar to that of health and safety management systems implemented across the globe. Thus, by integrating the different responses and practices adopted by the interviewees, the following procedure presented in figure 14 was constructed.

The process starts with the identification of all safety hazards and risks associated with the project on hand; this is followed by a detailed analysis and evaluation of these risks, according to which the safety management plans for the project are generated. Also, the necessary updates to the organizational health and safety policies are done at this stage. This is further complemented by the planning for an integrated risk management system to involve all relevant stakeholders.

With the commencement of the project, the safety management plan along with all the mitigation measures are implemented on-site. Regular health and safety audits and walk-throughs are done throughout the course of the project to identify additional risks and evaluate the residual risks from the implemented measures. From these inspections, performance data are gathered and compared against the pre-established key performance indicators (KPIs) of the project.

According to these results, updates to the safety management plan and organizational policies are done. Also, additional training requirements and arrangements with external third parties such as hospitals and firefighting agencies are identified, planned for, and conducted. These efforts are documented in the form of daily and monthly reports that are communicated to the corporate management.
In relation to their job authority, the majority of interviewees admitted that they work at the same hierarchical level as the project manager according to their respective organizational structure. All of the interviewees claimed that they report both to the project manager and to the corporate office.
Despite indicating the collaboration and support they gain from project managers; all interviewees expressed their dissatisfaction with this current practice in Egypt.

As stated by interviewee 2, “Unfortunately, my authority is at the level of the project manager; however, this is not the case abroad as the main saying or ruling goes to the safety manager.”. Similarly, interviewee 1 revealed that negotiations with the project manager should precede any safety decision as he stated, “I do negotiate with the project manager on safety issues to try to find possible solutions to emerging problems.”. These results defy the structures adopted by international construction companies where the HSE managers supersede project managers. Thereby, highlighting the great potential for emerging conflicts between project managers and HSE managers in Egypt.

4.1.1.3 Safety Inspection & Walkthroughs

Subsequently, the interviewees were asked about their inspection and walkthrough process through which new risks are identified during construction. All the interviews stated that their inspection is done in groups including safety supervisors and officers. The general process agreed on by all participants is as follows: 1. Deciding on the inspection date and time; 2. Conducting the inspection through random checks; 3. Recording the identified risks; 4. Analyzing the risks; 5. Developing new action plans; 6. Reporting; 7. Monitoring & control.

However, slight variations in each step were identified in the conducted interviews. To illustrate, the number of inspection tours conducted differs in each project ranging from twice a week to four times per week. Also, different risk recording schemes were found including normal paperwork processes, photography, and video recording. Besides, some of the interviews indicated that risk assessments are done during the tour itself.

For instance, interviewee 4 stated that “my eyes act as a camera while my brain works as a risk assessor; meaning that the picture of the site gets processed and rated by my brain in terms of its severity and likelihood; the processing of this information is dependent on experience and our studies”. Others indicated that the identified risks are discussed in a separate meeting while involving different engineers and in some cases the project manager. As stated by interviewee 3,
“These inspections are video recorded along with taking notes of the issues identified. Then, we do a close meeting where we discuss the identified hazards and set due dates to the safety measures that will be implemented with regards to these issues”. Figure 15 shows the generally adopted safety inspection and walkthrough process in Egypt.

![Figure 15: Generally adopted safety inspection and walkthrough process in Egypt.](image)

Next, the interviewees were asked about the safety inspection checklists that are regularly used in their checkups. A wide range of checklists emerged including checklists to inspect scaffolds, formwork, tower cranes, winches, forklifts, loaders, and other heavy equipment, hand tools, power tools, and other light equipment, fire emergencies, electrical cables, openings, guardrail systems, safety nets, stairs, access ways, and materials stored. Interviewees 2 and 4 further stated that they develop other forms of checklists that are related to the activities being performed on-site. This ensures that all activity-related risks are properly identified and controlled during the course of work; thereby, aiding in enhancing the safety performance of their projects.
Despite the wide range of checklists identified, all safety managers indicated that they are primarily used by safety officers in their daily inspection routines. On the contrary, HSE managers primarily depend on their experience and knowledge in their inspections and walkthroughs. As stated by interviewee 3, “We do have multiple checklists; however, in the safety walkthroughs, it mainly depends on visual inspection and my experience. The checklists are mostly used by safety officers and supervisors.”. This is further complemented by interviewee 4 who stated “For the safety officers, they have a checklist to be inspected in their daily routine; this checklist is related to the activity types that are being conducted on-site. However, the safety walkthroughs are primarily dependent on my experience and ability to locate potential threats”.

The aforementioned practice sheds light on the level of expertise gained by the HSE managers from their past experiences and encounters throughout their professional careers. Thus, it could easily be inferred that their knowledge has been built over the years to the extent that their eyes are now trained to identify potential threats in construction sites with minimal need to go over safety checklists. This is further supported by interviewee 2 who stated “From my experience, my eyes are trained to detect the problems only and accordingly, if something is hazardous in the short term, I take immediate actions”; whereas, interviewee 4 complements this by stating “the picture of the site gets processed and rated by my brain in terms of its severity and likelihood; this processing is dependent on experience and our studies”.

Hence, the aforementioned results highlight the significance of practical encounters in building the needed capacities and capabilities through experiential learning; thereby, supporting the main aim and motivation of this research. Interviewee 3 supported this notion by stating that “this training is needed in Egypt, specifically with the increase in the number of high-rise buildings and with the lack of experience in this field.”. Whereas, interviewee 1 stated, “Experience plays a crucial role in gaining the skills required. Due to my extensive experience, I am capable of promptly identifying the hazards or dangers and responding to them”. Accordingly, it could be concluded that through the provision of practical safety training, the trainees, whether safety officers or construction workers, could easily acquire and build tacit knowledge which qualifies them for their work in highly complex projects within a short period of time.
4.1.1.4 Identified Safety Hazards

The literature review provided a brief overview of some of the sources of hazards in high-rise construction; however, the list is incomprehensive and does not encompass all the potential sources of hazards. In the same vein, almost all relevant publications that were found did not provide detailed descriptions of hazard initiators, and consequences, along with the appropriate prevention and mitigation measures that should be implemented in high-rise construction. This necessitated the conduction of a further step through which quality information could be gathered from real experts. Figure 16 shows themes of main safety hazards identified the interviews.

Figure 16: Themes of main safety hazards identified from the interviews.
4.1.1.4.1 Handling and storage

To start with, all the experts asserted the significance of material handling and storage when it comes to high-rise construction. This is primarily attributed to the large quantities of materials stored, used, and transported on-site on a regular basis. This brings us to one of the major hazards that are often encountered in storage areas, which is the lack of organization (Interviewees 2, 3, & 5). This brings other forms of hazards including but not limited to contamination from waste, exposure to hazardous substances, and fire hazards.

Other hazards emerge from the materials that are being stored within the building. This includes the blockage of major access and egress routes. This was affirmed by interviewee 4 who stated, “materials stored inside buildings that are yet under construction should be placed away from hoist ways, evacuation routes, floor openings, and the exterior walls of the building”. In the same vein, interviewee 1 stated “Also, during normal operations, the stored materials should be kept at least 2 meters away from openings, roof edges, excavations, or trenches”. This not only increases the risks of having an inefficient evacuation mechanism but also, increases the risks of falling objects.

In addition, poor storage of materials could increase slip and trip hazards. This was confirmed by interviewee 5 who stated that “Interviewee 2 further adds “We also ensure that no jumping or walkthroughs are made as a result of existing materials”. Besides, having poor material handling and storage mechanisms also increases the risks of having severe injuries. Interviewee 5 explained this by stating “The same applies to material containing protruding elements, such as nails which could cause severe puncturing wounds. Therefore, protruding nails should be removed or bent prior to disposal and storage”.

Other hazards often emerge from exceeding the weight-rated capacities of certain machines and equipment. This often happens when transporting materials through hoists. Interviewee 3 explained this by stating “Therefore, when handling materials mechanically, workers should adhere to the rated capacities that determine the maximum weight the equipment can safely handle and the conditions under which it can handle that weight”. This not only decreases risks of equipment failure but also, aids in the proper utilization of the company’s resources.
The same hazard emerges from the manual transportation of materials where construction workers tend to carry around heavy materials leading to overexertion risks. This was confirmed by interviewee 3 who mentioned that “Manual material handling is a hazard that is often overlooked in construction sites; in fact, this hazard could lead to a wide form of injuries such as disc and ligaments of the low back among other injuries”.

4.1.1.4.2 Accessibility & egress

In the same vein, the poor accessibility of high-rise construction projects is an issue that was affirmed by all the interviewed experts. Such poor accessibility often emerges from the poor exit routes that often rely on wooden planks in high-rise projects. As stated by interviewee 2, “We also have unfinished ramps when, due to technical reasons, the stairs are unfinished”. One of the main hazards in relation to the use of wooden temporary planks is defaults in their structural safety; this is overcome by rigorous inspection as interviewee 2 clarified “We also inspect the ramps for their structural safety to ensure that they can carry the expected loads”.

There are several other risks associated with the use of wooden ramps. For example, in emergencies, there is a push force that increases the possibility of slips and trips. For this reason, interviewee 3 stated the following “We prohibit the use of wooden ramps in the cases of having unfinished stairs. We use either monkey ladders or scaffold staircases”. Likewise, interviewee 4 stated, “Therefore, we ensure having permanent access routes instead of depending on temporary access such as hoists and elevators as they get turned off during emergencies”. The interviewee further added temporary staircases should be limited to one storey only and the permanent staircases should be poured with the slab to eliminate any forms of risks that could emerge from poor accessibility.

The phenomenon is not only apparent during emergencies but also, during normal operations. As stated by interviewee 1, “the risks of limited accessibility often emerge around break times where all workers want to go down to have their breaks”. This is further supported in a study conducted by the organization of interviewee 1 where it was found that the main time that most accidents took place is between 11 am and 1 pm which is the break time. Most of these accidents include
falls, slips, and trips as a result of the thrust and repulsion forces of workers who rush to catch the hoist.

Other accidents were witnessed as a result of the poor safety of the main staircases. The first hazard is related to the poor lighting of exit routes; thus, interviewee 1 stated, “all staircases should be adequately lit to facilitate proper sight and eliminate the risks of falling, slipping, and tripping”. Another hazard is related to the lack of firefighting equipment on staircases which is confirmed by interviewee 4 who stated, “all staircases should be equipped with additional fire extinguishers to ensure maximum safety against fire hazards”.

4.1.1.4.3 Safety Facilities

Overhead protections, along with access roadways, pedestrian walkways, and barricades, are among the crucial safety facilities that should be constructed, and maintained in construction sites, as affirmed by all interviewees. However, it was apparent that overhead protection lacks adequate attention, specifically when it comes to high-rise construction, making it one of the main forms of hazards that could lead to risks from falling objects. The risks of this hazard are further exacerbated when access restriction to such areas is impractical or unfeasible. As stated by interviewee 3, “there are certain areas where it is impractical to ban or restrict access to. These areas include the hoist’s waiting area, working under/near scaffolds, or when a crane’s load passes over public or workers’ thoroughfares”.

To mitigate this hazard, interviewee 2 mentioned that “overhead protection systems should also be constructed wherever loads must be passed directly over workers, occupied workspaces, or occupied passageways”. Not only such protections should be provided on-ground but also, in all other locations where workers could be exposed to risks of falling objects. This was supported by interviewees 2 and 3 who stated that overhead protections should also be installed whenever the operator or workers are exposed to the risk of falling objects such as in forklifts, cradles, and scaffolds.

Besides overhead protections, the majority of experts also confirmed that the lack of safety signs is another form of hazard that is often encountered in high-rise construction. This is because such
signs often draw the workers’ attention to the existing hazards; thereby, causing them to be cautious and maintain safe working behaviors. Examples of safety signs that were discussed by the interviewees are signs indicating the existence of falling objects, hazardous materials, access restrictions to unauthorized personnel, flammable materials, overhead loads, and safety signs indicating the needed safety PPEs that should be worn by all workers.

4.1.1.4.4 Slab edges and openings

There is a huge consensus from all interviewees that falling from heights is the leading threatening factor in high-rise construction. As interviewee 2 states “Falling from heights is the number 1 concern in high-rise buildings”. This is further supported by interviewee 3 who stated “Falling from heights is the main concern in high-rise buildings. This is because a lot of work is being performed either from the edges of the building or from its exterior.”. Accordingly, while reviewing the interviewees’ responses, it was concluded that working on/near slab edges and slab openings was the main hazard that exacerbates the falling from height risks. Thus, hazards include the lack of guardrails, the lack of fall protection systems, having guardrails with missing components, and the lack of inspection of installed guardrails (Interviewees 1, 2, 3, 4, & 5).

However, it was observed that there is a general consensus that slab openings impose higher risks of falling from height as compared to slab edges. This is supported by Interviewee 1 who stated, “The most existing forms of risks are falling from a height, specifically in relation to slab openings”. The threats imposed are primarily related to working conditions where such openings normally get unnoticed by construction workers due to the lack of visible barricades, covers, and safety signs (Interviewees 1,2,4, &5). Slab openings associated with falling from height risks are often large enough in size; these include openings for staircases and elevator shafts. Whereas, slab openings that are associated with multiple falling objects risks include slab penetrations for routing of plumbing, fire protection piping, and ductwork between floors (Interviewees 1,2,4, &5).

Therefore, all interviewees agreed that the main role of safety management is to ensure safe working conditions through the appropriate implementation of risk mitigation measures and adequate inspection. These include having covers that are made of substantial materials, able to support twice the average weight of the employees, equipment, and material, and be securely
fastened. Covers must also be larger than the opening so that it does fall through the smaller hole, secured against displacement, and accompanied with safety signs stating, “Opening do Not Remove”.

4.1.1.4.5 Slab Pre-stressing

Another main source of a wide range of hazards, as expressed by the majority of interviewees in the pre-stressing process. This is based on the fact that the majority of high-rise buildings include pre-stressed slabs. Thus, the interviewees illustrated that the process is a hazardous process that could lead to a wide range of risks including but not limited to falls to the exterior of the building during jacking operations (Interviewees 1, 2, 3, & 4), concrete blow-outs on decks (Interviewees 2, 3, & 5), explosive release of a cable during tensioning operations (Interviewees 3, 4, & 5), lacerations from the cable ends, trips on materials, etc. (Interviewee 3).

The first hazard that was discussed by all interviewees is the lack of guardrails on the pre-stressing working platform. The second hazard that was discussed by the majority of the interviewees is having unauthorized workers in the pre-stressing zone. This was further explained by interviewee 2 who stated “No one shall be permitted to stand behind, in line with, or directly above the stressing equipment or the full length of the tendon(s), including the fixed end anchorage. This is because, due to the tremendous forces involved, if a failure occurs, there is a good possibility that high-velocity projectiles will be produced”.

A third hazard that was also discussed is the lack of barricades or physical barriers behind the stressing area. Interviewee 3 explained that by stating “If a strand should break, the wall will prevent it from flying about”. Other hazards were related to the existence of unattended tools and equipment on the working platform, poor housekeeping, and poor inspection of the pre-stressing equipment.

In relation to workers, the main risk that was discussed is the sharp edges of the steel rebars which could lead to several severe injuries. Therefore, interviewee 3 stated, “the end of a piece of reinforcing steel can be sharp, so workers must be cautious when working around it and Wear long pants to prevent scratches and cuts”. Similarly, overexertion injuries could occur while
moving heavy steel or while tying rebar. This could lead to repetitive strain injuries, particularly in the wrist and forearm.

4.1.1.4.6 Concreting

Similar to the prestressing process, the concreting process was another theme that was discussed by the majority of the experts. To start with, risks could emerge from the placement of plants and equipment, which include proximity to traffic, members of the public, powerlines, other plants, structures, and trenches (Interviewees 3, 4, & 5). However, the majority of hazards were attributed to the different tasks of the pouring process including, concrete delivery, pump and boom operation, concrete pipeline handling, concrete pouring, pump relocation, and pump cleaning (Interviewees 1, 2, 3, 4, & 5). These processes impose multiple risks such as workers falling onto concrete slabs, being crushed by slabs falling as they are hit, and getting pinned between concrete slabs.

To illustrate, when pumping concrete, there may be a risk of concrete lines bursting, lines becoming unrestrained and pipe clamps being dislodged (Interviewees 1 & 2). Also, damage to the delivery hose or the inappropriate selection of the delivery hose may also cause the discharge of concrete under pressure (Interviewees 2 & 4). These hazards could lead to risks such as being burned or blinded by concrete chemicals, being impaled on rebar sticking out of concrete slabs and falling from heights, among others (Interviewees 1, 2 & 4).

Within this context, the majority of the interviewees pointed out another hazard which is the existence of unauthorized employees in the pouring area. As stated by interviewee 4, “before commencing concrete pumping operations, you should ensure that people not involved in concrete pumping are excluded from the work area, and all personnel should remain clear of the delivery hose and the placing boom”. The main rationale behind this was attributed to the fact that pressurized concrete escaping from the enclosed pumping system has the potential to strike workers and others, causing injuries.

Other hazards that emerge during the pouring process could be related to the integrity and structural stability of the formwork. This was supported by interviewee 2 who stated, “before
starting the pour, someone must be designated to monitor the condition of the forms as the concrete is placed”. In the same vein, interviewee 4 added “Safety inspectors must be able to identify any sign of bulging, slipping, uplifting, sagging, etc., and have the authority and the means to stop the pour immediately”.

Another hazard that was discussed is the lack of a competent signaler who is trained and competent to observe and advise the pump/vehicle operators. As stated by interviewee 1, “there should also be If the vehicle or the pump is likely to contact a person, structure or moving plant on site, they should relay signals, from the placing gang to the pump operator”; whereas, interviewee 4 stated, “signalers direct the safe movement of the concrete placing boom and give clear and precise verbal instructions to maintain safety while pouring concrete”.

In relation to the workers’ unsafe behavior, interviewee 5 stated that employees often tend to extend the hose to reach other locations; this could lead to the “Hose whip” effect. This term is used to describe the uncontrolled, and rapid motion of the flexible rubber hose on the end of a concrete placing boom (Interviewee 5). Similarly, the lack of suitable PPEs was also discussed by the interviewees. This is because concrete can be slippery causing workers to slip and fall (Interviewees 2 & 5). Furthermore, the alkaline properties of wet cement can lead to third-degree burns (Interviewees 2 & 5). Therefore, workers should use appropriate personal protective equipment to protect skin from contact and long-term exposure, which can lead to chronic dermatitis.

Other hazards include poor ergonomics, such as improper lifting, awkward postures, and repetitive motions which could lead to risks such as back injuries from lifting heavy concrete slabs, sprains, strains, and other musculoskeletal disorders (Interviewee 2).

4.1.1.4.7 Table formwork

Likewise, three of the interviewees shed light on the hazards that emerged from table formwork. This is due to the fact that they are widely used for pouring slabs. One of the main hazards that was discussed by the interviewees is related to the fact that table formworks are lifted using tower cranes; thus, guardrails are removed increasing the risks of falling from heights (Interviewees 1 &
Therefore, workers must use fall protection that is appropriately anchored to good, solid anchorages that workers can tie off using their own personal fall arrest systems.

Likewise, receiving and rolling out table formworks is another hazardous situation that increases the risks of struck-by accidents. This is because being caught between a moving fly form and any part of the building can cause serious cuts, lacerations, contusions, broken bones, and amputations. As stated by interviewee 4, “all workers, receiving the fly form on the previously poured suspended slab, must beware of being struck by the incoming assembly”. Thus, they should never put themselves between the formwork and a column or wall. This also applies when the formwork is being rolled out. Interviewee 4 further pointed out that more problems start to emerge, as a direct result of the wind effect; thereby, increasing the probability of accidents. Such probability further increases with the increase in height as wind imposes higher risks in higher floors.

4.1.1.4.8 Tower cranes

Again, the majority of the interviewees affirmed that the erection, climbing, and dismantling of tower cranes are potentially hazardous processes that involve working at heights, awkward postures, lifting, and aligning components of significant size, and mass, and installing temporary support systems (Interviewees 1, 3, 4, & 5). To start with, one of the main hazards that was discussed by the interviewees was the lack of competent workers, specifically when it comes to erecting and dismantling the crane.

This is further supported by interviewee 3 who stated that “the erection of tower cranes requires workers experienced in such operations; workers involved in tower crane installation/dismantling should have adequate qualifications and need to possess relevant technical licenses or have completed a certified training program”. Thereby, shedding light on the significance of training programs to enhance the technical skills of workers.

This is because a wide range of risks could emerge as a result of competency; to illustrate, interviewee 2 stated that “when dismantling the crane, workers should never release any pins, bolts, pendants, etc., until the section or component is properly rigged, and balanced, and the total weight is being carried by another crane or derrick; if workers are incompetent enough to conduct
such operations, this could lead to disastrous consequences.” Interviewee 4 further stressed the importance of training programs to other workers including mast riggers, lift directors, and tower crane operators.

In relation to tower crane operations, one of the most hazardous scenarios that were discussed by the interviewees is having two or more overlapping tower cranes. Accordingly, interviewee 2 stated, “Although some projects do operate with an overlap at different levels, it is also associated with hazards as the lifting wire could get stuck. This is specified as extreme risk”. These risks could cause loss time accidents which affect the KPIs of the company, its reputation, and the productivity level of workers due to their affected motivation levels.

To overcome this problem, the majority of the interviewees ensured that the limit switch is functional in the case of overlapping tower cranes (Interviewees 1 & 4). Other safety measures include leaving clearance distance between cranes as indicated by interviewee 3 who stated, “Besides the anti-collision system, we leave a clearance distance of 6 meters between the two tower cranes to avoid accidents from wires”.

Even in the absence of overlapping tower cranes, risks and hazards still exist. Accordingly, another hazard that was discussed by the interviewees was the lack of signalers/spotters who would aid the crane operators, specifically when the load is out of view. As stated by interviewee 2, “The person responsible for directing the lift shall make sure that the load is properly secured, balanced, and positioned in the sling or lifting device before it is lifted more than a few inches.”

Another hazard that was discussed by the interviewees was the lack of appropriate PPEs most important of which is the fall protection system that should be worn by workers during the erection and dismantling processes. In the same context, they also discussed the significance of restricting access to areas underneath the work being performed. As stated by interviewee 3, “the following procedures should be maintained: the installation of fall protection system for workers working at height and suspending work under/near the erection/dismantling processes”. Interviewee 2 further supported this by stating that “the location of the tower crane should be safe for erection and
dismantling; thus, while deciding the optimal location of a crane, attention should be given to safety requirements besides the coverage radius of the crane”.

4.1.1.4.9 Scaffolds
Interestingly, the majority of the interviewees confirmed that an extremely high number of accidents is attributed to the use of scaffolds in high-rise construction; this is primarily based on the fact that a wide range of scaffolds is used including suspended and mast scaffolds. Therefore, the topic is given considerable importance by the safety teams. Interviewee 1 summarized the three primary causes of construction accidents during erection/dismantling, unsafe working behaviors, and poor working conditions.

To start with, one of the main hazards that was discussed by the interviewees is the lack of regular inspection and maintenance to the scaffold structure. This is because, even though intended as temporary structures, they are usually kept on-site for months and years in high-rise projects (Interviewees 1 & 3). As indicated by interviewee 3, “For example, all of the external finishes are done using suspended platforms that involve plenty of metal works. These metals rust so quickly given the high humidity level, even though they are resistant to erosion and rusting”.

Accordingly, interviewee 1 stressed the inspection process by stating, “components must be inspected for visible defects before the start of every shift”; whereas, interviewee 2 stated that “the structural integrity of scaffolds should be inspected after every occurrence”. In the same vein, interviewee 5 stated, “metal components should be checked for bends, cracks, holes, rust, and welding problems”.

Another hazard that is related to the inspection process is missing parts/components while using the scaffold. These include missing access ladder, handrail and guard rail, toe platforms, bracings, etc (Interviewees 1, 4, & 5). These lead to risks including falling from heights, falling objects, and electrical risks. This brings us to another hazard which is the lack of safety signs that indicate whether or not the scaffold is safe to be used by workers. Interviewee 2 further indicated that green tags are used to label inspected scaffolds that could be readily used by construction workers.
Accordingly, he stated that “When the scaffold is safe and inspected, a green tag is added to the scaffold, and workers are prevented from working on this scaffold”.

Another type of scaffold that was also discussed by the majority of interviewees is the mast scaffold; yet, the risks that are associated with mast scaffolds are much more severe compared to regular or suspended scaffolds. This was also highlighted by interviewee 5 who stated, “mast scaffolds may be less forgiving than other types of scaffolds if not correctly installed, operated, inspected, or dismantled”. Accordingly, one of the main hazards emerges from the inappropriate use of mast climbers. These include things such as exceeding the mast’s loading capacity and using inappropriate loading and unloading techniques (Interviewees 3, 4, & 5). Likewise, interviewee 4 shed light on the obstructions and protrusions that could impede the mast’s smooth flow; thereby, leading to severe risks.

However, it was apparent that the majority of hazards were attributed to unsafe working behaviors. These include having unsafe access to the working platform by jumping in/out when the mast climber is not at the ground level (Interviewee 4); similarly, workers tend to leave their tools and equipment unattended, which is the lack of safety nets, could lead to severe risks of falling objects (Interviewee 1).

4.1.4.10 Fire

Again, fire risks are considered among the severest in high-rise construction due to the limited accessibility of firefighting equipment. Thus, all interviewees indicated that they have temporary firefighting equipment on-site; however, another main hazard that emerges is the dependency on public pipelines which often show low-pressure levels. This is indicated by interviewee 1 who stated, “Depending on public infrastructure for the supply of water is associated with multiple risks”.

For this reason, interviewee 1 stated that “We also had temporary fire lines on every floor where temporary water was stored. These were also associated with smoke detectors in the storage area”. Hence, the installation of temporary water tanks on every floor aid in mitigating the risks of having low pressures. Likewise, another hazard emerges from having temporary firefighting systems that
are inadequate or insufficient to fire against potential fire accidents. This sheds light on the
significance of having risk management and emergency evacuation plans. As indicated by
interviewee 2, “Therefore, we have extinguishers on every floor which are distributed according
to the risk rate at every location”. Whereas, interviewee 1 stated, “We conduct both announced
and unannounced drills to ensure safe evacuations during emergencies”.

In the same context, the lack of reach of the installed temporary system is another hazard that was
discussed by interviewee 1. Therefore, he stated, “I ensure having constant access to water in all
floors by connecting a fire pipe in every storey at the central location within the floor. I also
ensured that these types could provide the needed water force and pressure that could extinguish
any fire at this location.”. Thus, safety officers should inspect that there is water reach in every
floor by regularly trying the fire hoses on every floor.

In fact, fire hazards, in relation to poor handling of waste and other flammable materials, have
been confirmed by all interviewees. To illustrate, interviewee 1 stated that “In low-rise buildings,
and in the case of fire due to poor housekeeping or poor storage management, I could easily
extinguish this fire. But imagine that this fire took place on the 20th floor of the building, how
could we extinguish it?”. The same applies to a wide range of flammable materials that are typically
being handled and stored in high-rise construction. Thus, interviewee 4 stated, “The primary
hazard from acetylene and propane, which are typically used for welding purposes, is
flammability.” Accordingly, flammable or explosive materials such as gasoline, oil, and cleaning
agents should be stored apart from other materials.

Similarly, other hazards that lead to fire risks in the poor organization and arrangement of the
storage areas. As stated by interviewee 1, “materials should be piled in a manner that minimizes
the internal spread of fire and provides convenient access for firefighting.”; whereas, interviewee
5 stated, “driveways between and around combustible storage piles must be wide enough to
facilitate the movement of firefighting equipment in fire emergencies. In the same context,
interviewee 3 stated, “the storage areas of flammable materials, either gas or liquid, must have
appropriate fire protection (fire extinguishers or fire suppression equipment)”. Whereas,
interviewee 5 stated, “Other combustibles must be stored in an area where smoking and using an open flame, a spark-producing device, or any other sources of heat or ignition, is prohibited”.

4.1.1.4.11 Unsafe working behaviors

Unsafe working behaviors have been widely discussed by the safety managers who were interviewed. As indicated by interviewee 1, “Most of the unique hazards are attributed to unsafe behaviors. These include workers standing outside the handrail to perform a specific task”. Interviewee 2 further supported this notion by affirming that “In general, 95% of all construction accidents, across the globe and not in Egypt only, occur due to unsafe acts; this number is not limited to workers only but also engineers do unsafe acts”.

Interviewee 4 stated that “We had a recent fall from height accident where the work stopped, and an investigation was conducted. The accident was primarily related to reckless human behavior where the man tried to jump from one platform to another as a shortcut instead of having to step down the ladder and reclimb to the other platform”. Thus, it could be concluded that the unsafe thinking of people is the main cause of accidents. The remaining 5% are attributed to either unsafe conditions or to unforeseen circumstances.

Laziness is a main contributing factor to unsafe working behaviors. As stated by interviewee 3, “Such acts are repeated on different levels because workers are too lazy to go to the storage area to get what they need”. To demonstrate a few of the examples that were given by the interviewees, workers tend not to wear their harnesses while working from heights even though they have it in place (Interviewee 1). Also, workers tend to have unsafe postures and body positions while working, such as a person fixing a steel piece with his legs to cut it which is considered an extreme risk (Interviewee 3).

An interesting fact that was revealed by the interviewees was the fact that young workers tend to show more reckless behavior as compared to older workers. In fact, falling from heights accidents are more prevalent in young workers who are more likely to conduct unsafe work behaviors in an attempt to impress or gain the attention and acknowledgment of their supervisors. As stated by interviewee 1, “This is since workers at a young age are mainly inexperienced; however, they want
to prove their qualifications to their managers. Therefore, they undertake higher risks and conduct more unsafe behaviors.” For this reason, the organization of interviewee 1 banned workers under the age of 25 from working from heights. Table 6 presents a summary of the hazards identified from the interviews.

4.1.1.5 Summary of identified hazards

Table 6: High-rise construction hazards identified from expert interviews

<table>
<thead>
<tr>
<th>Theme</th>
<th>Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling &amp; Storage</td>
<td>Lack of organization</td>
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<tr>
<td></td>
<td>Blockage of main access &amp; egress routes</td>
</tr>
<tr>
<td></td>
<td>Storing material at/near slab edges &amp; openings</td>
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<tr>
<td></td>
<td>Storage of hazardous materials</td>
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<td></td>
<td>Storage of flammable materials</td>
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<td></td>
<td>Storage of unsafe materials (for example with protruding nails)</td>
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<tr>
<td></td>
<td>Exceeding weight rated capacity of machines</td>
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<td></td>
<td>Manual handling by workers</td>
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<tr>
<td>Accessibility &amp; Egress</td>
<td>Lack of permanent access and egress routes (stairs)</td>
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<tr>
<td></td>
<td>Structural defaults in temporary access (wooden planks)</td>
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<tr>
<td></td>
<td>Thrust &amp; repulsion of workers during break times</td>
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<tr>
<td></td>
<td>Poor lighting of staircases</td>
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<tr>
<td></td>
<td>Lack of firefighting equipment in staircases</td>
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<tr>
<td>Safety Facilities</td>
<td>Lack of overhead protections whenever loads pass over workers</td>
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<tr>
<td></td>
<td>Lack of overhead protections on certain equipment such as forklifts,</td>
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<td></td>
<td>cradles, &amp; scaffolds.</td>
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<td></td>
<td>Lack of overhead protections in certain waiting areas, such as hoist</td>
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<tr>
<td></td>
<td>waiting area</td>
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<tr>
<td></td>
<td>Lack of access restriction to areas with risks of falling objects</td>
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<tr>
<td></td>
<td>Lack of safety signals</td>
</tr>
<tr>
<td>Slab edges &amp; openings</td>
<td>Lack of guardrails</td>
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<tr>
<td></td>
<td>Lack of fall protection systems</td>
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<tr>
<td></td>
<td>Having guardrails with missing components</td>
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<tr>
<td></td>
<td>Lack of inspection of installed guardrails</td>
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<td></td>
<td>Lack of covers for slab openings</td>
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<tr>
<td></td>
<td>Installed covers lack the needed strength to support the weight of</td>
</tr>
<tr>
<td></td>
<td>workers</td>
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<td></td>
<td>Lack of visible barricades around slab openings</td>
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<tr>
<td></td>
<td>Lack of safety signals around slab openings</td>
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<tr>
<td></td>
<td>Poor fastening of slab covers</td>
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<tr>
<td>Pre-stressing</td>
<td>Lack of guardrails on working platforms</td>
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<tr>
<td></td>
<td>Having unauthorized workers in the pre-stressing zone</td>
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<tr>
<td></td>
<td>Lack of barricades/ physical barriers behind the stressing area</td>
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<tr>
<td></td>
<td>Workers’ exposure to sharp edges from steel rebars</td>
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<tr>
<td></td>
<td>Repetitive work/movements (handling, placing, tying steel rebars)</td>
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<tr>
<td>Concreting</td>
<td>Having concrete plants in close proximity to other structures</td>
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<tr>
<td></td>
<td>Concrete being discharged under extremely high pressures</td>
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<td></td>
<td>Existence of unauthorized employees in the concrete pouring zone</td>
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<tr>
<td></td>
<td>Defaults in the structural integrity of formwork</td>
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<tr>
<td></td>
<td>Lack of competent signaler</td>
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<tr>
<td></td>
<td>Workers’ exposure to the alkaline properties of wet concrete</td>
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<tr>
<td></td>
<td>Lack of suitable PPEs</td>
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<tr>
<td></td>
<td>Workers’ unsafe behaviors</td>
</tr>
<tr>
<td>Table formwork</td>
<td>Receiving/rolling out table formwork</td>
</tr>
<tr>
<td></td>
<td>Absence of guardrails while receiving/rolling out table formwork</td>
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<tr>
<td></td>
<td>Lack of fall protection systems</td>
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<tr>
<td></td>
<td>Lack of suitable anchorage points for workers to tie their safety harness</td>
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<tr>
<td>Tower Cranes</td>
<td>Lack of competent erectors/dismantlers</td>
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<tr>
<td></td>
<td>Lack of competent tower crane operators</td>
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<tr>
<td></td>
<td>Lack of competent mast riggers and lift directors</td>
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<tr>
<td></td>
<td>Having two or more overlapping tower cranes</td>
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<td></td>
<td>Lack of limit switches/ anti-collision systems on tower cranes</td>
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<tr>
<td></td>
<td>Lack of signalers/spotters</td>
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<td></td>
<td>Lack of fall protection systems</td>
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<tr>
<td></td>
<td>Lack of access restriction to areas underneath load path</td>
</tr>
<tr>
<td>Scaffolds</td>
<td>Lack of regular inspection &amp; maintenance</td>
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<tr>
<td></td>
<td>Working on scaffolds with missing components</td>
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<tr>
<td></td>
<td>Lack of safety signs</td>
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<tr>
<td></td>
<td>Overloading working platforms</td>
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<tr>
<td></td>
<td>Having inappropriate loading/unloading techniques</td>
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<tr>
<td></td>
<td>Lack of suitable access means (scaffold stairs)</td>
</tr>
<tr>
<td>Fire</td>
<td>Poor accessibility of firefighting equipment</td>
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<tr>
<td></td>
<td>Reliance on public infrastructure for temporary firefighting systems installed</td>
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<tr>
<td></td>
<td>Lack of temporary water tanks on-site</td>
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<tr>
<td></td>
<td>Inadequate temporary firefighting equipment</td>
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<tr>
<td></td>
<td>Existing temporary equipment does not reach all corners of the building</td>
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<tr>
<td></td>
<td>Lack of risk management and evacuation plans</td>
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<tr>
<td>Poor handling of waste &amp; flammable materials</td>
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<tr>
<td>---------------------------------------------</td>
<td></td>
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<tr>
<td>Poor arrangement &amp; organization of storage areas</td>
<td></td>
</tr>
<tr>
<td>Unsafe working behaviors</td>
<td>Reckless human behavior, specially by young workers</td>
</tr>
<tr>
<td></td>
<td>Laziness of construction workers</td>
</tr>
<tr>
<td></td>
<td>Workers not wearing their PPEs</td>
</tr>
<tr>
<td></td>
<td>Workers having unsafe postures while working</td>
</tr>
</tbody>
</table>

4.1.2 Site visits

Accordingly, site visits were conducted to mega high-rise projects that are still under construction in Egypt. These site visits aimed to target projects under both concreting and finishing phases. Also, specific considerations were given to the location of the sites to cover a wide range of weather conditions and possible constraints; thus, projects in the main city, coastal areas, and arid/desert areas were conducted. Accordingly, 4 main site visits to four different high-rise building construction sites in Egypt have been conducted along with 1 site visit that was conducted in Vancouver, Canada. The following paragraphs provide a brief description of the site's visits.

4.1.2.1 Visited Sites

In total, five high-rise construction sites were visited to gather data about the main hazards that are encountered in high-rise construction projects. The following paragraphs shows the high-rise construction projects that were visited along with the identified hazards.

4.1.2.1.1 Site visit #1

The first project is located in the Sheikh Zayed district in the eastern suburbs of Giza governorate in Egypt. The climate of the area is classified as a “Hot desert” according to the Köppen-Geiger climate classification system. The gross area of the project is 165 acres with 85 acres being devoted to mid-rise and high-rise residential towers. The visited tower is a high-rise residential development with 20 storeys that was yet under construction. At the time of the visit, the concrete work of 17 storeys was completed with an active pouring process to the 18th floor; also, no external finishes were carried out. Accordingly, the site tour was limited to the concreting process along with a review of the constructed floors.

4.1.2.1.2 Site visit #2

The second project is located in the Maadi district in the southern part of Cairo governorate in Egypt. The climate in the area is classified as tropical and subtropical desert climate according to
the Köppen-Geiger climate classification system. The gross area of the project is 10,000 sqm with two main 23-storey towers. The first is a five-star hotel and the second, the visited tower, is a residential tower. At the time of the visit, the towers were fully constructed with about 70% of the finished work being done. Accordingly, the site tour was primarily concerned with external and internal finishes.

4.1.2.1.3 Site visit #3

The third project is located in New Alamein city, a new city that overlooks the Mediterranean Sea in North-west Egypt. Although the climate of the city is classified as tropical and subtropical desert climate according to the Köppen-Geiger climate classification system, the city is characterized by its high wind speeds, specifically during the winter months. The visited project is a residential tower with 40 storeys and a total built-up area of 275,000 sqm. At the time of the visit, the building was in its concreting phase with 22 floors being completed. The concreting process of the 23rd floor was in progress.

4.1.2.1.4 Site visit #4

The fourth project is also located in the New Alamein city in North-west Egypt. The project consists of four 32-storey towers and a podium with a total built-up area of 285,000 m2. The visited tower is tower number 3. During the time of the visit, the project was in its finishing phase with all the concrete work completed. The following paragraphs demonstrate the results obtained from the site visit.

4.1.2.1.5 Site visit #5

The final project is located in Vancouver, a mega city that lies in the mainland region of British Columbia, Southern Canada. The city is classified as oceanic or marine west coast by the Köppen climate classification with relatively high levels of precipitation during the winter months.

4.1.2.2 Identified Hazards

In relation to the identified hazards during site visits, 15 main themes emerged as seen in figure 17. These are hazards related to buildings’ perimeters, housekeeping, accessibility & egress, slab edges & openings, hoists, scaffolds, tower cranes, jumping formwork, cradles, vehicles, windscreens, weather conditions, and unsafe working behaviors.
4.1.2.2.1 Building’s perimeters

A major form of hazard is related to working at/near the building’s perimeter due to the increased risks from falling objects; this primarily emerges from the lack of appropriate access restriction mechanisms on-site. Therefore, to ensure safety, access to all areas of the building’s boundaries should be restricted to prevent any harm caused by falling objects.

In fact, multiple sources of falling objects were identified; these are often mitigated through the existence of safety nets. However, having safety nets that do not fully enclose the building’s perimeters, including the corners of the building, is another hazardous situation that is often
encountered in high-rise construction. Therefore, the safety officers indicated that this could lead to falling from heights and falling objects risks.

The safety officers on-site also stressed that the cleaning process of safety nets is itself a major form of hazard as it increases the risks of falling objects. During this process, the inclined safety net is pulled to a vertical position to lower all forms of waste into the slab, elevating the risks of falling objects. Therefore, during the cleaning process, access to all area’s underneath is restricted to maintain safety. Also, some safety nets are located in areas whose masonry work has been accomplished. In these cases, the risks of falling objects are further exacerbated as the stuck waste could be easily carried away by high wind speeds. Figure 18 shows a sample of hazards that exist in relation to safety nets in high-rise construction projects.

4.1.2.2 Accessibility and evacuation

Concerning accessibility and evacuation, wooden ramps, as seen in figure 19 (a), are primarily used as access ladders between floors in high-rise construction; thereby, acting as a hazard that increases fall and trip risks. These wooden ramps are constructed with an inclination of a 45-degree angle and include wooden platforms that act as treads. The ramp is guarded by handrails and mid-rails from both sides.

To ensure a safe evacuation route for all workers, the safety management team should insist on the concurrent construction of the staircases with the main floors. If concrete stairs are not feasible,
then the use of scaffold ladders should be mandated. Scaffold ladders were considered, by the sites’ safety managers, as the safest access route that facilitate evacuations during emergencies as compared to monkey ladders and wooden ramps. In areas of limited accessibility where monkey ladders/scaffold ladders would not fit, the use of wooden ramps could be allowed for heights up to 1.5 meters.

In addition, the safety manager indicated that in cases of emergency, all construction workers are trained on the evacuation process to safely evacuate the site. Accordingly, through modern communication tools, with safety supervisors, officers, engineers, and crane operators, the emergency case is promptly communicated to all relevant parties. Subsequently, according to the provided training, there should be emergency leaders who first evacuate the place of emergency followed by other places. This is done with the aid of assembly points that exist on all floors. This evacuation system eliminates the panic and stress that would lead to thrusts and repulsion as a result of an unorganized evacuation practice.

Another main hazard is related to the sole dependence on internal staircases or wooden ramps without having sufficient equipment that would aid in the rapid evacuation of construction workers. This severely increases the risks of crowd crushes, falls, and trips. Therefore, internal access routes should be further supported by the existence of multiple operating hoists and man-baskets, as seen in figure 19 (b), to aid in the evacuation process.

![Wooden ramps used as access pathways.](image1.png) ![Man-baskets used in emergency cases.](image2.png)

Figure 19: Means of access and egress provided on high-rise construction sites.
It was also observed that the main access to the emergency route was often blocked as a result of temporarily constructed workshops, as seen in figure 20 (a). These stacked materials could easily impede the movement of workers during emergency situations; thereby, exposing them to severe risks.

In addition, it was evident that the main problems with access routes emerge during the erection of the slab’s formwork, due to the lack of a clear walking pathway that leads to exit routes. This is another form of hazard that increases the risks of unsafe evacuation during emergencies. Therefore, additional safety measures should be implemented to prevent restricting access ways. To illustrate, the formwork for slabs should be erected from the farthest point to the evacuation route moving its way inward towards the escape ladders/hoists/ramps. Similarly, during the disassembly process, the dismantling of the formwork should start from the nearest point to the escape route working its way outward toward the farthest point of the slab. This is done to prevent any blockage to the evacuation pathway and to facilitate the escape process of workers during emergencies.

Besides temporary workshops, the storage of materials in access routes is another witnessed hazard that could prove to be of extreme risk in cases of emergency. This is because it blocks the passage
of workers and is often associated with trip/slip risks. Finally, the lack of essential fire fighting equipment, such as fire extinguishers, is another form of hazard that exists in major access and egress routes; this hazard is associated with multiple forms of risks that emerge from fire accidents including but not limited to blockage to exit routes by fire, suffocation, etc.

4.1.2.2.3 Housekeeping

Poor housekeeping is a major source of falling objects on-site as identified by site safety managers. Falling objects due to poor housekeeping are also attributed to the extremely high wind speeds that carry away loose objects. The risk is further exacerbated as the wind is capable of carrying away such loose materials to areas beyond the safety nets; thereby, not only affecting construction workers but also, imposing great risk on pedestrians and moving vehicles.

To ensure effective housekeeping and to prevent the tedious process of carrying waste from floors to the ground level, a garbage chute is often constructed in high-rise buildings. This chute is often made of steel pipes that are interconnected through welding. Thus, a major hazard relates to the accessibility to areas where such trash lands; therefore, access to the area in which the wastelands were totally restricted.

One of the main hazards considering trash chutes is related to the materials that usually get jammed in these pipes leading to their blockage. To solve the issue, construction workers have to dismantle the clogged pipe, using a scaffold, and re-weld it subsequent to the cleaning process. Another method used to unclog the jammed pipes was by allowing a worker inside the pipe to physically unclog the pipe. The main risk involved relates to the worker being stuck, unable to breathe, or losing consciousness. Another main hazard is related to having a welding process over the trash landing area as it increases fire risks. In fact, one of the safety managers acknowledged that a welding work once caught fire in the trash landing area.

Besides waste transportation, poor housekeeping could negatively affect workers and the flow of work on-site by acting as initiators to a wide form of risks such as falling, tripping, puncturing wounds, etc. While the existence of trash indoors is not associated with severe risks, their existence on/near the exterior edges of the building is. These include near external guardrails or on extended
working platforms. Not only does such waste impose poor working conditions for workers but also, are associated with risks from falling objects. These risks are magnified during the cleaning process where materials such as steel and concrete could easily fall.

4.1.2.2.4 Slab edges & openings

In relation to slab edges and openings, the main hazard is the lack of fences and guardrails which increases falling risks. This could include the total absence of the guardrail or the absence of an important element such as the handrails or the mid-rails. In fact, extreme falling risks emerge from the erection process of these guardrails, which is considered a source of hazard, since the erection process is done twice for each floor.

Firstly, guardrails that extend beyond the slab’s edge, as seen in figure 21 (a), are erected in conjunction with the formwork of the slab. Accordingly, they are rested on wooden boards that are bolted to the slab and are extended beyond the slab’s edge. After pouring and curing the concrete, construction workers erect other guardrails at the slab’s edge; subsequently, they attach their fall arrest systems to the newly erected guardrail to dismantle the guardrails that exist beyond the slab’s edge. The process is then repeated for all floors.

![Image](image1.jpg)

![Image](image2.jpg)

a. Steel Guardrails including both handrails and mid rails.

b. Access restriction to all ground areas around the building’s boundaries.

Figure 21: Protection to the edges and perimeter of the building.
Similarly, the erection of fence panels/parapets at slab edges with irregular shapes is another hazard that increases the probability of falling risks since guardrails need to be removed for the erection process to commence. However, due to such irregularities, regular scaffolds are not applicable. Accordingly, construction workers have to install these fences from within the building with no guardrails and scaffolds, which is the main reason that constitutes this work a hazardous work type. Therefore, to ensure safety and prevent falling from height risks, jack columns, made of steel pipes and anchored to the roof and the slab, should be erected every 2 meters. Thus, construction workers working on the erection process could anchor their tagline positioning belts to the erected jack columns to eliminate falling from heights risks.

In the same context, another major hazard is related to the prestressing process of the steel tendons of the slab. To do this, an extended platform, that is anchored to the slab, is constructed. This is accompanied by guardrails and mid-rails that are extended beyond the slab’s edge. The workers stand on the platform to perform the post-tensioning process; thereby, increasing the probability of falling from height. Again, the risk hazard could be mitigated by the use of fall protection systems, and safety nets.

In addition, falling objects are other forms of severe risks that are often encountered in relation to slab edges/openings. Therefore, the lack of safety nets is another major source of hazard that exacerbates the risks of falling objects at slab edges. The case is quite similar to slab openings that lack appropriate covers. Therefore, no work at slab edges should be allowed to commence without the existence of a safety net underneath. Safety nets should be installed around all the perimeters of the building with a maximum height of three storeys. Likewise, no slab opening should be left open/uncovered on site, regardless of its size. Furthermore, to ensure maximum safety, access to all ground areas within the building’s boundaries is restricted to eliminate the risks of falling objects.

Another major source of hazard in relation to slab openings is the openings that exist while installing slab formwork panels, as seen in figure 22 (b). Thus, while installing these panels, construction workers are at risk of falling since these openings cannot be covered during formwork
installation. Therefore, construction workers should wear either fall protection belts or tagline positioning harnesses during the formwork erection process.

Figure 22: Slab openings before and after pouring concrete.

4.1.2.2.5 Hoists

To start with, it is evident that a major source of hazard relates to the technicalities of the hoist. These include defaults in its mechanical and electrical components or defaults in its external and internal skeletons. This brings us to the second major source of hazard which is the lack of regular functional inspections and maintenance routines. Therefore, inspections of the hoist should include an inspection of its mechanical components, the motor, rotating parts, gears, masts, fixation points, and wire tracks are inspected.

With regards to the electrical components, the external and internal control panels, limit switch, power cables, and cable drums should be inspected. Moving on to the skeleton, the top guardrail, access points, and platforms should be inspected in the external skeleton, whereas, the cabin, emergency stop, fire extinguisher, and emergency ladders should be inspected in the internal structure of the hoist.

The lack of competent hoist operators is another major hazard that could exist in high-rise construction; therefore, an inspection of the operator’s skills should be done with the aid of an operator assessment form to check the operator’s qualifications, license, and experience. Other hazards also emerge from the lack of effective evacuation mechanisms in the cases of sudden
failures of the equipment, fire accidents, and sudden electricity cut-offs. Therefore, an effective evacuation mechanism should always be devised. Also, all hoists must include portable fire extinguishers, safety ladders, and emergency doors during operations. In addition, the skill assessment part should assess the operator’s skills in the escape process during emergency situations, in reacting to power cut-off risks, using fire extinguishers and, the emergency exit.

The aforementioned discussion sheds light on the hazards that could emerge due to the lack of training; therefore, all operators should be trained and examined before they are allowed to operate the hoists. However, another hazard emerges from the fact that there is a lack of international operation certificates for hoists which increases the dependence on internal certificates. This might lead to inconsistencies in the quality level of the training programs being offered to hoist operators; thereby, creating an urge for the development of rigorous training and examination schemes by companies to ensure safety.

Wind and extreme weather conditions also act as significant sources of hazards in relation to hoist operations. Therefore, outdoor hoists should not be allowed to operate in high wind speed velocities which are typically greater than 20m/s. In the event of special weather conditions, such as storms and thunderstorms, all vital components of the hoist should be inspected prior to using the hoist. Also, the use of hoists exposes workers to risks from falling objects, especially in the hoist’s waiting area. Therefore, a shielding platform should be constructed as a general precautionary measure at the hoist’s location, to prevent any harm to workers on-site from falling objects. Figure 23 shows a sample of hoists operating in the conducted site visits.
In some cases, due to the irregularities in the shape of the building, the hoist should be extended outside the building’s parameters with suspended scaffolding used to cross into and out of it. This forms a hazardous situation as the landing area of the hoist remains open in the absence of the hoist; thus, exposing workers to fall risks from extreme elevations. Accordingly, access gates should be constructed with a lock system that prevents workers from opening the gate unless the hoist has arrived. In addition, all platforms leading to and from the hoist should be guarded with handrails and mid-rails.

Other hazards emerge from unsafe working behaviors where workers tend to overload the hoist; therefore, all hoists operating on-site should be equipped with limit switches that turn off the hoist whenever the maximum load capacity is reached. The limit switch also stops the hoist from moving when the door is opened for whatever reason.

4.1.2.2.6 Scaffolds

When it comes to scaffolds, the main hazard that emerges is the lack of or defaults in its main components including but not limited to access ladders, guardrails, bracings, and toe platforms; therefore, these components should undergo rigorous forms of inspection prior to use to prevent the risks that emerge from the failure of the scaffold. Another form of hazard is the lack of safety signs that indicate whether or not the scaffold has been inspected and in safe to be used. Therefore,
a sign indicating that the scaffold has been inspected should be attached to the scaffold to indicate
to workers that it is ready to be used. No workers are allowed to work on scaffolds missing the
“scaffold is safe to use” sign. Figure 24 displays pictures from the site visits showing forms of
fences and parapets in irregularly shaped buildings.

![Figure 24](image)

Figure 24: Forms of fences and parapets in irregular shaped buildings.

Similar to other working platforms, the risk of falling objects is relatively high when it comes to
the use of scaffolds; thus, a toe board should always be constructed to prevent such risks. Similarly,
the lack of fall protection systems is another safety hazard that was frequently encountered on
sites. This increases the risks of fatal falls in cases of extremely high altitudes and the risks of
severe injuries in the case of falls from relatively lower heights. Therefore, no workers should be
allowed to work on a scaffold without wearing their fall protection systems.

In a few cases, it was evident that the main hazard emerged from the existence of a spacing between
the scaffold and the work area; while this spacing is not enough for a worker to fall through, it
increases the risks of having workers’ limbs or other body parts caught in between. Therefore, the
space between the scaffold and the activity’s location, such as the wall, should not exceed 80 cm.

On the other hand, the scaffolds that are often used for the external finishes of irregular-shaped
buildings are suspended scaffolds that are anchored to the slab through suspended racks. These
racks are usually made of truss beams where two-thirds of the beam is anchored to the slab and one-third of the beam is suspended. This option was considered safer as compared to having scaffolds from the ground floor due to the high wind speeds in some visited locations. Furthermore, they are more cost-effective and time efficient. Being suspended in the air is the main form of hazard that emerges from the use of this scaffolding type. Therefore, the multiple risks that emerge from the additional components of this system, as compared to traditional scaffolds, necessitate stricter forms of inspection.

Another form of hazard is related to the workers’ stepping in and out of the scaffold. Therefore, the fall arrest systems should include two main harnesses where construction workers are prohibited from unleashing the first harness before tying in the second one. For this reason, column jacks are normally constructed in the slab in all areas including scaffolds. These jacks are used as anchor points where the second harness is tied by construction workers before they cross into or out of the scaffold. Again, the second harness should be tied off into the jack before releasing the harness from the guardrails. This system ensures that they are safeguarded against fall risks at all times.

Finally, when it comes to workers’ conduct, another major hazard emerged which is carrying tools and materials as they climbed the scaffold. Accordingly, the safety team should always ensure that construction helpers are the ones who transport and handle the materials to the personnel working on the scaffolds.

4.1.2.2.7 Tower cranes

It has been acknowledged that the use of tower cranes is one of the most hazardous works performed in high-rise construction. Besides the technical aspects of operating the crane, the site visits indicated that a major hazard emerged from the lack of a guiding coordinator on site. Therefore, for superior safety performance, each tower crane should be guided by two coordinators, the first coordinating from the ground floor and the second coordinating on the floor under construction. When the load is rigged to the tower crane, the on-ground coordinator signals to both the on-floor coordinator and the crane’s operator that the load is ready to be lifted. During the lifting process, the on-floor coordinator restricts access to the area in which the load will be
unloaded. This safety system is further accompanied by a warning system that is activated when the load or hook approaches near or over personnel.

Another form of hazard is extreme weather conditions such as wind, rain, heavy fog, or snow, as they may severely affect the operations of the tower crane. Not only such effects manifested in the load being rigged and transported but also, could be manifested through defaults and failure in the equipment itself. Therefore, crane operations should cease in turbulent weather conditions. Although lifting operations should be halted at wind speeds exceeding 40 knots, 20m/s approximately, most of the visited sites recommended stopping tower crane operations at 35 knots, 18 m/s, for additional safety.

4.1.2.2.8 Slipping formwork

Slipping/jumping formwork hazards emerge from two primary factors namely, its mechanical components, and workers working on its platform. To start with the mechanical components, lack of proper inspection prior to operation is a major hazard that could lead to multiple severe risks. Therefore, considerable attention should be given to the inspection process of this type of formwork. Multiple aspects should be considered by safety officers while inspecting the slipping formwork. To start with, all mechanical components pertaining to the hydraulic jacks, including the motors, hydraulic pipes, and electrical distribution panels should be thoroughly examined regularly.

The working platform should also be inspected for its safety, stability, and reliability. Besides, a major hazard that exists in relation to the working platforms of climbing formworks is missing components, such as missing guardrails, suitable access ladders, or planks in the toe board, as seen in figure 25. Another hazard relates to the lack of basic safety requirements including fire extinguishers, first aid kits, proper illumination at night shifts, emergency lighting, etc.

As previously mentioned, working platforms increase the risks of falling objects; therefore, the access area to the slip work should be shielded with overhead protection or a safety net to prevent the risks of falling objects. These risks are further exacerbated during the cleaning process where materials could easily fall. Therefore, no cleaning of the platform should be permitted during the
shift; rather, cleaning should take place either during the break time or the end of the shift to ensure that no workers, who might get affected by falling objects, are on-site, as seen in figure 25.

Besides the aforementioned, hazards from workers' unsafe working behaviors on working platforms are also associated with risks from falling objects; these are often encountered as workers tend to leave loose or unstacked materials behind. In addition, they tend to leave their equipment unattended, which increases the risks of falling objects and trips by other workers.

![Figure 25: Jumping/slipping formwork on-site.](image)

4.1.2.2.9 Cradles/gondolas

Construction cradles are often used to install facade work in high-rise construction. Thus, among the hazards that are often encountered is the lack of proper inspection and maintenance to the equipment. Therefore, the equipment should be closely examined and inspected for its motors, emergency braking, safety lock, and safety wires, regularly, and before operations.

Likewise, hazards normally emerge from operating cradles in extreme weather conditions, specifically high wind speeds. Thus, all activities using cradles should be suspended at wind speeds exceeding 40 knots. However, for additional safety, cradle activities were stopped at the site at
wind speeds of 35 knots. Another hazardous situation emerges from the existence of protruding obstructions from the building. These obstructions could include steel bars or other services, such as electrical services, that could easily be entangled in the cradle; this would not only restrict the vertical movement of the cradle but also, increases risks of equipment failure and fatalities during operations. Therefore, safety managers should inspect the cradle’s path prior to operations to ensure that no obstructions exist. Considering the workers' unsafe working behavior, hazards emerge from the extreme loading of the cradle. This is usually witnessed when construction workers tend to use the equipment as a transportation device to transport materials and labor. Therefore, during their work, construction workers should adhere to the maximum load capacity of the cradle as indicated by the manufacturers.

Also, construction workers tend not to wear their fall protection systems during operations which increase the risks of falling from height. Thus, all workers should be mandated to wear their safety harness and attach it to the designated anchorage point. In the same vein, construction workers tend to adopt unsafe approaches to accessing and exiting the cradle, such as jumping off or accessing the cradle from within the building. Accordingly, all workers should be restricted from accessing or leaving the cradle except at the ground level.

4.1.2.2.10 Vehicles and moving equipment

To start with, the main hazard while considering vehicles and moving equipment is the lack of competent operators; therefore, all operators should be licensed to operate the specific equipment on hand. Similar to other equipment, the lack of inspection and proper maintenance is another form of hazard that increases the likelihood and impact of a wide range of risks. Therefore, all vehicles should be inspected for the following. First of all, the vehicle’s frame and interior should be inspected. Accordingly, the seatbelt, steering wheels, windows and windshield, windshield wiper, tires and tire air pressure, rearview mirrors, speedometer, and shock absorbers should be examined prior to operating the vehicle. Subsequently, the internal and mechanical aspects including the inspection of the jack, radiator coolant, engine oil, brake fluid, transmission oil, and battery are conducted.
Likewise, the lack of functional inspection prior to operations is another hazardous situation that is often encountered in construction sites in general; accordingly, a run-test should be conducted where the low beam and high beam headlights, tail, dash, stop, and turn signal lights, front and rear fog lights, and backup alarm should be tested. In this context, inspection prior to operations should also ensure the existence of all emergency safety equipment, such as portable fire extinguishers and first aid kits, during operations.

4.1.2.11 Windscreens

Windscreens are used to protect against high wind speeds that could reach up to 50 knots during the winter months. Therefore, they aid in eliminating delays in construction projects while ensuring the safety of all construction workers. These screens are lifted using tower cranes and are anchored to the slab. The fixation of these windscreens is considered among the hazardous work types in high-rise construction. Therefore, safety managers should ensure that workers anchor windscreens while being bound and guarded by guardrails. While working on these fixations, and even with the existence of guardrails, workers should be wearing their fall arrest systems.

4.1.2.12 Fire

There are multiple sources of fire hazards that were identified on the visited sites. One of the primary sources is the existence of a fuel station on-site to eliminate the risks of fuel shortage. Therefore, the station should always be equipped with a fire truck and all needed fire extinguishing equipment.

When it comes to working in the main building, another main hazard emerges from the limited accessibility of the firefighting equipment; thereby, exacerbating the risks of fire accidents in terms of loss of lives, cost, and time. Therefore, a temporary fire fighting hose cabinet should be installed on each floor. Another hazard emerges from the dependency on water from main water systems which, in some poor countries, might not be a stable or reliable source to rely on. Therefore, for superior safety management, the water pipes of the hoses should be connected to a temporary water storage tank that is primarily installed to ensure the availability of the needed supply of water during fire emergencies.
Besides, temporary fire extinguishers, should also be installed. Accordingly, portable fire extinguishing bottles should be added to each floor along with their usage instructions. However, the main hazard relates to the lack of enough extinguishers to cover the whole area. In fact, the number of extinguishers depends on the area of the floor, the nature of work being conducted, and the floor’s height from ground level. Therefore, the aforementioned elements should be thoroughly considered to determine the right number of extinguishers to be added to each floor. In the same vein, the lack of proper inspection of the temporary fighting systems installed on-site increases the risk of their failure to properly function when needed. Therefore, while conducting safety inspections, each extinguisher should be inspected for the amount of gas in it.

4.1.2.2.13 Electrical hazards

Most of the electrical hazards that were witnessed were a result of open wirings and loose wire connections, which increased the risks of electrocution. Therefore, all temporary electrical cables should be secured to the ground using electrical tapes. The risks are further magnified with the existence of a conducting material. To illustrate, to illuminate the staircases during construction, electrical wirings are normally constructed. In many cases, these wires are placed near to the steel guardrails of the staircase; thereby, leading to electrocution. Therefore, it should be ensured that these connections are made at levels that are high enough to not touch any conductive material.

In addition, during the finishing phase, most of the permanent cables/electricity sockets were being constructed. Accordingly, electrocution and fire hazards emerge when employees tend to use such electricity sources for heavy-duty equipment rather than having a new temporary electricity source. Other hazards are related to the workers’ unsafe working behaviors of leaving tools and equipment connected to electricity sources; thereby, increasing electrocution risks.

4.1.2.2.14 Weather conditions

The most common forms of threats due to weather conditions are imposed by the elevated heat temperatures during the summer months. This hazard is only manifested in open floors, floors that are yet under construction, as workers are directly exposed to the sun without shades. This causes fatigue, dizziness, and loss of balance and control. Therefore, safety officers ensure the constant existence of water dispensers.
4.1.2.15 Mostly encountered unsafe working behaviors

As identified by the safety officers on site, Egyptian construction workers are often characterized by their impassivity and indifference toward potential hazards. Thus, the most frequently observed behavior is not wearing the safety PPEs during work. To illustrate, during the visits, multiple workers working on the platform of the slipping form were not wearing their fall protection systems (shown in Figures 26 and 27).

A few of the workers were detected wearing their fall protection system; yet, it was unanchored to the guardrail. A few workers were detected doing welding jobs without gloves or face shields. As seen in figure 26. Also, a few rebar men were laying the rebars of the columns without wearing their gloves. Ironically, the stubbornness of workers in sticking to unsafe working behaviors even increases with any form of action taken against their unsafe attitudes including penalties and warnings. Besides, they are also characterized by their laziness and tendency to consider the shortest rather than the safest routes/ courses of action. Accordingly, they often tend to walk outside the designated pedestrian routes, use ladders instead of scaffolds, and use unsafe tools to accomplish the jobs at hand.

![Figure 26: Unsafe working behaviors detected on-site.](image)

a. Workers working on column rebar activity without gloves.

b. Worker not using the access ladder of the scaffold and not wearing his harness.

Similarly, another unsafe working behavior that is frequently observed in construction sites is resting/sitting/leaning on guardrails, as seen in figure 27. To prevent this phenomenon, the safety
team of one of the visited sites had to install observation cameras to promptly notify safety officers of any unsafe working behavior detected by the observation team. Another widely encountered misbehavior was related to construction workers extending their bodies outside of the building’s edge to call the hoist operator or to contact a colleague.

![Example images of unsafe working behaviors](image)

a. Workers working without fall protection systems during the pouring of the slab.

b. Workers resting on the formwork.

c. Construction workers resting on guardrails.

Figure 27: Examples of unsafe working behaviors encountered on site.

Also, construction workers tend to leave their electrical equipment connected to power sources even when they are away/ not using them. This is extremely dangerous as it could accidentally be operated/turned on leading to severe injuries. To demonstrate, a worker had led the marble-cutting tool plugged into the electricity cable while he was on his lunch break. This could lead to the amputation of different accidents if the equipment was accidentally turned on. Leaving unattended tools and equipment around the site was another misbehavior that widely occurs in construction sites. To illustrate, during the tour, it was evident that one of the painters had left his painting brush over the fire hose cabinet. This was done to prevent it from getting unclean. However, this is associated with several risks pertaining to falling objects.

In the same vein, smoking outside the designated smoking areas is also amongst the most encountered unsafe working behavior on-site; despite banning smoking, workers still smoke in unsafe areas leading to several fire instances. Furthermore, Egyptian construction workers often
breach the site laws by eating/drinking on site. This is extremely dangerous as the food/drinks can easily get contaminated by toxic materials such as asbestos, cement, paint dust, etc. Table 7 presents a summary of the identified hazards from the site visits.

### 4.1.2.3 Summary of the identified hazards

The following table summarizes all the hazards that were identified from the conducted site visits.

Table 7: High-rise construction hazards identified from site visits.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building's Perimeters</td>
<td>Lack of access restriction to building's perimeters</td>
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<tr>
<td></td>
<td>Having safety nets that do not fully enclose the building, even the corners</td>
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<tr>
<td></td>
<td>Cleaning process of the safety nets</td>
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<td></td>
<td>Stuck waste in safety nets</td>
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<tr>
<td>Accessibility &amp; Evacuation</td>
<td>The use of wooden ramps as access ladders</td>
</tr>
<tr>
<td></td>
<td>Lack of a proper evacuation mechanism</td>
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<tr>
<td></td>
<td>The sole dependence on internal stairs</td>
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<td></td>
<td>Blockage of main access routes by temporary workshops</td>
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<tr>
<td></td>
<td>Congestion of the work site during the erection of the slab's formwork</td>
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<tr>
<td></td>
<td>Inappropriate storage of materials near main egress routes</td>
</tr>
<tr>
<td></td>
<td>Lack of firefighting equipment in main egress routes</td>
</tr>
<tr>
<td>Housekeeping</td>
<td>Lack of access restriction to trash landing area</td>
</tr>
<tr>
<td></td>
<td>Blockage of trash chutes due to jammed waste</td>
</tr>
<tr>
<td></td>
<td>Welding processes to the pipes of the trash chutes conducted over the trash landing area</td>
</tr>
<tr>
<td></td>
<td>Existence of waste on/near exterior edges of the building</td>
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<tr>
<td>Slab edges &amp; openings</td>
<td>Erection of guardrails</td>
</tr>
<tr>
<td></td>
<td>Lack of guardrails</td>
</tr>
<tr>
<td></td>
<td>Missing components of guardrails (handrails or mid-rails)</td>
</tr>
<tr>
<td></td>
<td>Lack of fall protection systems</td>
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<tr>
<td></td>
<td>The use of suspended scaffolds</td>
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<tr>
<td></td>
<td>Slab pre-stressing</td>
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<tr>
<td></td>
<td>Lack of safety nets</td>
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<tr>
<td></td>
<td>Lack of suitable covers to slab openings</td>
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<tr>
<td></td>
<td>Inevitable openings while installing formwork of the slab</td>
</tr>
<tr>
<td>Hoists</td>
<td>Lack of inspection to the mechanical components of the hoist</td>
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<tr>
<td></td>
<td>Lack of inspection in the electrical components of the hoist</td>
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<tr>
<td></td>
<td>Lack of hoist operators</td>
</tr>
<tr>
<td>Category</td>
<td>Issues</td>
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<tr>
<td>-----------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Scaffolds</td>
<td>Lack of main components</td>
</tr>
<tr>
<td></td>
<td>Defaults in main components</td>
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<tr>
<td></td>
<td>Lack of safety signs</td>
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<tr>
<td></td>
<td>Lack of fall protection systems</td>
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<tr>
<td></td>
<td>The existence of spacings between the scaffold and the working area</td>
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<td></td>
<td>Having unattended equipment of the working platform</td>
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<tr>
<td></td>
<td>Unsafe working behaviors</td>
</tr>
<tr>
<td>Tower Cranes</td>
<td>Lack of guiding coordinator</td>
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<td></td>
<td>Extreme weather conditions</td>
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<tr>
<td>Slipping/jumping</td>
<td>Lack of inspection to mechanical components of the formwork</td>
</tr>
<tr>
<td>Formwork</td>
<td>Lack of inspection to electrical components of the formwork</td>
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<tr>
<td></td>
<td>Missing components in the working platform</td>
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<tr>
<td></td>
<td>Lack of overhead protection/safety nets underneath</td>
</tr>
<tr>
<td></td>
<td>Unattended tools &amp; equipment</td>
</tr>
<tr>
<td>Cradles/gondolas</td>
<td>Lack of inspection to the mechanical components of the cradle</td>
</tr>
<tr>
<td></td>
<td>Lack of inspection to the electrical components of the cradle</td>
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<td></td>
<td>Existence of protruding obstructions</td>
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<tr>
<td></td>
<td>Unsafe working behaviors</td>
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<tr>
<td></td>
<td>Extreme weather conditions</td>
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<tr>
<td>Vehicles &amp; equipment</td>
<td>Lack of competent operators</td>
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<td></td>
<td>Lack of proper inspection and maintenance</td>
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<td></td>
<td>Lack of functional inspection prior to operations</td>
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<td></td>
<td>Lack of emergency safety equipment</td>
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<tr>
<td>Windscreens</td>
<td>Fixing windscreens to the slab</td>
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<tr>
<td></td>
<td>Lack of fall protection systems while working on/near windscreens</td>
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<tr>
<td>Fire</td>
<td>The existence of fuel station on site</td>
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<td></td>
<td>The limited accessibility of firefighting equipment</td>
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<td></td>
<td>Lack of temporary firefighting systems on-site</td>
</tr>
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<td></td>
<td>Lack of temporary water storage tanks</td>
</tr>
<tr>
<td></td>
<td>Lack of regular inspection to the temporary firefighting systems</td>
</tr>
<tr>
<td>Electric Hazards</td>
<td>Existence of open-wire connections</td>
</tr>
<tr>
<td></td>
<td>Existence of a conducting material near open-wire connections</td>
</tr>
</tbody>
</table>
The use of heavy-duty equipment on sockets not designed to handle such loads
Leaving tools and equipment connected to electricity sources

<table>
<thead>
<tr>
<th>Weather conditions</th>
<th>Elevated heat temperatures</th>
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<tbody>
<tr>
<td></td>
<td>High wind speeds</td>
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<table>
<thead>
<tr>
<th>Unsafe working behaviors</th>
<th>Not wearing safety PPEs</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Resting/sitting/leaning on guardrails.</td>
</tr>
<tr>
<td></td>
<td>Workers extending their bodies outside of the building’s edge</td>
</tr>
<tr>
<td></td>
<td>Workers leaving their electrical equipment connected to power sources</td>
</tr>
<tr>
<td></td>
<td>Leaving unattended tools and equipment</td>
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<tr>
<td></td>
<td>Smoking</td>
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<tr>
<td></td>
<td>Eating/drinking on-site</td>
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</tbody>
</table>

4.2 The Developed Conceptual Framework for the Conduction of VR-based Safety Training Programs Based on Learning Theories

The following paragraphs present the results of the design phase of the conceptual framework starting with the identified targeted learning outcomes to the developed framework that would act as a basis for the development of the comprehensive training program.

4.2.1 Targeted Learning Outcomes

The outcomes identified in this research are relatively general outcomes and competencies that should be possessed by all workers on site, albeit to different extents. Therefore, the chosen outcomes are mainly directed toward understanding risk, system thinking, analytical, and decision-making skills. Therefore, trainees should be capable of anticipating, recognizing, evaluating, and controlling hazardous conditions and practices affecting people, property, and the environment. In addition, training programs should enable the trainees to work individually or on a team to critically analyze, interpret, and provide leadership to address and manage problems in occupational safety and health.

As stated by Tappura & Jääskeläinen, (2020), effective safety training programs should be capable of enhancing safety knowledge, safety attitudes, beliefs, motivation, safety behaviors, and safety performance. It is clear that the aforementioned outcomes are purely directed toward safety
knowledge, attitudes, and performance; however, besides safety awareness and knowledge, it has been acknowledged that workers have a vital role to play in maintaining safety on site. This is done through the enhancement of their safety perception which in return enables them to positively change job-related behaviors (Cavazza & Serpe, 2010).

Accordingly, safety training should not merely target to enhance workers' knowledge and competencies to maintain site safety but also, they should target workers’ cognitive levels and psychological orientations to introduce behavioral changes (Cavazza & Serpe, 2010). In fact, Cavazza & Serpe, (2010) found that training programs, if designed effectively, could introduce positive attitudes through changes in beliefs and emotions towards a better safety climate. Based on these factors, the targeted competencies/outcomes are as follows:

1. Enhanced safety culture motivation and perception
2. Enhanced hazard recognition & identification
3. Enhance identification of hazard initiators & consequences of hazards.
4. Improved risk assessment skills (Likelihood & Impact)
5. Enhanced awareness of preventative & mitigative measures
6. Enhanced selection of the right course of action.

### 4.2.2 Design of the Conceptual Framework for Conducting VR-based Safety Training

The following paragraph discuss the resulting design of the training framework along with the chosen learning theories along with the factors considered and would act as a basis for the design of the safety training program.

#### 4.2.2.1 Chosen Learning Theories

Based on the analysis of the focus group discussion, a general consensus on the elimination of two main theories, humanism, and cognitivism, was observed. To start with, humanism was eliminated for being a loosely structured theory that conforms to the findings from the literature (Alauddin, 2020). The experts asserted that following this theory would necessitate the development of different scenarios for each learning topic/module to satisfy the learning needs of different individuals, which is not practical in terms of the use of VR technology. Furthermore, there was a consensus that this theory is centered on a western culture which assumes that individuals are
intrinsically good and will naturally choose to follow the safety procedures in construction sites. However, this might not be the case in the cultures of undeveloped countries where construction workers need to be trained on how to responsibly act and react in the extremely hazardous conditions of construction sites.

Similarly, all experts agreed on the elimination of the cognitivist theory for the following reasons. First and foremost, it was considered to be based on deep clinical foundations that necessitate the understanding of several complex brain processes. This conforms to the findings from the literature that critiqued this theory for its dependency on complex experimental processes (Prestine & LeGrand, 1991); thus, it was agreed that this would be beyond the scope of the aims and objectives of this research. Furthermore, there was a general consensus from experts that this theory ignores crucial influential factors, specifically in undeveloped countries, such as the culture, social class, and upbringing of individuals. It was, therefore, ascertained that these factors play a crucial role in determining the learning potential and observed behaviors of construction workers who typically tend to be from lower social classes.

Moving on to socialism, the experts were divided equally as to whether this theory should be regarded as a basis for the development of the VR-based safety training program. The experts who were in favor of this theory based their arguments on the naturally occurring phenomenon of imitation of misbehaviors in social groups. Their perspective is supported by the findings of Li et al., (2021) which reveal that construction workers are often confronted with severe conformity pressures; thereby, causing them to easily conform to the unsafe behaviors of the group. On the other hand, the opposing experts viewed this as insufficient for the inclusion of the theory. The experts perceived this view as over-generalization which would lead to the disregard of other factors such as emotions, motivations, and personality types.

Accordingly, the researchers opted to eliminate this theory based on contentment with the views of the opposing experts. This is further supported by the following reasons. Firstly, as stated in the literature, this theory focuses on what happens in the surrounding environment rather than what the learner actually does or learns. Considering the VR environment, it would be impractical to demand trainees to imitate positive behaviors to learn (Alauddin, 2020). The barriers to this include
but are not limited to the development time of the model, technical difficulties, and the limitations of the technology itself where not all behaviors/actions could be easily replicated and imitated in the virtual environment.

Finally, the experts were left with two main theories which are behaviorism and constructivism. All of the experts were in favor of the behaviorism theory for the following reasons. Firstly, the behavioristic approach is based on the natural objectives of the provision of training programs which are primarily concerned with competence and skill development. This is further strengthened by the main objectives of this research which aims to introduce behavioral changes to enhance the safety of construction sites.

Secondly, the theory provides a solid foundation that would act as a guide for the development of the VR safety training program. This is going to be achieved by exposing the trainees to stimuli in the virtual environment and designing such stimuli to elicit desired responses; thereby, inducing behavioral changes in the desired direction towards enhancing safety performance. Thirdly, the theory allows for the development of new skills and competencies based on both desired and undesired stimuli which would bridge the existing gaps in existing traditional safety programs. Finally, the theory provides a strong basis for observing, gathering, and analyzing behavioral changes based on concrete justifications.

Likewise, all of the experts showed their support for the constructivism theory based on the following reasons. The main rationale is related to the nature of the VR technology itself which meets and supports all of the requirements of the theory. This includes the provision of a personal learning experience where the trainees actively participate to solve real-life problems in an immersive and interactive environment. This conforms to the findings from the literature which indicate that learning occurs through the integration of real-life current and past experiences (Bass, 2012). Also, the experts were in favor of this theory as it provides the basis for the shift from traditional learning and assessment techniques. Thus, it would complement the main drivers for the wide-scale adoption of VR technologies in modern-day education systems. Accordingly, the following research adopts a behavioristic/constructivist approach to the development of the conceptual framework for the design of VR-based safety training programs.
4.2.2.2 Factors Considered

Each of the chosen learning theory has a wide range of factors that should be considered while training adults; however, given the limitations of the VR technology, it would be infeasible to consider all the factors. Therefore, the following paragraphs presents the factors considered from each theory along with the rationale for considering them.

4.2.2.2.1 Behaviorism

The factors to be considered in relation to this theory are primarily associated with the stimulus provided to the trainees to elicit the desired behaviors. As stated by Baum, (2017), a stimulating environment could be in the form of reinforcements/rewards or punishments. Each is further divided into two subcategories indicating whether they are positive or negative reinforcements/punishments. Positive reinforcement entails adding reinforcers to increase the likelihood of the adoption and practicing of a certain behavior; whereas negative reinforcement entails the removal of undesirable stimulus to increase the likelihood of a behavior. On the other hand, positive punishment entails the addition of undesirable stimulus to decrease the likelihood of the adoption and practicing of a certain behavior; whereas negative punishment entails the removal of desirable stimulus to decrease the likelihood of a behavior (Baum, 2017).

From the focus group discussion, the need to include both reinforcements and punishments in each learning topic/module was ascertained by the majority of the experts. This was chosen based on a general belief that this would further reinforce and strengthen the learning process of trainees and maximize their learning outcomes. While several research papers have advocated against the inclusion of punishments in the learning process claiming that the inclusion of reinforcements is associated with better learning outcomes (Dad et al., 2010), the experts asserted that this does not apply to the virtual environment. This is since no actual harm would be caused to the trainees as a result of the punishment provided; rather, the experts believed that this is a crucial factor to demonstrate to the trainees the intensity and seriousness of construction accidents along with the severe consequences that could occur as a result. In relation to whether reinforcement and punishments should be positive or negative, again the majority believed that this should be left to the judgment of the developer of the program. This primarily emerged from the wide scope of hazards and accidents that could be covered in construction sites. Thus, it was concluded that
developers are more capable of determining the reinforcement/punishment types that would better serve the scenario at hand.

4.2.2.2 Constructivism

With regards to constructivism, the following factors emerged: real-life experiences, interactivity, engagement, problem-oriented training, and reflections. To start with, there was a huge emphasis on the provision of a training environment that resembles real-life experiences to the trainees. This was primarily derived from the urge to maximize the trainees’ sense of immersion and inclusion in the virtual environment. As ascertained by the experts, this would need consideration of the technical aspects of the VR model. Whereas, the planning of the scenarios along with the associated reinforcements/punishments used are the means through which interactivity and engagement should be considered. These findings are supported by Fromm et al., (2021) who stated that concrete experiences require realistic surroundings, character movement, basic interaction with objects, users, and intelligent agents, and realistic scenarios for the design of an effective VR experience.

Secondly, the experts agreed that the problem-oriented approach should be adopted in this design of the VR-based safety training program. This is done primarily to ensure the mental engagement of the trainees, besides their physical engagement and immersion in the model. The experts asserted that the use of a problem-oriented approach to the introduction of the learning modules in VR training would stimulate critical thinking and critical reflections; thereby, enhancing the problem-solving capabilities of the trainees. This is a vital skill in construction sites as hazards/accidents often require prompt and responsible reactions to be solved while mitigating all potential consequences (Li et al., 2019).

Finally, the majority of experts indicated the significance of reflections on the learning process. They confirmed that the trainees’ active reflections on their actions would allow them to reconstruct knowledge through an enhanced knowledge assimilation process. As stated by Hilgard, (1964), the cognitive feedback of learners where learners reflect on their decisions based on the consequences is crucial for adult learning. Also, immediate feedback that clearly reveals the weaknesses in their thought processes should be provided; this should also be accompanied by the
provision of models of superior performance which would aid in introducing a shift in the trainees' perspectives. These findings are supported by Kolb's learning cycle that emphasizes action-reflection cycles for constructing new meanings and logical conclusions which would act as the basis for the acquisition of new knowledge (Healey & Jenkins, 2000).

4.2.2.2.3 Adult learning principles

From the adult learning principles, the experts agreed on the inclusion of the following factors. Firstly, it is crucial to increase the learners’ need to acquire knowledge. This would be achieved by showing them the benefits of learning and the consequences of not learning. This conforms to the findings of Lindeman, (1926) who state that adult learners are motivated to learn as long as they perceive the needs and interests that the learning will satisfy. Secondly, the experts agreed that the training model should integrate external and internal motivators that would further drive the learners’ readiness to learn. This could also be accompanied by “goal-setting” practices where trainees are allowed to set goals that would be achieved upon their effective grasp and understanding of the learning content.

As stated by Taylor & Cranton, (2013), the process of goal setting by learners is a significant motivational tool for learning and personal development. This factor is supported by Knowles et al., (2005) who stated that external and internal motivations to learning significantly influence the learning process. Thirdly, the experts agreed that the learners’ frustrations, as a result of failure/potential punishments, should be accommodated. This is done to prevent a drop in their enthusiasm or excitement levels as they encounter failures throughout the learning process. This emerges from the fact that adults have lower learning potential and tolerance as compared to infants. Finally, the experts agreed that the trainees should be allowed to implement the newly learned knowledge in new experiences. Figure 28 shows a summary of the factors considered from the different learning theories.
4.2.2.3 Conceptual Framework

The developed conceptual framework is presented in figure 29 and is described using a fictitious example with reference to a fire hazard that is to be explained under a “safety of workplaces” module for the sake of illustration.
Firstly, before starting a new module/learning topic (Safety of workplaces), the learners’ need to learn should be established. This is done by showing trainees the benefits of learning this module and the potential consequences of not learning. To illustrate, the benefits shown could include saving construction time and costs; whereas, the consequences of not learning could include life-threatening accidents that would jeopardize the trainees’ lives and health. This need to learn is then...
reinforced by the provision of both external and internal motivators that would reveal to the trainees the expected gains that could be achieved upon the effective learning of the content of the module. These include getting back home safely to their families and ensuring that their colleagues are safe until the end of the project. Subsequently, the trainees are allowed to set goals to be achieved throughout the learning module. These could include minimizing their punishments and maximizing their rewards during the training. These steps are directly linked to outcome #1 which is enhancing the safety perception and motivation of the trainees.

Eventually, the learning process starts with the confrontation of the main problem to which the trainees are required to inspect the site of the accident. Based on the scenario, the trainees will be allowed to react and identify the potential sources of hazards. This is directly linked to learning outcomes #2 and #3 which are related to the trainees’ hazard and hazard initiator identification skills. If the trainees did not choose all the potential causes of the accidents correctly, they will be faced with punishment. Examples of such punishments include protruding fire, emerging black smoke, and workers suffocating and losing consciousness. This step is directly linked to outcomes #4 and outcome #5 which are related to the trainees’ risk assessment skills and the awareness of the consequences of hazards, along with their impacts and severity. The trainees are then provided a voice-over explaining how tricky the scenario was to accommodate their frustrations. They are then given some time to reflect on their choices before giving them feedback on the errors conducted.

Subsequently, the trainees are redirected to the scene and are allowed to re-choose the answers based on the feedback provided. Upon choosing the right answers, a reward/reinforcement is presented. This could be distinguishing the fire without causing any harm to the workers. Then, a voice-over presenting superior performance and all the safety measures that should be taken in similar circumstances is presented. This step is directly linked to outcome #6 which relates to the awareness of preventive and mitigative measures. In the following modules, the trainees will be presented with small quizzes where they can actively implement and practice their newly gained knowledge. This step is related to outcome #7 which examines the trainees’ ability in taking the right course of action in the future.
4.3 Pilot Study Validation Results

As previously mentioned, the validation of the developed training was conducted by comparing the mean scores of the four groups according to the aforementioned methodology; the following paragraphs present the results along with a detailed analysis and interpretation of such results.

4.3.1 Scenarios Designed for the Pilot Study

As mentioned earlier, the training was conducted using four scenarios that were developed for the pilot study. The scenarios are based on the inspection and operation of construction equipment and lifting appliances. Exact details of the design of the scenarios and how they were developed are provided in the section discussing the design of the training scenarios. The rationale for choosing construction equipment is to ensure the uniqueness of the modules that are being taught to the students. This was of great benefit to the accuracy and credibility of the obtained results as none of the research participants had prior knowledge of the safety procedures that should be followed while operating the construction equipment of the four modules. The scenarios are related to operating three pieces of equipment namely, construction hoist/elevator, construction cradles, and climbing/slipping formwork. As soon as the trainees wear their VR head-mounted display, a menu showing the four scenarios is presented to them. They were then requested to select the scenarios in the order that they preferred.

In total, the four scenarios included 21 hazards. The following paragraphs illustrate the sequence of these scenarios as viewed by groups 1 and 2. It is worth noting that group 3 was exposed to the accidents, whereas, group 4 was exposed to the necessary safety measures according to the aforementioned methodology.

4.3.1.1 Scenario 1-Climbing Formwork

Scenario 1 entails working with climbing formworks, a special type of formwork for vertical concrete structures that rises with the building process. It is an effective solution for buildings that are very repetitive in form. It is mostly used in the construction of towers, skyscrapers, and other tall vertical structures. Climbing formwork saves time and cost as they do not require constant erection and dismantling as compared to the traditional formwork; yet, their erection, inspection,
operation, and maintenance are vital to ensure the safety of construction workers in high-rise construction.

The scenario starts with the trainee being required to inspect the lifting operation of the self-climbing formwork while construction workers are working on its platform. Meanwhile, the trainees listen to an introductory voice-over that gives them a brief of the climbing formwork along with its benefits and usage. The trainees are then required to tour around the climbing formwork and identify the potential sources of hazards in relation to the workers’ operations on/near the climbing formwork.

The scenario included four main hazards namely (also shown in Figure 30),

1. Unsafe access to the working platform using regular stairs instead of scaffold stairs.
2. Workers having direct access to the area underneath the working platform without safety nets/overhead covers; thereby, exposing them to risks from falling objects.
3. Workers not wearing their fall protection system while working on the platform.
4. Workers leaving their tools, materials, and equipment unattended on the working platform.

a) Unsafe access to the climbing formwork’s working platform.  
b) Unattended tools, materials, and equipment left on the working platform.
c) Workers having access to the area underneath the platform without safety nets/cover heads.

d) Workers working on the platform without their fall protection system.

Figure 30: The types of hazards that existed in the climbing formwork scenario.

They then select the identified hazards from a list of hazards that appears on their screen; if the trainees failed to correctly identify all existing hazards, they were exposed to an accident where the virtual worker, who was standing underneath the working platform, was struck by falling equipment from the working platform leading him to lose consciousness and fall on the ground.
a) The list of hazards from which the trainees were to choose the existing hazards in the scenario.

b) An accident of a virtual worker being hit by a falling object as a result of the trainees’ failure to accurately identify all hazards.

Figure 31: The MCQ menu and the accident that appears to trainees upon their failure to accurately identify all the hazards that existed in the climbing formwork scenario.

The trainees then heard a voice-over explaining the hazards that exist in the scenario. They were then allowed to re-examine the working area and identify/select the hazards that existed. Upon their right responses, they were exposed to a superior performance practice that ensures the safety of all workers while working with climbing formwork. These include the installation of safety nets/over-head covers and scaffold stairs to ensure safe access to the working platform, the usage of safety signals that warn workers about the risks of falling objects, maintaining housekeeping on the working platform, and mandating all workers to wear their fall protection system while working from a height on the climbing formwork’s platform, as seen in figure 32. The trainees also heard another voice-over explaining why these safety measures are important on-site.
a) Installed overheads and safety signals to ensure safety while working with climbing formwork.

b) Installed scaffold ladders to provide workers with safe access means to the climbing formwork’s platform.

Figure 32: Safety practices that should be maintained on-site while working with self-climbing formworks.

4.3.1.2 Scenario 2-Construction Hoist

Scenario 2 entails working with construction hoists/elevators. They are equipment used to vertically lift people and material in a construction site, especially in high-rise buildings to facilitate access and egress. However, they are still associated with multiple hazards. This is evidenced by the fact that incidents involving construction hoists caused 93 deaths among construction workers between 1992 and 2003 (Rajendran & Clarke, 2011). Despite the number of fatalities associated with hoist operations and the similarity of hoists to tower cranes in terms of tall mast sections, building tie-ins, and public exposure, construction hoist installation and operation have received little attention (Rajendran & Clarke, 2011), which is why they are included in this training program.

The scenario starts with the trainees being asked to wait alongside other workers to take the hoist to exit the building. It was the workers’ break time and many were gathered around the hoist’s landing area to exit the building. Due to irregularities in the shape of the building, the hoist had to
be extended outside the building’s edge. A walking platform that connects the slab and the hoist was installed. Since the elevator does not have a calling button, a few of the workers were extending their bodies outside of the building’s edge to call the hoist. Subsequently, the hoist came up to pick the workers. Meanwhile, an introductory voice-over explaining the usage and benefits of construction hoists to high-rise construction was played. The trainees were then required to inspect the working area and identify the potential sources of hazards in relation to the hoist’s operations, as seen in figure 33.

The scenario included six main hazards namely,

1. The lack of a hoist operator.
2. Lack of access gates which prevents the workers from walking into the platform before the landing of the hoist.
3. The lack of guardrails alongside the walking/crossing platform.
4. Unsafe working behaviors as the workers were pushing each other and extending their bodies outside the platform to call the hoist.
5. Using the hoist to transport inappropriate materials that protruded outside the hoist’s cage.
6. The inappropriate landing of the hoist as it landed on a level that is higher than that of the slab/walking platform.

a) Unsafe Working behavior of a worker extending his body outside the walking platform.

b) Lack of hoist operator
c) Transporting protruding items.

d) Lack of guardrails on the walking platform.

e) Lack of access gates to the hoist’s walking platform.

f) Inappropriate landing of the hoist.

Figure 33: Hazards that existed in the hoist operation scenario.

The trainees were asked to identify the hazards in the scenario and choose them; upon their failure to correctly identify all existing hazards, they encountered two accidents. The first entailed a virtual worker who fell down as a result of the unsafe working behavior of another virtual worker who pushed him and due to the lack of guardrails on the working platform. The second accident is a
tripping accident of a virtual worker as a result of the unlevled landing of the hoist. Figure 34 shows the accidents that the trainees experience.

Figure 34: The two accidents encountered in the hoist’s operation scenario.

The trainees then heard a voice-over explaining the hazards that exist in the scenario. They were then allowed to re-examine the working area and identify/select the hazards that existed. Upon their right responses, they were exposed to a superior performance practice that ensures the safety
of all workers while operating construction hoists. These include the installation of both access gates and guardrails, having an experienced hoist operator, maintaining a safety culture and preventing unsafe working behaviors, and prohibiting the transport of inappropriate materials on construction hoists. Figure 35 shows the safety measures that should be taken while operating construction hoists. The trainees also heard another voice-over explaining why these safety measures are important on-site.

a) Having access gates that prevent workers from accessing the walking platform.

b) Maintaining a safety culture and preventing reckless behavior on site.
c) Installing guardrails and ensuring that the hoist’s landing is leveled with the walking platform.

d) Having an experienced and certified hoist operator.

Figure 35: Safety practices that should be maintained on-site while operating/using construction hoists.

4.3.1.3 Scenario 3-Cradle Inspection

The construction cradle machine is a special aerial work equipment that lifts operators, tools, and materials to a designated position for various installation and maintenance operations. They are being widely used for the installation of billboards, windows, window cleaning, external renovation, painting and plastering jobs, decoration of bridges, building facades, chimneys, silos, and other tall structures. However, it is still associated with multiple fatalities and injuries, which is why it was considered in this training.

The scenario starts with the trainee being asked to inspect the cradle before the start of a cladding activity to the facade of the building. The cradle has one operator who is about to ascend to conduct the cladding installation activity. Meanwhile, a few workers were doing their housekeeping job alongside the cradle. As soon as they entered the scenario, the trainees heard a brief introduction on the construction cradle/gondola along with its benefits to high-rise construction. Figure 36 shows the trainees’ view as they entered the scenario.
The scenario included seven main hazards namely,

1. The cradle was operated by a single operator.
2. Signs of damage and rust to the cradle.
3. Lack of functional inspection prior to operating the cradle.
4. Inappropriate access to the cradle’s platform as one worker who was standing on the second floor jumped into it while it was ascending.
5. Using the cradle to transport materials.
7. Lack of access restriction to the area underneath the cradle.

a) Workers working underneath the cradle’s operating area.  
b) Worker jumping into the cradle’s platform as it was ascending.
c) Using the cradle to transport materials to the upper storeys of the building/ cradle is operated by a single operator.

d) Using a rusted and worn cradle.

Figure 36: Hazards that existed in the cradle’s inspection scenario.

The trainees were asked to identify the hazards in the scenario and choose them; upon their failure to correctly identify all existing hazards, they encountered an accident that entailed the failure of the cradle as soon as the virtual worker jumped into it. Thus, the cradle fell to the ground and killed the virtual workers who were working underneath. Figure 37 shows the accidents encountered by the trainees in the cradle’s inspection scenario.
a) Failure of the cradle's rope as the virtual worker jumped into it.

b) Cradle failure led to the death of the workers who were working underneath.

Figure 37: Accidents encountered in the cradle’s inspection scenario.

The trainees then heard a voice-over explaining the hazards that exist in the scenario. They were then allowed to re-examine the working area and identify/select the hazards that existed. Upon their right responses, they were exposed to a superior performance practice that ensures the safety of all workers while operating construction cradles/gondolas. These include preventing access to the area underneath the cradle’s working area, installing safety nets, conducting functional inspections, and ensuring that two operators are operating the equipment. Figure 38 shows the safety measures that were presented to the trainees during the training.
a) Access to the area underneath the cradle is restricted.

b) Inspector writing a safety report after inspecting the cradle.

c) Cradle is operated by two operators.

d) Safety signs and safety nets are installed.

Figure 38: Safety practices that should be maintained on-site prior to operating/using construction cradles.

4.3.1.4 Scenario 4-Cradle’s operations

Scenario 4 is a continuation of scenario 3 and it covered the safety hazards in relation to operating the construction cradle. The trainees acted as the second operators and were asked to ascend with the main operator to oversee the cladding installation activity. Accordingly, the trainees were...
placed inside the equipment and climbed up the building as the equipment ascended. Figure 39 shows the views of the trainees as they ascended inside the cradle.

The trainees were then asked to identify the hazards that existed in the scenario. Four main hazards existed namely,

1. The existence of protruding items from the building’s edge.
2. Falling objects from simultaneous activities that were being conducted in upper storeys.
3. The lack of a fall protection system.
4. The use of unsafe equipment inside the cradle.

a) Protruding items/materials.  

b) Falling objects.
c) Operator not wearing his fall arrest belt.  

d) The use of unsafe equipment (ladder) inside the cradle.

Figure 39: Hazards that existed in the cradle’s operation scenario.

The trainees were asked to identify the hazards in the scenario and choose them; upon their failure to correctly identify all existing hazards, they encountered an accident that entailed the failure of the cradle as soon as the protruding item got stuck in the cradle. As it kept ascending, the protruding item prevented its movement; thereby, causing the rope to fail. The trainees experienced the fall as the cradle fell into the ground. Figure 40 shows the accident encountered by the trainees in the cradle’s operation scenario.
The trainees then heard a voice-over explaining the hazards that exist in the scenario. They were then allowed to re-examine the working area and identify/select the hazards that existed. Upon their right responses, they were exposed to a superior performance practice that ensures the safety
of all workers while operating construction cradles/gondolas. These include the removal of any protruding items prior to operations, having safety nets/overheads where risks of falling objects exist, installing safety signs, wearing fall protection belts, and the removal of all unsafe equipment from the cradle. Figure 41 shows the safety measures that were implemented and presented to the trainees.

![Safety measures](image1.jpg)

Figure 41: Safety practices that should be maintained on-site while operating/using construction cradles.

4.3.2 Pilot Study- Post-training Test

To assess the learning outcomes of the trainees, a questionnaire was sent to them after conducting the VR training. In their evaluation of the VR-based training outcomes, Dhalmahapatra et al., (2021) assessed the improvement in trainees’ learning through the assessment of their identification of the accident path elements post-training. This included the assessment of their hazard identification capabilities, the initiating events of the hazards, accident scenarios, and consequences. Therefore, the post-training test assessed the student’s ability to identify the hazards along with the associated potential accidents, the probability and impact of each risk, and the applicable safety measures that should be maintained on-site to mitigate these risks.

1. Hazard identification score
This score aims to assess the number of hazards that would be accurately identified by the trainees of the four different groups.

2. Accident-path score
This score aims to assess the trainees’ ability to accurately identify all accidents that might follow an existing hazard.

3. Probability Score
This score assesses the trainees’ ability to accurately evaluate the probability of occurrence of a risk that emerges from a hazard based on the qualitative assessment of high, medium, or low.

4. Impact Score
This score assesses the trainees’ ability to accurately evaluate the impact of a risk that emerges from a hazard based on the qualitative assessment of high, medium, or low.

5. Applicable preventative/mitigative safety measures score
This score aims to assess the trainees’ ability to accurately identify applicable hazard mitigation measures to eliminate the severity of the associated risks.

The questionnaire was a qualitative questionnaire, and the students were presented with 12 pictures including hazards that relate to climbing formworks, construction hoists, and construction cradles/gondolas. Figure 42 shows the pictures that were presented to the students in the questionnaire. In total, four pictures were presented in relation to each piece of equipment. Some of the pictures were sourced from the internet; whereas, the rest were manually developed and captured in Unity. The researcher resorted to developing a few of the scenarios to ensure that the trainees were asked about all the hazards that they were trained on in the training. This was the only viable option since the pictures found on the internet lacked the targeted hazards. Also, it was unpractical to go to real construction sites and try to introduce/resemble these hazards.
Figure 42: Pictures included in the post-training questionnaire.
To validate the results of the questionnaire, three safety experts were asked to identify the hazards in each picture, the potential accidents, the probability and impact of each risk, and the applicable safety measures that should be implemented to mitigate these risks. Subsequently, all the hazards that were identified by the three experts along with their respective accidents and safety measures were gathered and acted as a basis for grading the trainees’ responses.

4.3.1 Hazard Identification Score

The first analysis entailed the analysis of the hazard identification score for all four groups. The following table shows descriptive statistics of the obtained results including the mean and standard deviation values for all four groups. Table 8 presents a descriptive statistic of the hazard identification score.

Table 8: Descriptive statistics of the hazard identification score of the 4 groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Motivational Drivers</th>
<th>VR Training</th>
<th>Observations</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Yes</td>
<td>With accidents &amp; superior</td>
<td>20</td>
<td>24.0</td>
<td>5.7</td>
</tr>
<tr>
<td>Group 2</td>
<td>No</td>
<td>safety practices</td>
<td>20</td>
<td>17.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Group 3</td>
<td>No</td>
<td>With accidents</td>
<td>20</td>
<td>16.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Group 4</td>
<td>No</td>
<td>With superior safety practices</td>
<td>20</td>
<td>15.3</td>
<td>6.4</td>
</tr>
</tbody>
</table>

It is apparent that Group 1 has the highest mean score as compared to group 2, 3, and 4 who showed approximately similar mean values. When it comes to the scores’ range, it was apparent that group 3 has the lowest range, whereas, group 2 showed the highest range. Group 1 and 3 showed similar range values, as seen in figure 43. Thus, it could be concluded that group 2 has the highest variability in the scores obtained, whereas, group 3 was the most consistent in terms of the hazard identification score. This could also be evidenced from the standard deviations obtained where group 3 showed the lowest standard deviation while group 2 results were the highest in terms of the scores’ standard deviation.
4.3.1.1 Shapiro-Wilk Test

To start with, a normality test, using the Shapiro-Wilk test was conducted to ensure that the data is normally distributed; this is necessary to meet the prerequisites of conducting the ANOVA analysis. The results of the Shapiro-Wilk test confirmed the normality of the data, as seen in table 9. The null hypothesis is H0: The variable from which the sample was extracted follows a normal distribution. Whereas, the alternative hypothesis is Ha: The variable from which the sample was extracted does not follow a normal distribution. The significance level used is 5%. Since all the p-values obtained were greater than 0.05, the null hypothesis could not be rejected. Therefore, it could be stated that the hazard identification score of the four groups is normally distributed.

Table 9: Shapiro-Wilk test for “Hazard Identification Score”.

<table>
<thead>
<tr>
<th>Group</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.95</td>
<td>0.95</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
<td>0.32</td>
<td>0.32</td>
<td>0.53</td>
<td>0.42</td>
</tr>
<tr>
<td>Alpha (5%)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>
4.3.1.2 Levene’s F-Test

Subsequently, the F-test was conducted to ensure that all four groups have equal variances. The null hypothesis is H0: The variances are identical; whereas, the alternative hypothesis is Ha: At least one of the variances is different from another since the p-value obtained is greater than 0.05 as seen in table 10. Again, the significance level used is 5%. The results gave a p-value of 0.281 which is greater than the significance level; therefore, the null hypothesis could not be rejected. Accordingly, it was assumed that all groups have equal variances which allowed for the conduction of a normal one-way ANOVA analysis.

Table 10: Levene’s F-test to check the equality of variances between groups.

<table>
<thead>
<tr>
<th>Levene's test (Mean) / Two-tailed test:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F (Observed value)</td>
<td>1.300</td>
</tr>
<tr>
<td>F (Critical value)</td>
<td>2.72</td>
</tr>
<tr>
<td>DF1</td>
<td>3</td>
</tr>
<tr>
<td>DF2</td>
<td>76</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
<td>0.28</td>
</tr>
<tr>
<td>alpha</td>
<td>0.05</td>
</tr>
</tbody>
</table>

4.3.1.3 One-way ANOVA Analysis

Subsequently, a single-factor ANOVA analysis was conducted with a significance level of 5%. As seen in table 11, the p-value obtained was less than 0.05; therefore, there is sufficient evidence to reject the null hypothesis and conclude that there is a statistically significant difference between the means of the four groups. Hence, a Bonferroni post-hoc analysis was conducted to determine which groups differ from each other.

Table 11: One-way ANOVA analysis of the hazard identification score.

<table>
<thead>
<tr>
<th>Anova: Single Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Group 1</td>
</tr>
<tr>
<td>Group 2</td>
</tr>
<tr>
<td>Group 3</td>
</tr>
<tr>
<td>Group 4</td>
</tr>
</tbody>
</table>

ANOVA
It is worth noting that all four groups were exposed to the same hazards and preliminary scenes in the VR environment. As seen in table 12, the post-hoc analysis revealed that there is a statistically significant difference between the mean scores of group 1 in relation to groups 2, 3, and 4. This conforms to the research’s hypothesis stating that:

**H1:** It is predicted that the use of andragogy principles in VR-based training positively contributes to the learning outcomes of trainees.

However, no other significant difference was revealed between the other groups. These results indicate that the trainees of group 1 were able to identify a higher number of hazards as compared to groups 2, 3, and 4. Although group 1 and group 2 received the exact same training, group 2 did not receive the training induction which followed the andragogy principles; thus, it could be safely concluded that the higher hazard identification scores are purely attributed to the induction where the trainees were treated as adult learners and shown the benefits of learning and the consequences of not learning. These results are further verified by the fact that no other significant difference was found between groups 2, 3, and 4. Thus, it could be concluded that the andragogy induction session positively contributes to the hazard awareness and identification skills of the trainees.

Table 12: Post-hoc analysis for the hazard identification score.

<table>
<thead>
<tr>
<th>POST-HOC test</th>
<th>P-value</th>
<th>Original p-value</th>
<th>Bonferroni Corrected p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 Vs Group 2</td>
<td>0.00294203</td>
<td>0.05</td>
<td>0.008333333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 3</td>
<td>2.48324E-05</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 4</td>
<td>5.7114E-05</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Group 2 Vs Group 3</td>
<td>0.426384779</td>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Group 2 Vs Group 4</td>
<td>0.283004707</td>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Group 3 Vs Group 4</td>
<td>0.652970148</td>
<td></td>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>
4.3.2 Identification of the Accident Path Score

Subsequent to the hazard identification score, an analysis to the identification of accident path score was conducted. Table 13 shows descriptive statistics of the obtained results including the mean and standard deviation values for all four groups.

Table 13: Descriptive statistics of the accident-path identification score of the 4 groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Motivational Drivers</th>
<th>VR Training</th>
<th>Observations</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Yes</td>
<td>With accidents &amp; superior safety practices</td>
<td>20</td>
<td>21.700</td>
<td>4.37</td>
</tr>
<tr>
<td>Group 2</td>
<td>No</td>
<td></td>
<td>20</td>
<td>14.500</td>
<td>6.29</td>
</tr>
<tr>
<td>Group 3</td>
<td>No</td>
<td>With accidents</td>
<td>20</td>
<td>11.750</td>
<td>4.89</td>
</tr>
<tr>
<td>Group 4</td>
<td>No</td>
<td>With superior safety practices</td>
<td>20</td>
<td>10.950</td>
<td>5.27</td>
</tr>
</tbody>
</table>

Again, it was evidenced that group 1 had the highest mean value as compared to group 2, 3, and 4. Also, group 1 showed the smallest range in the obtained scores which shows that it was the most consistent group, whereas, group 2 had the biggest data range. This indicates that group 2 had the highest variability in scores. This is further evidenced by its standard deviation (6.29%), the highest as compared to the standard deviation of groups 1, 3 and 4. Figure 44 shows the box and whiskers plot of the accident-path identification score for all four groups.

![Box & Whisker plot of the “Accident-path Identification Score”](attachment:image.png)

Figure 44: Box & Whisker plot of the “Accident-path Identification Score”.
4.3.2.1 Shapiro-Wilk Test

Subsequently, the Shapiro-Wilk test was used to test the normality of the data. The p-values obtained for all four groups were a significance level of 0.05, as seen in table 14; therefore, the null hypothesis which states that “H0: The variable from which the sample was extracted follows a normal distribution” cannot be rejected.

Table 14: Shapiro-Wilk test for “Accident-path Identification Score”.

<table>
<thead>
<tr>
<th>Group</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.94</td>
<td>0.92</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>p-values (Two-tailed)</td>
<td>0.19</td>
<td>0.10</td>
<td>0.26</td>
<td>0.37</td>
</tr>
<tr>
<td>alpha</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

4.3.2.2 Levene’s F-Test

Then, Levene's F-Test, as seen in table 15, was conducted to check the equality of variances between all four groups; again, the p-value obtained is higher than the significance level. Therefore, the null hypothesis “H0: The variances are identical” cannot be rejected. Thus, it is concluded that all four groups have equal variances in their accident-path identification score.

Table 15: Levene’s F-test to check the equality of variances between groups.

<table>
<thead>
<tr>
<th>Levene's test (Mean) / Two-tailed test:</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (Observed value)</td>
</tr>
<tr>
<td>F (Critical value)</td>
</tr>
<tr>
<td>DF1</td>
</tr>
<tr>
<td>DF2</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
</tr>
<tr>
<td>alpha</td>
</tr>
</tbody>
</table>

4.3.2.3 One-way ANOVA Analysis

The aforementioned tests revealed that the data points for the “Accident-path identification score” met the assumptions of normality and equality of variances; therefore, the One-way ANOVA analysis was conducted. The results, as seen in table 16, revealed that the p-value obtained (1.13E-08) is less than the significance level; therefore, there is sufficient evidence to reject the null hypothesis and conclude that there is a statistically significant difference between the means of the
four groups. Subsequently, the Bonferroni post hoc analysis was conducted to identify which groups differ.

Table 16: One-way ANOVA analysis for the accident-path identification score.

<table>
<thead>
<tr>
<th>Anova: Single Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Group 1</td>
</tr>
<tr>
<td>Group 2</td>
</tr>
<tr>
<td>Group 3</td>
</tr>
<tr>
<td>Group 4</td>
</tr>
</tbody>
</table>

**ANOVA**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1436.05</td>
<td>3</td>
<td>478.68</td>
<td>17.341</td>
<td>1.13E-08</td>
<td>2.72</td>
</tr>
<tr>
<td>Within Groups</td>
<td>2097.9</td>
<td>76</td>
<td>27.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3533.95</td>
<td>79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The post-hoc analysis, as seen in table 17, revealed that the only significance difference lies between Group 1 and all other three groups; however, no other significance difference was identified. Accordingly, the following interpretations could be made. Firstly, the significance difference that was found in group 1 could be purely attributed to the fact that they were capable of identifying more hazards; therefore, they were able to identify more accident-paths in the presented pictures. Again, this increase could be attributable to the andragogy induction session that made the trainees more focused and more capable of identifying existing hazards along with their potential accident paths. This is a further proof to the research’s first hypothesis which states that:

**H1:** It is predicted that the use of andragogy principles in VR-based training positively contributes to the learning outcomes of trainees.

On the other hand, no statistically significant difference was found between the groups who viewed the consequential accidents in the VR environment namely, group 2 and 3, and the ones who did not view the consequential accidents of the existing hazards in the VR environment namely, group 4. This goes against the research’s second hypothesis which states that:
**H2:** It is predicted that exposing trainees to consequential accidents enhances their accident-path identification skills.

A possible reason for such results could be due to the fact that the accidents in the construction industry are limited and confined to falling, struck-by, electrocution, fire, and a few other accidents; all of which could be easily predicted based on the identified hazard.

<table>
<thead>
<tr>
<th>POST-HOC test</th>
<th>P-value</th>
<th>Original p-value</th>
<th>Bonferroni Corrected p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 Vs Group 2</td>
<td>0.00015397</td>
<td>0.05</td>
<td>0.008333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 3</td>
<td>4.859E-08</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 4</td>
<td>2.2561E-08</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Group 2 Vs Group 3</td>
<td>0.13138527</td>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Group 2 Vs Group 4</td>
<td>0.06054818</td>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Group 3 Vs Group 4</td>
<td>0.62172062</td>
<td></td>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>

### 4.3.3 Probability Assessment Score

Then, an analysis of the trainees’ ability to accurately assess the probability of the risks that are associated with the existing hazards in the questionnaire pictures was conducted. Table 18 shows descriptive statistics of the obtained results including the mean and standard deviation values for all four groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Motivational Drivers</th>
<th>VR Training</th>
<th>Observations</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Yes</td>
<td>With accidents &amp; superior safety practices</td>
<td>20</td>
<td>11.60</td>
<td>3.28</td>
</tr>
<tr>
<td>Group 2</td>
<td>No</td>
<td>With accidents</td>
<td>20</td>
<td>8.50</td>
<td>2.26</td>
</tr>
<tr>
<td>Group 3</td>
<td>No</td>
<td>With accidents</td>
<td>20</td>
<td>7.75</td>
<td>2.65</td>
</tr>
<tr>
<td>Group 4</td>
<td>No</td>
<td>With superior safety practices</td>
<td>20</td>
<td>5.40</td>
<td>1.90</td>
</tr>
</tbody>
</table>

As seen, group 1 scored the highest mean value in terms of their ability to rate the probability of occurrence of the existing risks; whereas, group 4 scores the lowest in terms of their mean score. When it comes to the variability in the scores, group 1 has the highest range followed by group 3,
2, and 4 respectively. This is further supported by the standard deviation values which shows that group 1 has the highest standard deviation followed by group 3, 2, and 4 respectively. The following figure shows the box and whisker plot for the probability scores of all four groups.

4.3.3.1 Shapiro-Wilk Test

The Shapiro-Wilk test was then conducted to check the normality of data with the following hypothesis: H0: The variable from which the sample was extracted follows a normal distribution; Ha: The variable from which the sample was extracted does not follow a normal distribution. The significance level used is 0.05. The results in table 19 revealed that the scores of groups 2 and 4 are not normally distributed; therefore, the ANOVA analysis could not be conducted. Instead, the Kruskal-Wallis test was conducted to check whether there is statistically significant difference between the means of the four groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.95</td>
<td>0.89</td>
<td>0.95</td>
<td>0.90</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
<td>0.35</td>
<td>0.04</td>
<td>0.35</td>
<td>0.04</td>
</tr>
<tr>
<td>alpha</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

4.3.3.2 Kruskal-Wallis Test

The Kruskal-Wallis test was conducted since two subgroups namely, group 2 and 4, were found to be not normally distributed, as seen in table 20. The null hypothesis used is: H0: the mean ranks on some outcome variables are equal across all populations; whereas, the alternative hypothesis used is H1: the mean ranks on some outcome variables are not equal across all populations. The significance level used is 0.05. The results revealed that the p-value obtained was less than the significance level; therefore, it could be stated that there is sufficient evidence to reject the null hypothesis. Thus, the alternative hypothesis is accepted.

<table>
<thead>
<tr>
<th>Kruskal-Wallis test / Two-tailed test:</th>
</tr>
</thead>
<tbody>
<tr>
<td>K (Observed value)</td>
</tr>
<tr>
<td>K (Critical value)</td>
</tr>
</tbody>
</table>
Accordingly, a post-hoc analysis was conducted to identify where the difference lies, as seen in table 21. The results revealed that there is a statistically significant difference between group 1 and the rest of the groups; again, this could be attributed to their enhanced hazard and accident path identification skills. Similarly, a statistically significant difference was found between the probability scores of the groups who viewed consequential accidents in the VR environment namely, group 2 and 3, and the ones who did not namely, group 4. Thus, group 2 and 3 were better capable of assessing the probability of the risks that were presented to them. These results validate the third hypothesis of this research which states that:

**H3:** It is predicted that exposing trainees to consequential accidents enhances their ability to assess the probability of risks that are attributable to the identified hazards.

Further proof to this is that no statistically significant difference was found between the probability scores of groups 2 and 3; thereby, showing that probability assessments are identical in groups who viewed consequential accidents in their training.

Table 21: Post-hoc analysis for the probability score.

<table>
<thead>
<tr>
<th>POST-HOC test</th>
<th>P-value</th>
<th>Original p-value</th>
<th>Bonferroni Corrected p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 Vs Group 2</td>
<td>0.001280478</td>
<td>0.05</td>
<td>0.008333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 3</td>
<td>0.000223303</td>
<td>0.05</td>
<td>0.008333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 4</td>
<td>9.49292E-09</td>
<td>0.05</td>
<td>0.008333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 2 Vs Group 3</td>
<td>0.341904031</td>
<td>0.05</td>
<td>0.008333</td>
<td>No</td>
</tr>
<tr>
<td>Group 2 Vs Group 4</td>
<td>3.44596E-05</td>
<td>0.05</td>
<td>0.008333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 3 Vs Group 4</td>
<td>0.002634884</td>
<td>0.05</td>
<td>0.008333</td>
<td>Yes</td>
</tr>
</tbody>
</table>
4.3.4 Impact Assessment Score

Similarly, an analysis of the trainees’ impact assessment score was conducted. Table 22 shows descriptive statistics of the obtained results including the mean and standard deviation values for all four groups.

Table 22: Descriptive statistics of the impact assessment score of the 4 groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Motivational Drivers</th>
<th>VR Training</th>
<th>Observations</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Yes</td>
<td>With accidents &amp; superior safety practices</td>
<td>20</td>
<td>12.75</td>
<td>3.57</td>
</tr>
<tr>
<td>Group 2</td>
<td>No</td>
<td></td>
<td>20</td>
<td>10.40</td>
<td>3.15</td>
</tr>
<tr>
<td>Group 3</td>
<td>No</td>
<td>With accidents</td>
<td>20</td>
<td>9.90</td>
<td>3.75</td>
</tr>
<tr>
<td>Group 4</td>
<td>No</td>
<td>With superior safety practices</td>
<td>20</td>
<td>6.70</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Similar to previous results, group 1 had the highest mean value for the impact score. This is followed by group 2, 3, and 4 respectively. The standard deviation of all four groups were relatively close suggesting that the variability in the data points is similar across all groups. The following figure shows a box and whiskers plot of the impact assessment score of all four groups. Figure 45 shows the box and whisker plots of the impact assessment score of the four groups.

![Box & Whisker plot of the “Impact assessment score”](image)

Figure 45: Box & Whisker plot of the “Impact assessment score”.
4.3.4.1 Shapiro-Wilk Test

The results of the Shapiro-Wilk test, as presented in table 23, indicate the normality of the data as they revealed that the p-value obtained was higher than the significance level of 0.05 for all four groups; thus, the null hypothesis cannot be rejected.

Table 23: Shapiro-Wilk test for “Impact assessment score”.

<table>
<thead>
<tr>
<th>Group</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.97</td>
<td>0.97</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
<td>0.66</td>
<td>0.81</td>
<td>0.66</td>
<td>0.89</td>
</tr>
<tr>
<td>alpha</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

4.3.4.2 Levene’s F-Test

The results of the F-test yielded a p-value of 0.941 which is greater than the significance level of 0.05, as seen in table 24; therefore, the null hypothesis cannot be rejected. Accordingly, the variances of the impact score of all four groups are identical.

Table 24: Levene’s F-test to check the equality of variances between groups

<table>
<thead>
<tr>
<th>Levene's test (Mean) / Two-tailed test:</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (Observed value)</td>
</tr>
<tr>
<td>F (Critical value)</td>
</tr>
<tr>
<td>DF1</td>
</tr>
<tr>
<td>DF2</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
</tr>
<tr>
<td>alpha</td>
</tr>
</tbody>
</table>

4.3.4.3 One-way ANOVA Analysis

Since the normality and equality of variances have been verified, a single one-way ANOVA analysis was performed, as presented in table 25. The results yielded a p-value of 7.48E-06 which is less than the significance level of 0.05. Therefore, there is sufficient evidence to reject the null hypothesis and conclude that there is a statistically significant difference between the groups. Accordingly, a post-hoc analysis was performed to identify where such differences lie.
Table 25: One-way ANOVA analysis of the impact assessment score.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>20</td>
<td>255</td>
<td>12.75</td>
<td>12.72</td>
</tr>
<tr>
<td>Group 2</td>
<td>20</td>
<td>208</td>
<td>10.40</td>
<td>9.94</td>
</tr>
<tr>
<td>Group 3</td>
<td>20</td>
<td>198</td>
<td>9.90</td>
<td>14.09</td>
</tr>
<tr>
<td>Group 4</td>
<td>20</td>
<td>134</td>
<td>6.70</td>
<td>10.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>372.14</td>
<td>3</td>
<td>124.04</td>
<td>10.49</td>
<td>7.48E-06</td>
<td>2.72</td>
</tr>
<tr>
<td>Within Groups</td>
<td>898.55</td>
<td>76</td>
<td>11.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1270.69</td>
<td>79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The post-hoc analysis revealed that, unlike previous results, no statistically significant difference exists between the mean scores of group 1 as compared to group 2 and 3. Likewise, no statistically significant difference was found between group 2 and 3. Table 26 presents the results of the post hoc analysis. Accordingly, the following interpretations are made. Firstly, the trainees of group 1 were more likely to over-assess the impacts of the accidents which caused them to lose more scores despite the fact that they were able to accurately identify more hazards and accident paths. Such over-assessment could be attributed to the induction session which discussed the impacts of not learning, in general, in terms of fatal and nonfatal injuries, cost overruns, schedule delays, and such, which might have caused them to exaggerate the impacts of the risks.

Secondly, Group 2 and 3 were more likely to accurately assess the impact of the identified hazards, despite the fact that they identified fewer hazards, as compared to group 1. This caused them to score high in the impact assessment score; therefore, yielding no statistically significant differences between their group scores and the scores of groups 1.

When it comes to group 4, the post-hoc analysis revealed a statistically significant difference between their impact assessment scores and the impact assessment scores of groups 1, 2, and 3. The much lower grades could be attributed to the fact that they tended to under-estimate the impact of the accidents since they did not view consequential accidents in the VR environment. Thus, the following conclusion could be drawn: Introducing trainees to consequential accidents, without the
andragogy induction session, enhances the trainees’ impact assessment of the risks. This proves the fourth hypothesis of this research which states that:

**H4:** It is predicted that exposing trainees to consequential accidents enhances their ability to assess the impact of risks that are attributable to the identified hazards.

Table 26: Post-hoc analysis for the impact assessment score.

<table>
<thead>
<tr>
<th>POST-HOC test</th>
<th>P-value</th>
<th>Original p-value</th>
<th>Bonferroni Corrected p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 Vs Group 2</td>
<td>0.033372</td>
<td>0.05</td>
<td>0.008333</td>
<td>No</td>
</tr>
<tr>
<td>Group 1 Vs Group 3</td>
<td>0.018503</td>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Group 1 Vs Group 4</td>
<td>1.95E-06</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Group 2 Vs Group 3</td>
<td>0.650889</td>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Group 2 Vs Group 4</td>
<td>0.000770</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Group 3 Vs Group 4</td>
<td>0.006442</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

4.3.5 Hazard Mitigation Score

Consequently, an analysis of the trainees’ hazard mitigation score was conducted. Table 27 shows descriptive statistics of the obtained results including the mean and standard deviation values for all four groups.

Table 27: Descriptive statistics of the hazard mitigation score of the 4 groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Motivational Drivers</th>
<th>VR Training</th>
<th>Observations</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Yes</td>
<td>With accidents &amp; superior safety practices</td>
<td>20</td>
<td>18.45</td>
<td>4.50</td>
</tr>
<tr>
<td>Group 2</td>
<td>No</td>
<td>With accidents</td>
<td>20</td>
<td>13.55</td>
<td>5.49</td>
</tr>
<tr>
<td>Group 3</td>
<td>No</td>
<td>With superior safety practices</td>
<td>20</td>
<td>8.55</td>
<td>3.05</td>
</tr>
<tr>
<td>Group 4</td>
<td>No</td>
<td>With superior safety practices</td>
<td>20</td>
<td>12.55</td>
<td>2.74</td>
</tr>
</tbody>
</table>

As observed from the results, group 1 had the highest mean score in terms of their ability to identify the needed measures to mitigate existing hazards; this was followed by group 2, 4, and 3 respectively. In terms of variability, group 2 showed the highest variability in their scores; whereas, group 4 showed the least variability which is evidenced from their standard deviations. Figure 46 shows the box and whisker plots of the hazard mitigation score of the four groups.
4.3.5.1 Shapiro-Wilk Test

The Shapiro-Wilk test as seen in table 28, proved that the results are normally distributed; hence, the F-test was then conducted to check the equality of variances between the four groups.

Table 28: Shapiro-Wilk test for “Hazard Mitigation score”.

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.98</td>
<td>0.93</td>
<td>0.91</td>
<td>0.92</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
<td>0.96</td>
<td>0.16</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>alpha</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

4.3.5.2 Levene’s F-Test

The Levene’s F test yielded a p-value of 0.001 which is less than the significance level, as presented in table 29; therefore, the null hypothesis stating that: “H0: The variances are identical” should be rejected. Thus, the alternative hypothesis stating that at least one of variances is different from another is accepted. Accordingly, the Welch ANOVA test is conducted.
Table 29: Levene’s F-test to check the equality of variances between groups.

<table>
<thead>
<tr>
<th>Levene's test (Mean) / Two-tailed test:</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (Observed value)</td>
</tr>
<tr>
<td>F (Critical value)</td>
</tr>
<tr>
<td>DF1</td>
</tr>
<tr>
<td>DF2</td>
</tr>
<tr>
<td>p-value (Two-tailed)</td>
</tr>
<tr>
<td>alpha</td>
</tr>
</tbody>
</table>

Signification codes: 0 < "***" < 0.001 < "**" < 0.01 < "*" < 0.05 < "." < 0.1 < " " < 1

4.3.5.3 Welch ANOVA

Welch and Brown-Forsythe ANOVA are more reliable than the classic F when variances are unequal. The significance level obtained in the Welch ANOVA test is less than 0.05; therefore, the null hypothesis that states that: “H0: The means of all groups are equal” could be rejected. Hence, there is a statistically significant difference between the means of the four groups. Table 30 shows the results of the Welch ANOVA test of the hazard mitigation scores of all four groups.

Table 30: Welch ANOVA test of the hazard mitigation scores of all four groups.

<table>
<thead>
<tr>
<th>Robust test of equality of means (Y):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistic</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Welch statistic</td>
</tr>
<tr>
<td>Brown-Forsythe F-ratio</td>
</tr>
</tbody>
</table>

Accordingly, a post-hoc analysis was performed to determine where the difference lies, as seen in table 31. The results of the post-hoc analysis revealed that there is a statistically significant difference between group 1 in relation to groups 2, 3, and 4. Such significance, again, could be attributed to the induction session which made trainees more focused during the training; thus, they were able to accurately identify and list applicable safety measures that should be taken to mitigate the risks of existing hazards. The significant difference could also be attributed to the fact that group 1 were also capable of identifying higher numbers of hazards and accident-path, which further contributed to their hazard mitigation scores.

Similarly, statistically significant differences were found between group 2 and 3 and group 3 and 4. This significance acts as evidence of the fact that the trainees who were introduced to the right
course of actions in the VR environment were better capable of listing the appropriate safety mitigation measures that should be taken as compared to those who did not, namely, group 3. This confirms the research’s fifth hypothesis which is:

**H5:** It is predicted that exposing trainees to the right course of action enhances the trainees’ safety management and hazard mitigation skills.

These findings are further supported by the fact that no statistically significant difference was found between the hazard mitigation scores of groups 2 and group 4 since the two groups were introduced to the same hazard mitigation measures in the VR environment.

<table>
<thead>
<tr>
<th>POST-HOC test</th>
<th>P-value</th>
<th>Original p-value</th>
<th>Bonferroni Corrected p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 Vs Group 2</td>
<td>0.003850968</td>
<td></td>
<td>0.008333</td>
<td>Yes</td>
</tr>
<tr>
<td>Group 1 Vs Group 3</td>
<td>1.93697E-09</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Group 1 Vs Group 4</td>
<td>2.04687E-05</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Group 2 Vs Group 3</td>
<td>0.001273148</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Group 2 Vs Group 4</td>
<td>0.472336571</td>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Group 3 Vs Group 4</td>
<td>9.75048E-05</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

### 4.3.6 Results’ Summary

To sum up the findings, it was evident that the consideration of the andragogy principles has resulted in a significant increase in the trainees’ hazard identification, identification of accident path, probability assessments, and hazard mitigation skills. However, it did not positively contribute to the trainees’ ability to assess the impacts of the hazard; on the contrary, the trainees of group 1 tended to over-assess the impact of hazards as compared to other groups.

When it comes to the introduction of consequential accidents in the VR training, the results revealed no significant difference between groups, other than group 1 which were able to identify more accidents as a result of the enhancement in their hazard identification skills. Thus, it was assumed that since accidents in the construction industry are somehow limited and known, the
trainees of both the groups that experienced consequential accidents and the ones that did not were easily capable of predicting accident paths.

However, the results revealed that experiencing consequential accidents in the VR environment enhanced the trainees’ ability to assess the probability of risks. Likewise, the trainees of groups 2 and 3 were better capable of assessing the impact of the identified hazard as compared to group 4 who did not view any form of accidents in the virtual environment. Thus, the following conclusion could be made: although the introduction of consequential accidents does not positively contribute to the trainees’ ability to identify accident paths, it enhanced the trainees’ ability to assess the probability and impact of existing hazards; hence, positively contributing towards the trainees’ ability to assess the severity of hazards.

When it comes to experiencing the safety mitigation measures that should be maintained on site, the results revealed that the groups that experienced the right course of action in the virtual environment were better capable of identifying the needed and most applicable hazard mitigation measures as compared to the group that did not.

4.4 The Designed VR-based Safety Training Program for High-rise Construction

Based on the steps discussed in the methodology section, the following paragraphs reveal the final modules that were developed for the training program, the chapters of each module, and the detailed content of each chapter.

4.4.1 Designed Modules

Based on the primary and secondary data that were gathered from the literature review, interviews, and site visits in this research, a few themes emerged. Figure 48 shows the main modules developed for the VR-based safety training program for high-rise construction. Likewise, table 32 provides a description of the content of each module.
Table 32: Modules of the VR-based safety training program for high-rise construction.

<table>
<thead>
<tr>
<th>Module No.</th>
<th>Module Name</th>
<th>Module description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General Safety Procedures</td>
<td>This module covers the basic concepts of safety management in construction sites including the hierarchy of controls, the risk management process, and safety inspection and walkthroughs.</td>
</tr>
<tr>
<td>2</td>
<td>General &amp; Enabling Work</td>
<td>This module covers the basic concepts that are not directly related to specific trades within high-rise construction yet play a crucial role in the facilitation and enablement of all other trades and activities.</td>
</tr>
<tr>
<td>3</td>
<td>Structural Frames, Formwork, &amp; Concrete Work</td>
<td>This module covers topics and concepts related to the main activities of the Highrise’s superstructure.</td>
</tr>
<tr>
<td>4</td>
<td>Lifting Appliances &amp; Gear</td>
<td>This module covers topics and concepts related to the lifting appliances and gear that are responsible for lifting and transporting workers, materials, and equipment to extremely high altitudes.</td>
</tr>
<tr>
<td>5</td>
<td>Machine, Equipment, &amp; Hand Tools</td>
<td>This module covers topics and concepts related to the major machines, equipment, and tools used in construction, with specific emphasis to the ones that are particularly used in high-rise construction.</td>
</tr>
<tr>
<td>6</td>
<td>Safety of Workplaces</td>
<td>This module covers topics and concepts related to maintaining the safety of workplaces, with particular emphasis on the specific characteristics of high-rise buildings in terms of altitude, confinement of spaces, and the challenges of delivering the appropriate rescue and recovery measures.</td>
</tr>
<tr>
<td>7</td>
<td>Personal Conduct</td>
<td>This module covers topics and concepts related to unsafe working behaviors and other...</td>
</tr>
</tbody>
</table>
4.4.2 Designed Units/Chapters Under each Module

In total, twenty-two chapters have been developed under the seven modules of the comprehensive training program. Table 33 presents a summary of all the chapters under each module. The first module “General Safety Procedures” has three chapters that provide an inclusive overview of the general safety procedures that should be practiced and maintained by an organization. Thus, it starts by the “Hierarchy of Controls” chapter where the roles and responsibilities of the safety management team and the project manager is explained. The second chapter “Risk Management Process” discusses the safety management process including the risk identification, analysis, and response plan. Finally, chapter 3 “Inspections & Walkthroughs” discusses the inspection and monitoring of safety risks on site.

The second module “General & Enabling Works” includes four chapters. The first chapter “Buildings’ Boundaries” discusses all the precautionary measures that should be maintained in relation to the site boundaries and the boundaries of the building itself including but not limited to accessibility, access authorizations, etc. The second chapter “Housekeeping” discusses the housekeeping practices that should be maintained in general, and in high-rise construction projects in specific. This includes but is not limited to the usage of trash chutes and safety nets. The third chapter “Material Handling & Storage” discusses the hazards and precautionary measures that should be maintained in relation to material handling and storage including permanent and temporary storage areas. The fourth chapter “Buildings’ Accessibility & Egress” discusses every aspect in relation to the safe access and evacuation of high-rise construction sites during both normal and emergency situations.

The third chapter “Structural Frames, Formwork, & Concrete Work” has three chapters that discuss every aspect pertaining to the construction of the superstructure. The first chapter “Formwork” covers a wide range of special types of formworks that are specifically used in high-rise construction such as suspended formwork, table formwork, and slipping formwork. The second chapter “Concrete Work” discusses all aspects pertaining to the concreting process including the reinforcement, pre-stressing process, and the concreting itself. Chapter 3 “Temporary
Enabling Structures” covers all the temporary structures that are needed to aid in commencing the superstructure such as guardrails and temporary working platforms.

The fourth chapter “Lifting Appliances & Gear” has three chapters that discuss the equipment and machinery used for the transportation of material and workers on site. Thus, the first chapter “Tower Cranes” discusses all hazards and safety measures that should be maintained while operating tower cranes. The second chapter “Hoists” discusses all hazards and safety measures that should be maintained while construction hoists/elevators. Lastly, chapter 3 “Cradles” discusses all hazards and safety measures that should be maintained while operating construction cradles/gondolas.

The fifth chapter “Machine, Equipment & Hand Tools” has two chapters that discusses the hazards and precautionary measures that should be maintained while operating simple vehicles and hand tools in a wide range of trades. The sixth chapter “Safety of Workplaces” discusses how to maintain the general safety of the construction site. Thus, it has five main chapters that discuss fire and electrical hazards, extreme weather conditions, first aid, and work permits that should be obtained before commencing hazardous and dangerous work activities. The last chapter “Personal Conduct” is concerned with the hazards that primarily emerge from the conduct of construction workers on site. Thus, chapter 1 “Human Factors” covers the intrinsic responses of construction workers to factors that inevitably exist in high-rise construction projects such as extreme weather conditions and extremely high altitudes. The second chapter “Unsafe Working Behavior” discusses the unsafe behaviors of construction workers during construction.

Table 33: Chapters included under each module of the comprehensive VR-based safety training program.

<table>
<thead>
<tr>
<th>Module No.</th>
<th>Module Name</th>
<th>Unit/Chapter s No.</th>
<th>Unit/Chapter Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General Safety Procedures</td>
<td>1</td>
<td>Hierarchy of Controls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Risk Management Process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Inspections &amp; Walkthroughs</td>
</tr>
<tr>
<td>2</td>
<td>General &amp; Enabling Work</td>
<td>1</td>
<td>Buildings’ Boundaries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Housekeeping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Material Handling &amp; Storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Buildings’ Accessibility &amp; Egress</td>
</tr>
</tbody>
</table>
While the previous sections provided a general overview of the modules of the training along with their respective chapters, this section provides a detailed description of the content of each chapter.

### 4.4.3 Chapters’ Content

While the previous sections provided a general overview of the modules of the training along with their respective chapters, this section provides a detailed description of the content of each chapter.

#### 4.4.3.1 Module 1: General Safety Procedures

As stated previously, this chapter encompasses organization-wide processes that are implemented to manage safety risks in construction sites in general, and in high-rise construction projects in specific. Thus, it discusses the systematic approaches to safety risk management managing safety, including organizational structures, accountabilities, policies, and procedures. The significance of this module emerges from the fact that having effective safety procedures helps minimize risk and protect against accidents in the workplace.

#### 4.4.3.1.1 Chapter 1.1: Hierarchy of Controls

This chapter provides a general overview of the competencies that should be maintained by the safety management team. Thus, it provides the trainees with knowledge on general management functions, practices, and procedures regarding safety and occupational health concepts, principles, practices, methods, and techniques. Hence, this chapter discusses safety measures in relation to:
1. The minimum qualification requirements for the technical personnel performing safety-related functions.
2. The main responsibilities and duties of safety managers and safety team members in maintaining safety precaution, strategies and policy.
3. Basic skills competencies that should be acquired by safety managers and members of the safety management team.
4. Knowledge on vital safety management aspects such as the rules and regulation of the workplace, a socio-humanitarian aspect that consider the human lives involved, and lastly is the accidents aspects.
5. The hierarchy of authority and controls that should be maintained in construction sites between safety managers.

4.4.3.1.2 Chapter 1.2: Safety Risk Management process

This chapter discusses all aspects pertaining to the safety risk management process through an evaluation process that weighs the potential costs of a risk against the potential benefits in order to take corrective decisions that aid in mitigating expected hazards in the most time-efficient and cost-effective manner. Hence, this chapter discusses the following risk management processes.

1. Hazard identification and data gathering procedures.
2. Risk assessment along with common risk assessment tools and techniques, risk evaluation, and risk prioritization.
3. Risk management plans including risk response, monitoring, and control plans.
4. Data documentation and reporting procedures.

4.4.3.1.2 Chapter 1.3: Inspection & Walkthroughs

This chapter discusses all aspects pertaining to the inspection and safety walkthroughs that should be done by the safety management team throughout the commencement of construction. Thus, the chapters’ content includes:

1. Inspection times, frequencies, and procedures.
2. Safety inspection checklists to be used in checkups.
3. Risk recording schemes including normal paperwork processes, photography, and video recording.
4. Updates to the original safety risk management plan.
4.4.3.2 Module 2: General & Enabling Work

As mentioned earlier, General and Enabling works are a generic description for site preparation works that might take place prior and during work under the main construction contract. Their main purpose is to facilitate the execution of construction activities in the safest means possible with minimal effort and time. The main significance of this module emerges from the fact that it enables the proper management and avoidance of chaos in construction sites. However, it is worth noting that since this is a general chapter, its contents will be frequently tapped-onto in chapters of this training program as well.

4.4.3.2.1 Chapter 2.1: Building’s Boundaries.

This chapter applies to all simple work or temporary workshops that are being constructed at/near the perimeters of the building and the site boundaries as a whole throughout the progress of the work. This is of great significance to protect construction workers and the members of the public, specifically vulnerable groups including children and elder people, from falling into trenches, being hit by a falling object, or being struck by a moving vehicle. Thus, the chapter discusses safety measures in relation to:

1. Access restriction/ unauthorized access to the site.
2. Safety measures to be applied when access to the site is granted to visitors.
3. Definition of the exterior boundaries of the site.
4. Fencing of building’s perimeter.
5. Protection against falling objects.
6. Safety measures to areas where access cannot be banned such as the hoist’s waiting area.
7. Applicable safety signs indicating the safety hazards that exist while working at/near building’s perimeters.
8. Applicable safety working behaviors that should be maintained by construction workers.

4.4.3.2.2 Chapter 2.2: Housekeeping

This chapter applies to the housekeeping practices that are specific to high-rise construction to prevent fire accidents, tripping, slipping, striking protruding items, cutting, puncturing, or tearing the skin of hands, or other parts of the body, on projecting nails. Thus, the chapter covers housekeeping safety measures in relation to:
2. Workspaces and passageways.
3. Working platforms.
4. The usage of trash chutes/ garbage chutes in high-rise construction.
5. Safety measures that should be implemented while cleaning safety nets.
6. Relevant inspection to identify housekeeping issues.

4.4.3.2.3 Chapter 2.3: Material handling & storage

This chapter applies to the safety measures that relate to the handling and storage of materials to ensure the storage of compatible materials and prevent any tripping and falling hazards along with obstructing major access ways. Thus, the contents of this chapter cover safety measures in relation to:

1. Storage of flammable & hazardous materials.
2. Storage and handling of typical construction materials.
3. Temporary storage areas and workshops, specifically the ones that are within the building.
4. Workers’ safe working behaviors in relation to manual material handling.
5. Workers’ safe working behaviors in relation to mechanical material handling.
6. Relevant housekeeping practices.

4.4.3.2.4 Chapter 2.4: Accessibility & Egress

In high rise buildings with large areas, safety requirements necessitate the existence of safe access and egress routes; this is done to minimize the travel distance of workers during emergencies and ensure their rapid and efficient egress. Thus, the content of this chapter covers safety measures in relation to:

1. Permanent & temporary stairs in high-rise construction.
2. Main access and egress lanes, routes, and paths to the nearest exiting stairs, specifically in congested or confined spaces.
3. Safety measures and working behaviors in relation to egress and evacuation during emergency situations.
4. Emergency egress and evacuation plans.
5. Safety signals and measures that should be maintained in all access and egress routes.

6. Relevant housekeeping practices to prevent obstructions to main access/egress routes and paths.

**4.4.3.3 Module 3: Structural frames, formwork & concrete work**

This module covers all aspects that relate to the construction of the building’s superstructure. Thus, it mainly covers formworks, reinforcement, prestressing, concreting, and the use of other temporary enabling structures that facilitate the conduction of construction activities in general. It also covers guarding structures that are erected to maintain a safe working environment for all construction workers on site. The following paragraphs illustrate the exact contents of the three chapters of this module namely, formwork, concrete work, and temporary enabling structures.

**4.4.3.3.1 Chapter 3.1: Formwork**

Unlike traditional buildings, high-rise buildings require the use of highly complex forms of formwork with relatively mature construction techniques and technology. The formwork system has a vital role to play, especially in the high-rise structures, in mechanizing the activities to achieve speed, increase productivity, and utilize economies of scale in bringing down the unit cost; thereby, facilitating the construction process. The chapter covers two main types of formworks namely, climbing formwork and table formworks. Thus, the contents of this chapter cover safety measures in relation to:

1. Safety measures that should be maintained in all working platforms during the erection & dismantling of formworks.

2. Safety measures that should be maintained to access and evacuate formwork structures.

3. Safety of all construction workers in terms of applicable PPEs, overexertion injuries, struck-by accidents from incoming assembly, and safe working behaviors.

4. Safe operating environment and safety measures in extreme weather conditions such as wind speeds of 10 meter per second or higher, heavy rain, heavy snow, and dense fog.
5. Basic safety requirements that should also be maintained on working platforms include fire extinguishers, first aid kit, proper illumination at night shifts.

6. Relevant housekeeping practices to prevent slips, trips, and falling hazards.

4.4.3.3.2 Chapter 3.2: Concrete work

In concreting operations, risks may arise from known hazards including, but not limited to, reinforcement and steel prestressing, concrete placing booms, pipelines, pipe clamps, and delivery hoses. Hazards could also emerge from the placement of plant and equipment, that include proximity to traffic, members of the public, power lines, other plant, structures, and trenches. These hazards impose multiple risks such as, Workers falling onto concrete slabs, being crushed by slabs falling as they are hit, getting pinned between concrete slabs, being burned or blinded by concrete chemicals, being impaled on rebar sticking out of concrete slabs, and falling from heights, among others. Thus, the content of this chapter covers safety measures in relation to:

1. Workers’ safety during the reinforcement process.

2. Safety measures that should be maintained during the prestressing process.

3. Safe work practices that should be maintained prior to and during the tensioning process.

4. Safety measures that should be maintained during the concreting process.

5. Safe work practices that should be maintained prior to and during the concreting process.

6. Relevant housekeeping practices to prevent fire, CO overexposure, third-degree burns from concrete exposures, etc.

4.4.3.3.3 Chapter 3.3: Temporary enabling structures

Similar to general and enabling works, temporary enabling structures are structures that are erected to facilitate the conduction of main construction activities. They are used to provide workers with access, and a working platform at the most comfortable and productive height. Yet, they are often associated with many hazards including but not limited to fall hazards, falling object hazards, electrical hazards, and handling of materials hazards. The hazards also emerge from the fact that they are often kept in place for months. Thus, the content of this chapter covers safety measures in relation to:
1. Safety measures that should be maintained while working with temporary platforms.
2. Safety measures that should be maintained while working with regular scaffolds, suspended scaffolds, and mast scaffolds.
3. Safety practices and inspections that should be practiced with all temporary enabling structures.
4. Guarding structures, parapets, fences and additional safety measures that should be maintained in relation to all structural openings and slab edges.
5. Safety measures that should be maintained while working with climbing edge/windscreeens.
6. Safety culture and safe working behaviors while working with temporary enabling structures.

4.4.3.4 Module 4: Lifting appliances & gear

It is apparent that many of the primary challenges that emerge in high-rise construction are attributed to the extremely high altitudes at which construction activities/trades are being carried out. This necessitated shedding light on the hazards and risks that are encountered while using lifting appliances & gear. These are mainly used to transport labor, materials, and equipment to their designated locations. Thus, the module covers three main lifting gears namely, tower cranes, construction hoists, and construction cradles/gondolas. It is worth noting that mast scaffolds could also be regarded as lifting gear; however, they are covered under module 3 as a temporary enabling structure.

4.4.3.4.1 Chapter 4.1: Construction Hoists

Construction hoists/elevators are equipment used to vertically lift people and material in a construction site, especially in high-rise buildings to facilitate access and egress. However, they are still associated with multiple hazards. Despite the number of fatalities associated with hoist operations and the similarity of hoists to tower cranes in terms of tall mast sections, building tie-ins, and public exposure, construction hoist installation and operation have received little attention. Therefore, the content of this chapter covers the following:

1. The competencies and qualifications of hoist operators.
2. The safety procedures that should be maintained while accessing and evacuating construction hoists.
3. The safety measures that should be maintained inside construction hoists.
4. The safe operations of construction hoists.
5. Safety culture and safe working behaviors while working with construction hoists.

4.4.3.4.2 Chapter 4.2: Cranes

Tower crane is a type of lifting structure which utilizes a vertical mast or tower to support a working boom in an elevated position. Loads are suspended from the working boom. It has been acknowledged that a large percentage of accidents and fatalities are attributed to operating tower cranes. Therefore, the content of this chapter encompasses:

1. The competencies and qualifications of crane operators.
2. The safety procedures that should be maintained while accessing and evacuating construction crane.
3. The safety measures that should be maintained inside construction crane.
4. The safe operations of construction crane.
5. Safety culture and safe working behaviors while working with construction crane.

4.4.3.4.3 Chapter 4.3: Construction Cradles/Gondolas

The construction cradle machine is a special aerial work equipment that lifts operators, tools, and materials to a designated position for various installation and maintenance operations. They are being widely used for the installation of billboards, windows, window cleaning, external renovation, painting and plastering jobs, decoration of bridges, building facades, chimneys, silos, and other tall structures. However, it is still associated with multiple fatalities and injuries, which is why it was considered in this training. Therefore, the content of this chapter includes:

1. The competencies and qualifications of cradle operators.
2. The safety procedures that should be maintained while accessing and evacuating construction cradles.
3. The safety measures that should be maintained inside construction cradles.
4. The safe operations of construction cradles.
5. Safety culture and safe working behaviors while working with construction cradles.
Figure 48: Details of the contents of each chapter of the VR-based comprehensive safety training for high-rise construction.
4.5 The Developed VR-based Safety Training Program for High-rise Construction

The developed comprehensive VR-based safety training for high-rise construction consists of seven main modules covering twenty-five. The software used in this research is Unity2019. The main engine scripting in Unity is C#. The main hardware component used is the Meta Quest 2 (initially sold as Oculus Quest 2). While developing the VR-based safety training program for high-rise construction, several factors were considered namely, immersion, presence, and embodiment.

All the digital assets used within the training program are either purchased from Unity store or TurboSquid. In certain specific cases where sophisticated assets were not found, they were manually created using Revit. Animations were used for two primary purposes. First, they were used as a background effect where other animated workers surround the trainees. The second aim of using animations was to enhance the realism of the accidents that are to be witnessed by the trainees. Finally, a wide form of background effects was used in the training program. This includes but is not limited to the noise of the construction site, the noise of nearby construction workers, sound effects of existing wind or by-passing equipment, etc. The comprehensive VR-based safety training program is available upon request.

The total duration of the training is approximately 3.5 hours which might vary according to the performance of each trainee. The training program has a user-friendly interface with a main menu that lists all the training modules. Thus, although the sequence provided is the best sequence for grasping the content of the training, the trainees could choose to be trained on any of its modules separately. Similarly, each module is divided into scenarios that could be accessed separately and in any order. This enhances the flexibility of the training program.

Although the VR-based training program was implemented and tested on the Meta Quest 2, formerly known as Oculus Quest 2, it is applicable on other VR headsets including but not limited to HP Reverb G2, HTC Vive Pro 2, HTC Vive Cosmos Elite, HP Reverb G2, etc. The full training program is available at the American University of Cairo and is available to interested audience by request. The average time to complete each scenario is 7 minutes and the average duration of
conducting the full training is 280 minutes. The targeted audience is both construction labour and safety officers working in high-rise construction projects; however, the content of the training program could also be used in other residential and commercial projects. The recommended prerequisites of this training is any form of certified safety training such as OSHA construction and IOSH.

4.6 Recommendations for Future Development of VR-based Safety Training Programs

During the pilot study, observations and discussions with the trainees were made to gain their feedback about the developed conceptual framework for conducting VR-based safety training programs. Hence, conclusions and further improvements to the framework were derived. The following paragraphs discuss these findings and provide recommendations that aid in developing better VR-based safety training programs.

4.6.1 Derived and Recommended Technical Improvements to the Training Framework

The following paragraphs present the recommended technical improvements that would aid in enhancing the efficiency and effectiveness of the developed training framework.

4.6.1.1 Controller Lags as a Result of High-Render Resolution

To start with, it was apparent that one of the main difficulties that was encountered by the trainees was related to the VR controllers. Thus, they faced difficulties in precisely pointing the laser of the controllers to the areas they wanted to move to which impeded their ability to smoothly travel around the site. Furthermore, the trainees faced some lags in the laser pointer while trying to hover over and select the existing hazards. These difficulties are attributed to the excessively high graphics that were used in the training. This problem could be overcome by reducing the render resolution of the surrounding objects while keeping the resolution of the targeted objects/assets high to maintain visual clarity.

4.6.1.2 Background Sound Effects

As stated earlier, background sound effects of the construction site along with wind and the sound effects of near-by trades were added to enhance the realism of the VR-based safety training. While
such consideration did contribute to the realism of the training and enhanced the sense of presence and immersion of the trainees, such sound effects acted as a main distractor while the trainees received their feedback through voice-overs. Thus, it is recommended that future research should consider lowering/silencing the background sound effects while providing trainees with feedback on their performance.

4.6.1.3 Artificial Intelligence (AI-based) Feedback

Thirdly, the feedback was provided to the trainees using voice-overs that were generated using AI voice generators that turn text into speech. This was more practical since hiring a professional voice actor was infeasible. In addition, using AI voice generators provided the research with more flexibility since the content could be easily amended and updated. However, one of the main limitations of the technology is that it is based on a synthetic voice which reduces the quality and clarity of the generated speech. Thus, some trainees faced difficulties in fully and easily comprehending the feedback provided. Another main limitation is that AI voice generators cannot convey emotions; thus, some trainees faced slight boredom due to the semi-monotonic and unnatural voice. Therefore, it is recommended that future research consider using human-read audio to enhance the quality of the feedback provided.

4.6.2 Derived and Recommended General Improvements to the Training Framework

Besides technical recommendations, general improvements were also derived from observations and discussions with the trainees; these improvements are discussed hereunder.

4.6.2.1 Pre-training Theoretical Explanations

Another challenge that was encountered by the trainees is the introduction of new terminologies during the training session. Thus, the training session was slightly interrupted with a few of the trainees to get to explain them these new terminologies. This is particularly the case since the trainees were undergraduate students who did not have strong background information on construction equipment. While the urge for a pre-training session might not be prominent in the case of construction workers, it is recommended to have a pre-training session whenever entirely new information is going to be introduced. This session would clarify the meanings of new terminologies to the trainees; thereby, eliminating potential interruptions during the VR-based
safety training session and enhancing the trainees’ focus and grasp of the information being taught during the training.

4.6.2.2 Personalized Feedback

As mentioned earlier, the trainees were exposed to two main types of feedback, one upon their failure to accurately identify all existing hazards in the scenario and the other after successfully identifying all hazards in the scenario. However, the feedback provided was unified to all students regardless of the difference in their wrong choices. This made the feedback provided slightly long. Therefore, it is recommended that future VR-based training programs provide personalized and response-specific feedback to each trainee according to their performance and answer choices. This would aid in shortening the duration of the training and prevent any side effects that might emerge because of wearing the VR headset for long periods of time.

4.6.2.3 Using Helpful Hints

Similarly, when the trainees failed to accurately identify all the hazards in each scenario, the feedback directly provided the trainees with explanations of existing hazards before allowing them to re-inspect the site and re-attempt to identify the hazards on their own. It was apparent that such feedback provision enabled them to promptly and accurately identify the hazards later; yet, this was based on their fresh memory of the new information gained. While this research did not assess the information retention of the trainees, it is expected that the lack of deep and critical thinking could impede their ability to recall information later. Therefore, it is recommended that hints are provided to the trainees prior to full explanations of the right answers to allow for cognitive scaffolding which engraves the content being taught in the trainees’ mind.
CHAPTER 5: DISCUSSION

This chapter provides a detailed discussion of the results obtained from the pilot study. It compares the findings of this research against findings from the literature to provide a better understanding of the results obtained and to pave the way for accurate conclusions to be drawn and recommendations to be made. It has been acknowledged that the development of theoretical frameworks for engineering education has been widely supported by academics and researchers. As stated by Mejia et al., (2018), critical theoretical frameworks are necessary to develop anti-deficit approaches to engineering education research (p.2). Yet, the findings of this research revealed a gap in the development of frameworks with direct reference to learning theories both for regular and VR-based training programs. Thus, in recognition of such a lack, this research developed and validated a framework that could be used for VR-based safety training programs.

The following paragraphs provide a detailed discussion of the most significant pillars of the developed framework namely, andragogy principles, and reinforcements and punishments as part of the behaviorism theory.

5.1 Andragogy principles

It was evident that the consideration of the andragogy principles has resulted in a significant increase in the trainees’ hazard identification, identification of accident paths, probability assessments, and hazard mitigation skills. Such improvements were primarily found in group 1 which attained significantly higher scores as compared to groups 2, 3, and 4.

This proves the first main hypothesis of this research stating that: “**H1:** It is predicted that the use of andragogy principles in VR-based training positively contributes to the learning outcomes of trainees” with statistically significant results. The enhancement in all the aforementioned factors, therefore, signifies a general enhancement of the trainees’ safety culture as a direct result of incorporating main andragogy principles. This is further supported by Enríquez et al., (2022) who state that andragogy principles aid in developing a culture of safety among trainees.

One of the main advantages of incorporating andragogy principles in construction safety training is the fact that it provokes the trainees’ interest in safety. As stated by Bhandari et al., (2019), “There is a pressing need to design safety training modules using principles of adult learning (e.g.,
andragogy, self-directed learning) that initiate and sustain interest in safety among construction workers” (p. 59). Hence, it could be concluded that the framework successfully achieved its first main targeted learning outcome which is: Enhanced safety culture motivation and perception.

Such interest could act as a main driving force toward learning and hence, improvements in hazard awareness and recognition. In fact, it has been proven that the enhancement is hazard identification is of great significance to the safety of construction sites. This is because of the enhanced hazard communication capabilities of workers through which prompt corrective measures could be implemented to mitigate the hazards (Demirkesen & Arditi, 2015). This is further supported by Hashem, et al., (2019) who stated that “In an event where hazards are not recognized, chances of injuries radically increase. Hazard recognition is a fundamental aspect for the success of any safety program” (p.19).

The fact that VR-based safety training enhances the trainees’ hazard awareness and identification skills has been already acknowledged in the literature (Le et al., 2014; Perlman et al., 2014; Martinez et al., 2020; Eiris et al., 2020; Dhalmahapatra et al., 2021; Mora-Serrano et al., 2021). Therefore, it is beyond the scope of this research. Rather, the main focus of this research was to develop a methodology training formwork that would further elevate the potential of VR technology.

Therefore, it could be stated that the inclusion of andragogy principles has proved significant results in relation to enhancing the trainees’ hazard awareness and identification skills. thereby, yielding a concrete foundation on which such improvements could be attributed to the consideration of main andragogy principles namely, their need to know and having a goal-oriented approach. Again, this showcases that the developed training framework successfully enhanced the second targeted learning outcome of this research which is: Enhanced hazard recognition & identification.

The consideration of andragogy principles have not been previously devised in VR-based training neither in general training programs nor in safety training programs. This is the case despite the fact that the consideration of andragogy principles and adult learning theories in safety training
has been advocated for by many researchers (Galbraith & Fouch, 2007; Tretsiakova-McNally et al., 2017; Bhandari et al., 2019; Enríquez et al., 2022). As stated by Galbraith & Fouch, (2007), “Andragogy is relevant to safety training because minimizing even one error could prevent permanent damage (p.41).

The case is quite similar when it comes to construction safety training. This is further supported by Albert & Hallowell, (2012) who acknowledged the fact that construction hazard recognition programs often lack roots in learning theories; rather, they are often based on pedagogy techniques that do not meet the requirements of adult learners. Despite the lack of existing research that could directly support/negate the findings of this research, the researchers sought to base the research’s discussion on similar findings.

The enhancement in the trainees’ overall scores could be attributed to the direct addressing of the learners’ need to know. As stated by Enríquez et al., (2022), “One of the measures that must be taken to improve the safety culture is to make people aware of why it is important to follow procedures and adopt good practices” (p.10). Whereas, Alexander, (1999) stated that “Adults must see the relevance of the material to their immediate needs”. This consideration has positively contributed to the trainees’ motivation to learn; thereby, enhancing their hazard identification skills along with their ability to assess the probability of risks and take applicable corrective measures. Similar findings have been found in the literature.

To illustrate, Albert & Hallowell, (2012) advocated for the introduction of a diagnosis of needs assessment, one that is much similar to the induction session that was provided to group 1 before the training. During the assessment, the trainees would be exposed to models of desired performance. The authors concluded that such an introduction would aid the trainees in identifying the gaps in their knowledge which enhances their motivation to learn. As stated by the authors “Then, a competence appraisal of the current safety process is conducted and is compared to the desired model. This exposes areas of concerns with the current safety status, allowing learners to comprehend and perceive the need for improvement” (p. 5).
Likewise, Galbraith & Fouch, (2007) designed a new laboratory safety training program that incorporated adult learning principles. Their results revealed that the trainees’ who attended the new training scored higher as compared to the ones who attended the traditional training. One of the most significant contributing elements of the new training, as discussed by the authors, is “relevance”. Relevance is a similar concept of addressing the learners’ need to know and it was discussed by the authors as relevancy-oriented/immediacy where the training objectives are set immediately so that the trainees can understand the rationale behind learning. As stated by the authors, “They (the trainees) were made aware of gaps in their knowledge, and where they are versus where they need to be and why (Galbraith & Fouch, 2007, p.40). Such an approach has contributed to the learners’ motivation to learn, causing them to score higher as compared to the learners of the traditional laboratory safety training.

Thus, addressing the learners’ need to know allows learners to clearly understand the personal benefits of acquiring knowledge and skills which motivate them to learn to improve their personal performance (Albert & Hallowell, 2012). Cook & Artino, (2016) found that relatedness and value attributions to the content that is being learned is closely associated to the trainees’ motivation to learn. Similarly, Houde, (2006) found that not knowing why learning something is important is often associated with a state of no or low motivation; on the other hand, providing the learner with a connection between learning and a core benefit that the learner appreciates, and values instantly brings them from a state of no motivation to a state of motivation to learn. These findings were further supported by Požega et al., (2020) who found that the motivation of the trainees to learn has increased after they were made aware of the different ways in which they would benefit from the training.

Likewise, Cook & Artino, (2016) stated that motivational drivers to learn are based on task value in terms of its importance and interest to learners; these drivers then lead to observable behaviors in terms of learners’ engagement levels, performance, effort, and persistence to achieve. This is further supported by Galbraith & Fouch, (2007) who stated that “Explaining how the training will help the participants encourages their participation (p.40). In addition, Požega et al., (2020) found that incorporating the principles of andragogy in training designs aided in attracting and sustaining
the attention of participants, motivating them, and encouraging their active participation throughout the training session.

In the same context, Hagen & Park, (2016) found that the core assumptions of andragogy have connections to neural networks related to memory and cognition. Such connections are based on the enhanced motivation levels to learn which promotes the learners’ focus and retention capacity through active participation and engagement throughout the training session; thereby, enabling learners to attain higher levels of achievement in their learning process. In the same vein, allowing the trainees to set their own goals and learning objectives aids in reducing resistance and improves the active participation of the trainees during the training session (Albert & Hallowell, 2012).

The training has also incorporated other parts of the andragogy principles which have been experienced by all four groups; these include autonomous and self-directed learning. As stated by Galbraith & Fouch, (2007), training programs that support self-direction have trainers who act as facilitators rather than instructors/teachers. This was the case in the VR training as the trainees were allowed to learn at their own pace, answering questions wrongly as many times as they fully understood and grasped the content of the training. Other principles that were integrated into the training were having a problem-oriented approach and feedback cycles.

5.2 Consequential Accidents
The potential of simulating accidents in safety training has been revealed for decades (Rubinsky, & Smith, 1973). However, most of the studied simulations were based on non-immersive computer-based simulations. Similarly, none of the existing research has attempted to quantify the effects of accident simulation on learning. Therefore, this research intended to investigate the effects of accident simulations on the learning outcomes of trainees.

Accident simulation was introduced into the training framework as part of the operant conditioning theory within the behaviorism learning theory. Thus, accidents were introduced as a form of positive punishment; as stated by Cherry, (2020), positive punishment “involves an aversive stimulus that is added to the situation. For this reason, positive punishment is sometimes referred to as punishment by the application.”. Therefore, multiple forms of accidents were introduced as
a form of unpleasant outcomes to undesired behaviors, which were negligence to crucial sources of risks or in other words, failure to accurately identify all existing hazards.

The results revealed that there is a statistically significant difference between the accident identification score of group 1 as compared to all other groups. This was attributable to the fact that they were able to identify more hazards as compared to other groups; hence, they were able to identify more accidents correctly. This supports the fact that the developed framework has positively contributed to the third targeted learning outcome of this research which is: Enhance the identification of hazard initiators & consequences of hazards.

However, no statistically significant difference in the accident identification score was found between the groups who viewed consequential accidents and the ones who did not. This negates the research’s second hypothesis which states that: “H2: It is predicted that exposing trainees to consequential accidents enhances their accident-path identification skills”. This was attributed to the fact that construction accidents are often limited to certain accident types that are well-known and could be easily predicted by the trainees.

This is further evidenced by the limited types of accidents that are being identified in the literature. To illustrate, OSHA’s fatal four discusses the four most common types of accidents in construction sites namely, falls, struck-by, electrocution, and caught-in-between (Sikra, 2021). Similarly, Choi et al., (2019) found that falls and struck-by accidents are the most common types of accidents encountered in the US, South Korea, and China. Whereas, Jeong, (1998) identified the most 10 common accidents in the construction industry as Falls, Machinery accidents, vehicle accidents, slips or trips, electrocution, ground collapse, overexertion injuries, fire/explosion, stuck-between, and being hit by an object. Therefore, it was apparent that the primary focus of existing research is to analyze the root causes of accidents (Harvey et al., 2018; Winge et al., 2019; Tong et al., 2020).

In fact, hazards are considered the root causes of risks and accidents. As stated by Liu et al., (2016), “it is clear that if the status hazards are not identified, they will directly break through the “three layers of defense” which includes control criteria, control measures, and rectification measures,
and then trigger accidents under some conditions.” (p.279). This places a huge emphasis on the significance of hazard identification to be able to take sufficient controls to eliminate potential accidents. While the second element, which is the introduction of consequential accidents, did not prove to be beneficial to the trainees’ accident identification score, it could be associated with other benefits.

Thus, the results revealed that experiencing consequential accidents in the VR environment enhanced the trainees’ overall risk perception. As stated by Hallowell, (2010), “Risk perception is defined as the subjective judgment that one makes about the frequency and severity of particular risks. Typically, these values are obtained by questioning individuals about specific risk scenarios and aggregating the data.” (p.403). It has been acknowledged that several factors affect the risk perception of construction workers including but not limited to age, years of experience, cultural differences, etc (Liu et al., 2016). However, since the research participants are all undergraduate students, it could be stated that the aforementioned factors are all controlled for. Therefore, any differences in the risk perceptions of the trainees could be safely attributed to the differences in the training procedure.

Considering the trainees’ assessment of the probability of risks, it was apparent that groups 2 and 3 were better able to assess the probability of risks as compared to group 4. This supported the research’s third hypothesis which stated: “**H3:** It is predicted that exposing trainees to consequential accidents enhances their ability to assess the probability of risks that are attributable to the identified hazards.”

Such improvements could be explained and interpreted by understanding the psychological mechanisms by which people evaluate the frequency or likelihood of events. One such heuristic is “Availability” or “Associative distance”. This means that people can better assess the probability of an event when recalling similar instances of events becomes easier. As stated by Tversky & Kahneman, (1973), “a person could estimate the numerosity of a class, the likelihood of an event, or the frequency of co-occurrences by assessing the ease with which the relevant mental operation of retrieval, construction, or association can be carried out.” (p.208). Based on the aforementioned discussion, it could be inferred that the trainees who viewed consequential accidents were better
able to assess the probability of their occurrences since they were better able to recall how often such accidents occurred as compared to the trainees of group 4.

When it comes to impact ratings, the results revealed that the trainees who did not experience consequential accidents namely, group 4, tended to underestimate the impacts of risks as compared to other groups. These results support the research’s fourth hypothesis which states that “\textbf{H4:} It is predicted that exposing trainees to consequential accidents enhances their ability to assess the impact of risks that are attributable to the identified hazards.”. Thus, it could be concluded that not exposing trainees to consequential accidents impaired their risk-assessment skills. These results conform to the findings of the literature which reveal that construction workers who have not experienced real-life accidents tend to have lower risk perceptions as compared to the ones who experienced or endured accidents (Kashmiri et al., 2020).

Another interesting interpretation of this finding could be related to the trainees’ habituation to risks. As defined by Daalmans & Daalmans, (2012), Risk habituation is a decrease in risk sensitivity to repeated exposure to hazards. This means that the more workers tend to experience a hazard, the less becomes their perception of the associated risk (Daalmans & Daalmans, 2012). Blaauwgeers et al. (2013) also added that in real-life, risk habituation increases when workers do not experience any negative consequence of the existing hazard or their unsafe work behaviors.

Similarly, Kim et al., (2021) found that repeated exposure to hazards in the virtual environment increased the trainees’ habituation to hazards. Thus, it could be stated that the trainees of group 4 experienced risk habituation since they did not experience any form of consequence in the virtual environment. Accordingly, Kim et al., (2021) found that the accident simulation in the VR environment has generated sustained impacts in mitigating the effects of habituation.

It was also apparent that groups 2 and 3 were better able to accurately assess risk impacts as compared to trainees of group 4, again confirming, in part, the fourth hypothesis of this research. Based on the aforementioned discussion, it could be argued that groups 2 and 3 experienced slower risk habituation rates as a result of their increased attention to hazards following their experience of the simulated accident. These results do not conform to the findings of Jazayeri & Dadi, (2020)
which reveal that construction workers, who previously experienced accidents were more likely to have exaggerated impact ratings of existing hazards. A possible interpretation of these findings could be as follows: since the trainees of groups 2 and 3 experienced consequential accidents without physically enduring any losses, injuries, or pain, they were more likely to accurately interpret the impact ratings of potential accidents.

In other words, it could be stated that introducing trainees to consequential accidents in the VR environment provided the right mix that neutralized the low-impact assessment that could have been made in the case of not experiencing the accident (similar to group 4) and the high impact assessment that could have been made as a result of actually experiencing the accident and enduring its consequences (similar to the findings from the literature); thereby, causing them to have optimum impact ratings.

However, this was not the case when it comes to the trainees of group 1 who also viewed consequential accidents; rather, group 1 tended to over-assess the impact of hazards as compared to other groups. Since groups 1, 2, and 3 all viewed consequential accidents, these results imply that the variations in impact scores could be attributed to the inclusion of andragogy principles. Thus, it could be stated that the inclusion of andragogy principles did not positively contribute to the trainees’ ability to assess the impacts of the hazard.

Nevertheless, evidence from the literature suggests that there might be other interpretations for these results. To illustrate, Kashmiri et al., (2020) revealed two crucial finds; firstly, the trainees’ who were enrolled in highly engaging safety training programs tended to have higher risk perceptions as compared to the trainees who were enrolled in low-engagement training programs. Secondly, it was also found that the effect of training on risk perception is highly mediated by hazard recognition performance; therefore, the trainees who were capable of identifying more hazards had higher risk perceptions. As stated by Kashmiri et al., (2020), “Therefore, workers representing projects that offered high-engagement training were able to identify a larger proportion of hazards, and consequently perceived that safety risk was relatively higher”.

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These results also conform to the findings of Jazayeri & Dadi, (2020) which reveal that construction workers with more years of experience tend to have higher perceptions on the impacts of risks; this was primarily attributed to the fact that they were exposed to more hazards and accidents throughout their work-life. However, different findings were revealed by Zhao et al., (2021) where it was found that the enhancement of hazard identification and recognition skills was associated with better ratings of impacts. Yet, it is worth noting that the research participants were workers from the chemical industry, which might be a possible reason for the variation in results.

The aforementioned results indicate that the devised framework has greatly contributed to the fourth targeted outcome of this research which is: Improved risk assessment skills (Likelihood & Impact). Nevertheless, it is apparent that having an accurate perception of risks, in terms of their probability and impact, is the ideal case for effective safety management. This is because adequate safety measures would be taken at the right cost and effort to eliminate potential accidents (Kashmiri et al., 2020). While higher perceptions of risks could be associated with additional costs due to need to take additional safety measures that are not necessarily needed, it could be argued that it is much better than having low perceptions of risks; where risks are underestimated leading to inadequate safety controls (Kashmiri et al., 2020).

Figure 49: Conceptual safety management process. Source: (Kashmiri et al., 2020).

Accident simulations in safety training were also associated with other benefits. To illustrate, Bhandari et al., (2019) simulated actual past injuries and incorporated them into the safety training of construction workers. The results revealed a significant increase in the trainees’ situational interest; thereby, making them experience sustained interest during the training. As found by the authors, workers who experienced a fictitious injury through simulations were not only more interested in the training but also, found greater value in the subject matter being taught (Bhandari}
et al., 2019). Thus, it could be stated that experiencing consequential accidents in the VR environment has increased the interest of the trainees.

Other studies have predicted sustained improvements in the trainees’ safety behaviors after being introduced to simulated accidents in their safety training programs (Rubinsky, & Smith, 1973). While this research did not focus on behavioral changes, it lays the ground for future research opportunities to measure and quantify the changes in behaviors that could be achieved upon experiencing positive punishments or consequential accidents in the VR environment.

5.3 Hazard Mitigation Measures

When it comes to the hazard mitigation scores, the results revealed that there is a statistically significant difference between group 1 as compared to other groups. This could be ascribed to the trainees’ enhanced ability to identify more hazards and hence, more applicable hazard mitigation measures. Concerning other groups, the results revealed that the ones who did experience corrective measures in the VR environment namely, groups 2 and 4 obtained statistically significantly higher scores as compared to group 3. This supports the research’s fifth hypothesis which states: H5: It is predicted that exposing trainees to the right course of action enhances the trainees’ safety management and hazard mitigation skills.

Despite the fact that group 3 received similar auditory feedback which details the needed hazard mitigation measures that should be implemented, groups 2 and 4 outperformed group 3. This is attributed to the fact that trainees were better able to recall the safety measures viewed in the VR environment, compare them against the pictures, and identify the missing ones to mitigate existing hazards. These findings are further supported by Krokos et al., (2018) who found that the VR experience significantly enhances memory recall experience; thereby, providing users with a memorable experience. Therefore, it could be safely concluded that the developed framework positively contributes to the fifth and sixth targeted learning outcomes of this research which are: Enhanced awareness of preventative & mitigative measures; and Enhanced selection of the right course of action.
In fact, a similar VR approach has been proposed by Stone et al., (2021) to aid in achieving community resilience against natural hazards; thus, the researchers propose that simulating natural hazards, their consequences, and the consequences of applicable protective measures is predicted to influence attitudes and behavioral intentions of the general public to take protective action. Likewise, a similar VR-based framework has been proposed by Asad et al., (2021) to train workers in the oil and gas industry. In their model, the trainees would be exposed to potential hazards and their suitable controlling measures for onshore and offshore drilling sites. It is expected that the training would aid the trainees in developing effective hazard-controlling strategies to overcome challenging industrial hazards (Asad et al., 2021).

However, none of the aforementioned models have been tested yet. Hence, it could be safely stated that this research is the first to quantify the effects of experiencing protective safety measures in the virtual environment on the trainees’ ability to accurately devise the needed hazard mitigation measures. This significantly contributes to their safety management skills, one of the major targeted learning outcomes of this training module.

When it comes to the comparison between groups 2 and 4, no statistically significant difference was found between the groups, albeit group 2 had a higher average score as compared to group 4. Despite the fact that both of them viewed corrective measures, group 2 was introduced to negative reinforcement as part of their operant conditioning. As defined by Cherry, (2020), negative reinforcement involves “the removal of a negative outcome to strengthen a behavior”. As a form of reinforcement, negative reinforcements tend to strengthen a behavior that precedes it; accordingly, the learner is being rewarded for this behavior by the removal of an adverse impact or consequence.

Thus, the accident that was experienced by group 2 was initially removed as a form of negative reinforcement before they were introduced to the applicable safety measures. This followed the desired behavior, which is their increased attention toward existing hazards and their ability to accurately identify them. While negative reinforcements did not yield statistically significant differences, it somehow aided in improving the hazard identification score of group 2 as compared to group 4.
Nevertheless, evidence from the literature suggests other benefits of reinforcements in general. To illustrate, it has been acknowledged that reinforcements, whether positive or negative, have a significant effect on trainees’ knowledge retention (Solomon, 2018). This trait is a direct measure of the effectiveness of training programs, especially when it comes to safety training. Similar findings have also been found in the literature when it comes to the relationship between reinforcements and memory in learning (Solomon, 2018).

While this research did not study the trainees’ ability to recall the learned information, it is predicted that the trainees who viewed all the applicable safety measures would be capable of detecting any missing safety measures and or devising additional safety measures in real construction sites. This is supported by the interesting findings of Godden, & Baddeley, (1975) which reveal that, based on context-dependent memory, people can easily recall things in a particular situation if they have previously experienced a similar context. Thus, it could be argued that having experienced the right course of action and applicable safety measures that should be maintained in the VR environment, the trainees could easily recall such measures and apply them in real construction sites.
CHAPTER 6: CONCLUSION

6.1 Research Summary

To conclude, this research aimed to develop a comprehensive a fully comprehensive, immersive, and interactive VR-based safety training program that tackles hazardous aspects of high-rise building construction based on learning theories. The following paragraphs presents a conclusion of the findings of this research in relation to each of the objectives.

6.1.1 Objective 1: To Identify all Potential Safety Hazards in High-rise Building Construction.

To achieve this objective, an extensive review of the literature, interviews with safety experts, and site visits to high-rise construction sites were conducted. The results of the literature yielded seven main safety hazard themes which are more of general hazards in nature. These are as follows: 1. Lack of adequate training; 2. Poor working conditions; 3. Poor safety management; 4. Lack of adequate safety measures; 5. Human acts/behaviors; 6. Human acts/behaviors; and 7. Tough working environment. In total, 20 main hazards were gathered from the literature review under the aforementioned themes.

Concerning the safety interviews, five main interviews with safety managers of high-rise construction projects were conducted. In total, eleven main themes of sources of hazards were identified from the interviews namely, 1. Handling & Storage; 2. Accessibility & Egress; 3. Safety Facilities; 4. Slab edges & openings; 5. Concrete Pre-stressing; 6. Concreting; 7. Formwork; 8. Tower Cranes; 9. Scaffolds; 10. Fire hazards; and 11. Unsafe working behaviors. In total, 71 hazards were identified under the aforementioned themes.

With regards to the site visits, five main site visits were conducted to mega high-rise projects that are still under construction. In total, fifteen main themes of sources of hazards were identified from the interviews namely, 1. Building's Perimeters; 2. Accessibility & Evacuation; 3. Housekeeping; 4. Slab edges & openings; 5. Hoists; 6. Scaffolds; 7. Tower Cranes; 8. Slipping/jumping Formwork; 9. Cradles/gondolas; 10. Vehicles & equipment; 11. Windscreens; 12. Fire hazards; 13. Electric Hazards; 14. Extreme weather conditions; and 15. Unsafe working behaviors. Thus, 76 hazards were identified under the aforementioned themes.
6.1.2 Objective 2: To Design and Validate a Conceptual Framework for the Conduction of VR-based Safety Training Programs Based on Learning Theories

The main aim of this objective is to ensure the development of an effective and efficient safety training program that meets international standards and is successfully capable of lowering accident rates in high-rise construction projects. Thus, the main targeted learning outcomes were initially identified as: enhanced safety culture, hazard recognition & identification, consequence awareness, risk assessment skills (Likelihood & Impact), and hazard mitigation skills. The developed conceptual framework is based on three main learning theories namely, behaviorism, constructivism, and andragogy principles.

Evaluation of the results was made by comparing the mean values using multiple statistical tests to compare variances in research data. To start with, it was evident that the introduction of andragogy principles positively contributed to the trainees’ learning outcomes in terms of their hazard awareness, identification, assessment, and mitigation skills. This could be directly attributed to the enhancement in the trainees’ safety interest, motivation to learn, focus, and self-direction; all of which resulted in enhanced engagement, effort, persistence, and knowledge-retention capacity by the trainees; thereby, leading to higher performance and learning outcomes.

Likewise, the introduction of punishments or consequential accidents in VR-based training programs was also associated with positive outcomes in relation to the trainees’ hazard assessment skills. This is directly attributed to enhanced risk perception level accidents and similar accidents that aided them in accurately assessing the probability of future accidents and enhanced situational interest. Moreover, exposing trainees to consequential accidents aided them in overcoming the risk habituation phenomenon, a phenomenon that decreases the risk sensitivity as a result of repeated exposure to hazards without any negative consequence. However, it was apparent that combining both andragogy principles and consequential accidents caused the trainees of group 1 to over-assess the impacts of the risks.

Finally, it was also evident that the introduction of hazard mitigation measures in the virtual environment positively contributed to the trainees’ hazard management skills along with an enhanced selection of the right course of action. This is another interesting finding of this research.
as this research is the first to quantify the effects of experiencing protective safety measures in the virtual environment on the trainees’ ability to accurately devise the needed hazard mitigation measures. The findings revealed that the improvement is directly related to the enhancement in the trainees’ memory recall which allowed them to better recall the safety measures viewed in the VR environment, compare them against existing situations, and identify the missing and needed safety measures to mitigate existing hazards.

6.1.3 Objective 3: The Design and development of the Comprehensive VR-based Safety Training Program for High-rise Construction

After categorizing the hazards identified from the literature review, site visits, and expert interviews, seven main modules for the comprehensive VR-based safety training program for high-rise construction were developed namely, 1. General Safety Procedures; 2. General & Enabling Work; 3. Structural Frames, Formwork, & Concrete Work; 4. Lifting Appliances & Gear; 5. Machine, Equipment, & Hand Tools; 6. Safety of Workplaces; and 7. Personal Conduct. In total, twenty-five chapters have been developed under the seven modules of the comprehensive training program. The software used in this research is Unity2019. The main engine scripting in Unity is C#. The main hardware component used is the Meta Quest 2 (initially sold as Oculus Quest 2).

6.1.4 Recommendations for Future Developments of VR-based Safety Training Programs

To conclude, the framework developed proved its efficiency and effectiveness in achieving the desired learning outcomes using VR-based training programs. However, the following recommendations could further contribute to the learning outcomes of the trainees and aid in elevating the potential of the technology. To start with the technical recommendations, it is recommended that the render resolution of the surrounding objects be reduced while keeping the resolution of the targeted objects/assets high to maintain visual clarity. Secondly, it is recommended that future research should consider lowering/silencing the background sound effects while providing trainees with feedback on their performance. Finally, it is recommended that future research consider using human-read audio or better-quality AI audio generators to enhance the quality of the feedback provided.
Moving on to the general recommendations, providing the trainees with a pre-training theoretical session, whenever entirely new information is going to be presented, is recommended. Secondly, it is recommended that future VR-based training programs provide personalized and response-specific feedback to each trainee according to their performance and answer choices to shorten the training duration. Lastly, the provision of hints to the trainees, prior to full explanations of the right answers, is recommended to allow for cognitive scaffolding which further engraves the content being taught in the trainees’ mind.

6.2 Limitations and Recommendations for Future Research

Based on the findings, the following limitations and recommendations are provided.

- First and foremost, this research targeted the immediate improvements in the learning outcomes of the trainees, without direct measurements of the sustainability of the attained outcomes, which is a main limitation in this research. Therefore, it is recommended that future research examine the extent to which the improvements in the learning outcomes could be sustained over a longer period.

- Secondly, the focus of this research was to inspect the effects of the training on the learning outcomes of the trainees; however, it did not assess the extent to which the gained knowledge could be readily applied in practice, which is another limitation in this research. Therefore, future research should consider assessing the extent to which this training framework is effective in introducing positive behavioral changes that reflect an enhanced safety culture by the trainees.

- Thirdly, this research found that addressing the learners’ need to learn without direct instruction from psychologists could lead to reactions of intense fear and anxiety from the trainees. Therefore, it is recommended that the induction session, based on andragogy principles, needs extensive planning and design with guidance from people with expertise in the field of psychology.

- Finally, it is recommended that future research further examine the effects of introducing negative reinforcements on the learning outcomes of the trainees.
REFERENCES


