DEVELOPMENT AND PILOT TESTING OF A SERIOUS GAME FOR CONSTRUCTION FALL PROTECTION AWARENESS TRAINING

By

Mrudul Patil

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Construction Management – Master of Science

2020

ABSTRACT

DEVELOPMENT AND PILOT TESTING OF A SERIOUS GAME FOR CONSTRUCTION FALL PROTECTION AWARENESS TRAINING

By

Mrudul Patil

Construction proves to be one of the most dangerous and deadly trades in the United States. The major cause of fatal injuries in construction is due to falls and their occurrence has only increased over the years. Ineffective and low-engaging methods used to deliver construction safety training contents are among the major factors that contribute to high rates of injury. This can be prevented through more effective safety training. Serious Games are interactive training tools used with modern computer applications that offer engagement missing in traditional construction safety training methods. The purpose of this thesis is to develop, and pilot test a construction safety training Serious Game titled*, FallSafe,* that focuses on fall protection training*.*

FallSafe is implemented in Virtual Reality to create a life-like training experience and uses first-person perspective and storyline to engage the player in reporting on-site hazards as a construction safety intern attending their first day of work on site. The implementation of a Serious Game framework during the development of *FallSafe* ensures consistent delivery of desired learning outcomes.

FallSafe is then pilot tested on six students and is found to be an engaging and effective method of construction safety training and received praise for its storyline, interactivity & use of Virtual Reality technology to deliver construction safety training. *FallSafe* has the potential to be further developed, tested, and implemented to teach construction safety on a large scale which could help prevent injury and death onsite and decrease costs to firms.

ACKNOWLEDGEMENTS

I am deeply grateful to my advisor, Dr. Mohamed El-Gafy for providing me with this unique and wonderful research opportunity. Thank you for your constant support and for the insightful conversations that helped me develop my thoughts and ideas. Thank you to my committee members, Dr. Dong Zhao and Dr. Trish Machemer for your great inputs and suggestions that added great value to this research work.

I would like to thank my parents, Ujjwal and Hemlata and, my brother, Sayujya for loving me and, for their unconditional support throughout my journey in life. I am grateful to my friends Aakash, Ritesh, Kaitlin, Ahamed, Nitesh, Pandey, Amar, Sree, Fateh, Harsh and Pidiha for always being there for me and for providing me with ideas to excel and succeed in life. I am deeply grateful for all of your contributions to me. Without your support, this endeavor could not have been possible.

I thoroughly enjoyed my time here at MSU thanks to Dr. George Berghorn, Dr. Matt Syal, Dr. Sinem Mollaoglu and Prof. Time Mrozowski. I am grateful to you for educating me in variety of topics. Thank you for making my time here at MSU memorable, I shall cherish this experience lifelong.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

SG	Serious Games
VR	Virtual Reality
HMD	Head Mounted Display
NPC	Non-Playable Character
SG	Serious Games
VR	Virtual Reality
HMD	Head Mounted Display
NPC	Non-Playable Character
OSHA	Occupational Safety and Health Administration
UES	User Engagement Scale
UE	User Engagement
BIM	Building Information Modelling
MDA	Mechanics-Dynamics-Aesthetics Framework
DPE	Design, Play, and Experience Framework
PPE	Personal Protection Equipment
FA	Focused Attention
PU	Perceived Usability
AE	Aesthetic Appeal
EN	Endurability
NO	Novelty
FI	Felt Involvement
RW	Reward Factor

Chapter 1: Introduction

There is evidence that suggests current construction safety training is ineffective and often taught through low-engaging methods (Burke et al., 2006, Shamsudin et al., 2018). These inadequacies result in great costs to employers and society (Wilkins, 2011). A review of current research on the engagement provided by e-learning versus traditional methods of teaching construction safety training reveals highly engaging teaching tools result in greater knowledge retention. The idea of developing an interactive, engaging, and therefore more effective method of construction safety training in the form of a Serious Game using Virtual Reality is the basis for this thesis.

1.1. Background

The construction industry employs approximately 8% of the total U.S. workforce and has the highest fatality rate of any industry at over 20%. The high-risk nature of the industry produces enormous costs to employers and society. In 2004, the U.S. Census Bureau found that construction firms paid more for worker's compensation premiums than any other industry employers following 460,000 disabling injuries equating to a $15.64 billion cost to firms (Hallowell, 2010). Everett and Frank (1996) discovered a shocking statistic in nonresidential construction alone: for every new project, the cost of accidents is factored in at anywhere from 7.9% to 15% of the total project cost for new construction. Employers will need to invest in effective accident and injury prevention, such as enhanced safety training, to move away from these shocking statistics and decrease excessive costs and fatalities. Current research suggests there are many inadequacies in our current construction safety training methods.

A review of selected construction industry surveys and investigations reveals that lack of proper safety training often occurs prior to workplace mishaps which result in worker injuries

and deaths (Cohen et al., 1998). Studies have found several shortcomings regarding the current health and safety training in the construction industry. Wilkins (2011) in a study of 121 construction professionals who had completed their Occupational Safety and Health Administration (OSHA) 10-Hour safety training observes workforce dissatisfaction with the effectiveness of safety training they had undergone. In their survey it was found that 74% of the participants undertook training only to satisfy a requirement put forward by their employer as opposed to learning construction safety best practices. Burke et al. (2006) reported that health and safety training is commonly taught through passive techniques like lectures. Shamsudin et al. (2018) reports that passive learning methods are ineffective in delivering training content. These inadequacies in delivering training content are among the major factors that contribute to high rates of injury in construction (Wilkins, 2011).

According to a study, 71% of organizations that undertook safety training initiatives report lower injury rates (Lingard, 2010). Although all forms of training provide positive behavioral performance improvements, workers show greater knowledge retention along with reduced accidents, injuries, and illness when the training method is more engaging (Burke et al., 2006). One way to address high rates of injury and deaths of workers in construction and decrease costs to employers and society is through more engaging, and therefore effective, safety training methods. The effectiveness of the training depends directly on how organizations communicate training requirements with its workers. Studies show that site supervisors taking on a trainer role can be beneficial., and safety training that has a narrow focus specifically including hazard recognition is more effective in reducing injury and death onsite (Colligan and Cohen, 2004). Loosemore and Malouf (2019) suggest the use of an interactive method of safety training to help shape a worker's positive attitude towards safety.

Hallowell (2010) calls for an increase in investment by construction firms towards improving the quality of existing training programs, pointing out that only 2.2% of the price of a

facility is devoted towards safety efforts. They also found convincing construction managers that safety training is cost-effective for firms is essential to prioritize accident and injury prevention. Ho and Dzeng (2010) report safety training through digital learning to be beneficial to companies economically as well as in providing effective training for construction workers. They also found that independent nature of e-learning both improves user satisfaction and is economical as it reduces the risk of training-related injury, property damage, and operator error on site.

Serious Games show potential to provide engagement and interactivity missing in conventional lecture-based training (Clark et al., 2016, Erhel & Jamet, 2013). Yusoff (2010) defines a Serious Game as "A learning tool that incorporates game technology for the purpose of achieving learning objectives rather than pure entertainment." Serious Games can be used as an effective and engaging e-learning tool for construction safety training that considers the importance of cost-benefit to construction firms. An added Virtual Reality component will create a hands-on and highly interactive environment, it is the next closest training experience to on-site learning. The purpose of this study is to develop a construction safety training Serious Game implemented in Virtual Reality, with a specific focus on hazard recognition, to enhance knowledge retention and promote safe behavior in the field of construction.

1.2 Research Objectives

This study aims to develop an interactive and engaging method of construction safety training in the form of a Serious Game. The research objectives are to:

Develop a Serious Game for Fall Prevention Training that[1]

1. Incorporates relevant safety training contents;

[1] The scope of the safety training content in the Serious Game is limited to Fall Prevention Training Guide published by the Occupational Safety and Health Administration (OSHA, 2020).

2. Implements the Serious Game in a Virtual Reality (VR) environment to increase its engagement and interaction qualities; and
3. Validates the Serious Game by conducting a pilot study.

1.3 Scope of Research

The objective of this study is to develop an interactive and engaging safety training module in the form of a Serious Game and then to pilot test that Serious Game. The purpose of pilot testing the game is to receive feedback from participants that will help further advance game development and enhance delivery of safety training contents. Best practices for developing a Serious Game will be discussed. The Serious Game is presented here as an alternative to conventional lecture-based training, but comparisons between these two forms of training is outside the scope of this study and could be addressed in future works.

1.4 Research Methodology

1.4.1 Understanding Serious Games

A comprehensive literature review is conducted to understand Serious Games and engagement provided by them. In section 2.1, a definition for Serious Games in addition to their history, purpose, and utility as a training tool is discussed to provide the reader with a detailed understanding of how Serious Games have developed over time, and the ways they have and can be used to effectively transfer knowledge to participants.

Section 2.2 will describe the engagement provided by Serious Games, which is the focus for our research in describing why they are so effective and enjoyable for learners as opposed to passive or traditional teaching methods.

Comparison studies between Serious Games and conventional tools of safety training in terms of knowledge transfer to the participant is discussed in section 2.3.1. These traditional tools are also discussed in the broader realm of e-learning and its engagement and efficacy in

section 2.3.2. Then Section 2.4.1 provides a brief history of Serious Games developed in the field of construction safety, and 2.4.2 specifically details the use of Virtual Reality in construction safety training. In section 2.5.1, the game framework is discussed, which is the structure used to develop a comprehensive Serious Game that is implemented in *FallSafe,* the game that is created for this thesis. Characteristics of Serious Games that support learning and best practices for developing Serious Games are discussed in section 2.5.2.

1.4.2 Development of Serious Game

A Serious Game development timeline is provided for the readers to highlight important processes and methods used. Technology used in the development of the Serious Game is discussed. Through the literature review a suitable Serious Game framework is selected, which forms the basis for the game's development.

Throughout the development of *FallSafe*, the game is play-tested on participants to receive (continuous) feedback. This allows improvements to be made in the game to achieve desired learning outcomes.

1.4.3 Selection of Safety Training Content

The motivation to select the OSHA Fall Prevention Training Guide as safety training content for *FallSafe* is due falls at construction sites being a top cause of injury and death. According to OSHA, the most frequently cited violated standard for the fiscal year 2019 was: "Duty to have fall protection." (29 CFR 1926.501) (see Table 1.1). This violation has been on top of OSHA's list for 9 consecutive years (Druley, 2019).

Year	*Number of violations recorded by OSHA for that fiscal Year (Duty to have Fall Protection)*
2011	*7139*
2012	*7250*
2013	*8739*
2014	*7516*
2015	*7402*
2016	*6906*
2017	*6887*
2018	*7216*
2019	*7014*

Table 1.1: Number of violations recorded by OSHA from 2011 - 2019 (Duty to have Fall Protection)

For the fiscal year 2018: Out of 1008 fatal injuries in construction, 338 (33.5%) were due to falls, slips, trips (fatal injuries due to falls to lower level: 320). Falls are the major cause of fatal injuries in construction and their occurrence has only increased over the years (see Figure 1.1).

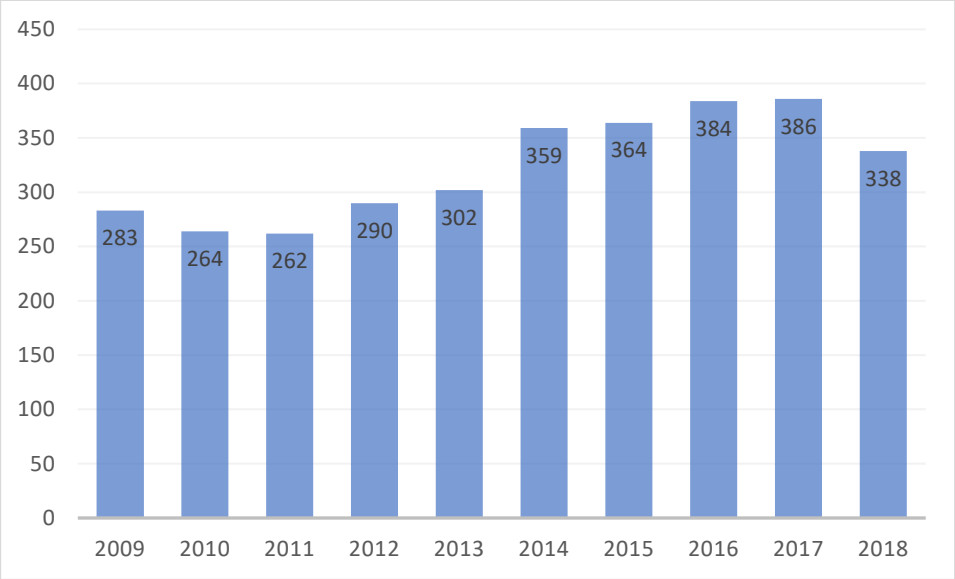

Figure 1.1: Fatal injuries in construction due to falls, slips, trips

Out of those 338 fatal injuries, 111 took place in the domain of residential construction. Over the past few years, falls, slips, trips have been a major factor contributing to fatal injuries in residential construction (Census of Fatal Occupational Injuries [CFOI], 2019) (see Figure 1.2).

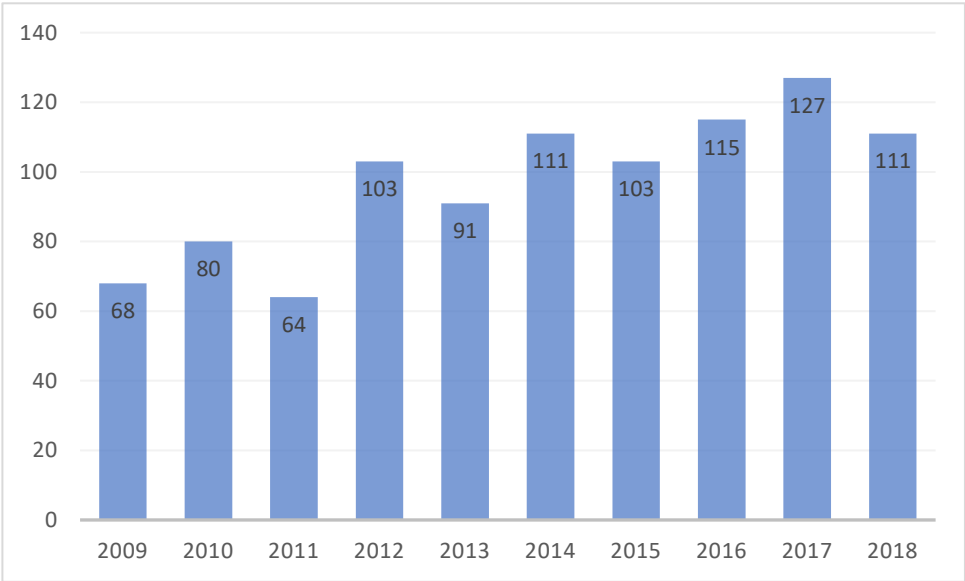

Figure 1.2: Fatal injuries in residential construction due to falls, slips, trips

Analyzing the above data, the focus of our training content is directed towards fall prevention (residential construction).

1.4.4 Validation of Serious Game

Validation of the *FallSafe* is carried out through pilot testing on a group of students from Michigan State University - School of Planning, Designing & Construction - Construction Management program. Six participants are selected ranging from those having no safety experience to students who have undergone safety training.

A pre-survey will help us collect information regarding safety training background and basic demographic information of the participants and their experience in playing games. The survey contains a follow up survey and a User Engagement Scale (UES) consisting of 31 questions to be scored on a 5-point Likert scale. The purpose of the feedback survey and UES is to obtain feedback regarding effective delivery of learning content and overall engagement provided by *FallSafe*.

1.5 Definition of Key Terms

1. Serious Games - “A learning tool that incorporates game technology for the purpose of achieving learning objectives rather than pure entertainment.” (Yusoff, 2010)
2. Virtual Reality – “Virtual Reality is the use of computers and human-computer interfaces to create the effect of a three-dimensional world containing interactive objects with a strong sense of three-dimensional presence.” (Bryson, 1996)
3. E-Learning - Digital learning methods; learning through the use of computers.
4. Engagement (regarding Serious Games) - A state of being wholly focused, invested, and internally motivated during game play.

5. Serious Game Framework - Underlying structure that ensures delivery of learning content through Serious Game play.
6. User Engagement Scale - A series of 31 questions based on 4-6 dimensions that can help measure user engagement of survey participants. (O'Brien, 2018)

1.6 Organization of Thesis

Chapter 1 consists of the introduction. Literature review conducted is discussed in Chapter 2. Chapter 3 describes the research methodology: Development of Serious Game with the safety contents. Chapter 4 discusses pilot testing and results. Chapter 5 consists of a conclusion, with suggestions for further research and studies.

Chapter 2: Literature Review

This literature review serves to familiarize readers and researchers with a comprehensive overview of Serious Games. This overview of their history and purpose, in addition to their current application as training tools in construction and other industries, provides a better understanding of why they are so valuable for transferring knowledge. A best definition for Serious Games is selected, then following is a brief history of their development and broad applications. Engagement provided by Serious Games, e-learning tools in general compared to traditional teaching tools, and recent examples of the use of e-learning and Virtual Reality in the field of construction safety training is discussed. This chapter concludes with the structural components (Serious Game framework) necessary to create an effective Serious Game, and a brief chapter review. This comprehensive literature review is carefully considered in the development of *FallSafe*.

2.1 Overview of Serious Games

2.1.1 Definitions Provided for Serious Games

It is important to note that for the purpose of this study, Serious Games specifically refers to educational games used with modern computer applications. Wilkinson (2016), in their research on the history Serious Games, stated that, games created and played for the purpose of learning or training, for example to teach military preparedness, could date back to the 7th century. The precursor to chess, called “Chaturanga”, developed in India is a very early example of a military strategy game. The game “Monopoly” is a more modern (originated in 1902) example of a Serious Game used to teach an anecdotal lesson (Wilkinson, 2016). For this study it is most relevant to speak on modern Serious Games that utilize E-learning, from basic computer applications to Virtual Reality.

The term was coined, with regards to its modern usage, by Clark Abt (1970). The following statement describes Abt's thoughts on Serious Games and is similar to definitions that would be proposed much later as Serious Games gain popularity as training tools and become economically important, as well as further researched and developed: "Games may be played seriously or casually. We are concerned with Serious Games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that Serious Games are not, or should not be, entertaining." Many have wrestled with the oxymoronic nature of the phrase "Serious Games", regarding whether it should be implicitly stated that while a game is inherently entertaining and this aids in engagement, it may not be the primary focus of a Serious Game (Djaouti, et al., 2011).

More definitions follow that attempt to pinpoint the exact purpose and function of a Serious Game. Garrison et al. (2002) refers to Serious Games as instructional games designed for training or educational purposes. Michael and Chen (2006) define a Serious Game as: "... a game in which education (in its various forms) is the primary goal., rather than entertainment", and add that, "Serious Games are games that use the artistic medium of games to deliver a message, teach a lesson, or provide an experience." The experience aspect of this definition is particularly relatable to the current study, as the use of Virtual Reality provides a near life-like training experience. Yusoff (2010) narrows the definition to: "a learning tool that incorporates game technology for the purpose of achieving learning objectives rather than pure entertainment." It is clear from the above definitions that Serious Games are learning tools that may or may not be entertaining and utilize gaming technology. Michael and Chen (2006) feel Serious Games to be primarily educational., another (Zyda, 2005) argues instruction should be embedded into the story, and entertainment is the primary goal of a Serious Game. While video games combine story, art, and software, Serious Games include these, but also add pedagogy (Zyda, 2005). Both perspectives are valid, and pedagogical experts and video game designers need to work together to create effective Serious Games (Zyda, 2005).

While several definitions present similar concepts, the most specific and detailed definition, provided by Bergeron, B. (2006) guided this study. He defines a Serious Game as an interactive computer application, with or without an important hardware element, that

1. Has a challenging goal
2. Is fun to play and/or engaging
3. Incorporates some concept of scoring
4. Imparts to the user a skill, knowledge, or attitude that can be applied in the real world

These key concepts are all present in the construction safety training game, *FallSafe*, and in section 2.2 more information is present regarding motivation and entertainment that contribute to engagement. A more in-depth, but brief history of the development of Serious Games using game technology is in the following section, beginning with Abt's work in designing Serious Games for the military.

2.1.2 Serious Games: Brief Developmental History and Current Applications

While some of the first computers ever built had games programmed on them for research purposes, the first games designed for training purposes were created by Clark Abt in the 1960's and 1970's (Abt, 1970). Abt was well-funded in his efforts to create interactive training games for the military, Serious Games that teach military preparedness could date back thousands of years. He designed digital Serious Games in order to amend what he considered "motivational inadequacies" in the current education system by providing an interactive and engaging experience as opposed to a passive one. Abt also felt the digital world provides a place to experiment and explore safely (Wilkinson, 2016).

While there was concern for video games providing too much of a fantasy experience, for example people not confined to the laws of gravity, the idea of low-cost simulation training was of particular interest to the military and still is as discussed by Suzi (2007). Building upon previous games designed for military training, in 1980 Atari released "Army Battlezone", the first publicly

available military training game (Susi, 2007). However, the game that set the stage for Serious Games to be used as effective training tools worthy of investment on a large scale was “America’s Army”, released by the United States military for free PC download in 2002. At one point an estimate of 30% of young adults ages 16-24 born in the U.S. knew some idea of what army life was like from playing this computer game, as it only depicts real weapons, gear, and transportation. “America’s Army” succeeds as both an educational Serious Game and recruitment endeavor on a large scale, Army recruits increased in the early 2000’s and implementing the game cost 15% less than past recruitment programs (Susi, 2007).

Susi (2007) discusses some common misconceptions and lesser- known benefits of video game play, these include cause for concern for potential negative impacts of Serious Games or violent video games in general., such as withdrawal from social activity, addiction, or increased aggression, but these claims are not supported by most research. Instead, some heightened states of physiology or emotion can occur occasionally in the short-term, such as rapid heart rate, but these physiological responses are almost always briefly experienced only during game play. Susi (2007) also describes how Serious Games demonstrate positive effects on psychology, skill development, and physiology, including for rehabilitation purposes and improvements in hand-eye coordination, for many participants across applications. Positive effects of training with serious games, such as rapid decision making, improvements in hand-eye coordination, and collaboration with team members, are attractive to a variety of industries and employers (Susi, 2007).

While Serious Games may have originated for military training purposes and are still widely used in that way today, Serious Games are becoming increasingly essential as training tools for a variety of industries. Michael and Chen (2006) describe a broad range of training applications for Serious Games, in addition to military, that include healthcare, corporate, education, art, politics, government, and religion. Zyda (2005) adds that potential applications

also include strategic communication and human performance engineering. Healthcare applications are particularly broad, and could include training surgeons, treating mental and behavioral health disorders, and providing physical rehabilitation services, just to name a few. Serious Games have shown great promise in treating children with Autism, as they are being used to teach social and communication skills, such as (facial) emotion recognition (Grossard, 2017). They are used as distraction therapy during painful medical procedures for the chronically ill, and for those who suffer from pre-treatment anxiety (Susi, 2007).

Outside of traditional employment training, artistic and religious applications for Serious Games are also broad, especially as teaching tools centered around a physical space, like a museum. Wakkary et al. (2009) developed a Serious Game, called "*Kurio*", that allowed families to virtually visit art museums, and the Serious Game, "Mystery at the Museum" developed in 2005, is an interactive multi-player game that encourages players to work together and think critically about the exhibits they encounter during game play (Froschauer, 2011).

In 2017, two brothers sought funding through Kickstarter (https://www.kickstarter.com/projects/1622773351/the-bible-videogame-david), an online crowdsourcing website, to create a Serious Game that would teach the stories of the bible. It is entitled, "The Bible Videogame: David", and nearly $50,000 USD was raised to fund its production and distribution. A search for "Serious Game" in Kickstarter on October 02, 2020 produced 53 results for Serious Game projects designers are seeking to fund. While this may not indicate Serious Games have mainstream popularity, their popularity and access to play and development is expanding greatly since their original applications in the late 20th century.

In a world that has a rapidly changing climate and is experiencing natural disasters increasing in severity and frequency Meera (2016) suggests that teaching disaster preparedness on a large scale is essential. Serious Games are being developed that teach preparedness and risk mitigation, for example flood risk management. They have the potential to reach a large

audience, as the image-based nature of Serious Games allows them to be made available to people who are illiterate, who belong to some of the highest risk groups for disaster impacts (Meera, 2016). Serious Games are now being widely applied as training tools for a variety of corporations, especially regarding safety-based training as in the construction industry, which provides the need and inspiration for *FallSafe*. Now that the reader has a better understanding of the history and applications of Serious Games, it is important to discuss player engagement, which is why Serious Games are so effective at delivering content and have such broad applications as teaching and training tools.

2.2 Engagement in Games

2.2.1 Player Motivation

Abt's training-based Serious Games in the 1970's result from the idea that the current training and education methods at the time were demotivating, and Serious Games would provide greater interaction and engagement (Abt, 1970). Garris et al., (2002) describe the process of engagement for a player in a video game using an Input-process-Outcome game model. They state that if learning content is incorporated well within game attributes or characteristics, a game cycle is activated in which "users are engaged in repetitive play and continually return to the game activity over time" (p. 445). The cycle engages and induces self-motivation in the player, which leads to understanding of learning content. Here, motivation is described by the author as a willingness or desire to engage in a task. As mentioned in the definition for Serious Games that guides this study, motivating components such as challenging goals, fun, and scorekeeping are important components that facilitate learning.

Gee (2003) describes motivation as the most critical factor that facilitates learning. According to them, good video games create an environment for people to recreate and learn simultaneously and players absorb themselves in the game environment, something that

traditional tools cannot achieve. When players deeply engage in an activity, they are in a state of “flow”. Csikszentmihalyi (2009) describes the positive experience of being fully engaged in an activity (game) as being in a state of “flow”, “in which one completes task(s) at hand gracefully and effortlessly with a great sense of ease, control, and intense focus”. During this state of ease, players may be more open to learning. Bente and Breuer (2010) shares the idea of “stealth learning”, where players process learning content within Serious Games without considering learning activity embedded within as being external. Learning knowledge should be implicitly delivered through Serious Game play, and any successful Serious Game should aim to achieve this kind of implicit teaching.

Boyle and Connolly (2008) undertook a review of theories that explained player enjoyment while playing video games. They report that human beings, in order to satisfy their psychological needs of esteem, recognition, achievement, satisfaction and enjoyment, take part in activities that enable this satisfaction. They found video games to be one of the activities that enables human satisfaction (Boyle and Connolly, 2008). Players are motivated to participate in such activities (video games) in order to satisfy their psychological needs, and this positive reinforcement in turn leads to player engagement in video games.

Consider a previous study by Wilkins (2011) that is discussed where most workers complete their safety training requirements out of obligation, which implies they were not motivated to participate and learn. They found that there are significant work culture and behavior changes that will need to take place to make the construction industry safer; what needs to be addressed is motivating participants to learn construction safety best practices through more engaging training methods that meet these psychological needs, and in order to make these changes, trainees will need to be highly motivated through enjoyable training (Wilkins, 2011). Serious Games deliver training content effectively in an interactive environment that is motivating and enjoyable, often because it provides entertainment.

2.2.2 Entertainment

While some researchers feel Serious Games should be instructional before entertaining (Michael and Chen, 2006), Zyda (2005) states Serious Game designers should draw inspiration from video game designers and put entertainment first. They state, “Pedagogy and story integration involve determining theories and developing practices for inserting learning opportunities into story, such that participants find the story immersive and entertaining because the embedded instruction remains subordinate to it” (p. 29). This is the same logic as implicit learning as is discussed above; if the story is immersive, learning takes place unbeknownst to the player. Entertainment is key to successful Serious Game learning. The game must motivate the player to keep engaging in game play, but unlike video games (entertainment-only), Serious Games infuse instruction into game play to deliver training content.

Bente and Breuer (2010) stress the importance of entertainment in games designed for learning and report that we should always access entertainment within a game when effectiveness of learning through games is discussed. Entertainment influences player involvement as described by Antonova and Ekambaram (2011): games create interest by using drama, storyline, humor and characters to create a memorable learning environment. These factors add to player engagement and facilitate them to recall moments and information they learn in the game environment with ease. Dickey (2005) discusses various strategies that are used in video games to engage the player:

1. Player positioning within the game: Games use the First-Person Perspective (Dickey, 2005, p. 69) in which the player experiences the game environment from the viewpoint of the player’s virtual character.
2. Narrative: The use of story within the game to create engagement
3. Interactive choice: Use of characters, game environment, player choices within the game to create engagement

The first-person perspective is enhanced in *FallSafe* due to the use of Virtual Reality. Players can look in any direction as in real life and view the construction site and surrounding land and city. They can interact with objects in the environment, such as grasping an item, with hands they can see and move with two hand controllers. *FallSafe* proceeds through a narrative, moving task to task while delivering training content. Use of characters includes the first-person player as a construction safety intern interacting with the site safety coordinator. All these components were added to enhance engagement in the game, and therefore recall of safety contents. Entertainment in *FallSafe* contributes to greater engagement often missing in traditional training methods.

2.3 E-learning & Serious Games Compared to Traditional Training Tools

Traditional tools of training like conventional lecture-based teaching lack engagement for participants and efficiency in delivering construction safety content to trainees. Burke et al. (2006) state that health and safety training is commonly taught through passive techniques, such as lectures, which are a low engaging form of delivering training content. Wilkins's (2011) study of 121 construction professionals who had completed their lecture-based OSHA 10-Hour safety training observe workforce dissatisfaction with the effectiveness of safety training they had undergone. These shortcomings concerning passive lecture-based learning are further discussed in this review by comparing them with Serious Games in terms of trainees' understanding of the learning content delivered through these methods. Two components of health and safety training that facilitate understanding are discussed here: engagement and efficiency.

Serious Games are an interactive form of training, and they require the player or learner to become engaged in game play to achieve the learning objectives. Use of interactive methods to deliver learning content is proven to be successful (Hake, 1998, Lin et al., 2011, Guo et al., 2012, Clark et al., 2016, Erhel and Jamet, 2013). Hake (1998) carried out an in-depth analysis comparing interactive entertainment methods to teach learning content with traditional

methods. They conducted a survey consisting of almost 6000 students and reported that interactive entertainment vastly increased the effectiveness with which the content was delivered. Interactive entertainment is a key feature of Serious Games and often not possible with passive methods, which are less engaging, and as is reported by these students, less effective.

Games have shown to invoke self-learning interests in players. Lin et al. (2011) developed a Serious Game called “Safety Inspector” to educate students concerning various safety violations and hazards present on a construction site. Pilot study of “Safety Inspector” reveals that game learning exercises motivate players to refresh their safety knowledge and increase learners’ interest in the subject. Serious Games open possibilities for player collaboration within games to aid in learning activity, a function not found in traditional., passive methods, as group assignments often lack entertainment. Guo et al. (2012) developed a Serious Game for training players in a construction plant: Heavy Equipment Crane Operations. A standout feature of the game includes two players collaborating and working together to accomplish a task as a team. The collaboration activity improves worker communication and teamwork efficiency. Interacting with other learners often aids engagement and retention of knowledge as well.

Serious Games are also compared with traditional tools to study their effectiveness in content delivery. Clark et al. (2016) studied the effectiveness of Serious Games by comparing them to non-game instruction mediums. The results demonstrate that Serious Games prove to be more effective and support intrapersonal development better than their non-game counterparts. Erhel and Jamet (2013) analyzed conditions under which Serious Game learning was more effective when compared to traditional learning. They conducted two experiments in their study; in the first experiment, they found traditional learning facilitates better knowledge comprehension than Serious Games. In the following experiment, they found that adding a feedback module to Serious Games allows participants to process learning content more effectively than traditional learning. Adding the post gameplay tool helps to strengthen knowledge learned during gameplay.

This demonstrates that to increase effectiveness and meet specific learning goals, educational content in a Serious Game medium should be designed to meet specific learning requirements.

Although Erhel and Jamet's study (2013) highlights the engagement, efficiency, and effectiveness of Serious Games, studies also show a lack of empirical data available in research to gauge their effectiveness. Prior research efforts by Girard el al. (2013) and Gao et al. (2017) demonstrate that qualitatively Serious Games are more effective than traditional tools, but lack of prior studies makes it difficult to empirically compare the two. We do have evidence to support that players experience motivation, engagement, and have better concentration while playing Serious Games compared to when undertaking traditional training (Hake, 1998, Lin et al., 2011). Serious Games help trainees develop skills through technology, which develops different skill sets than traditional training. Research shows that Serious Games are more effective in transferring training content to trainees compared to traditional tools (Hake, 1998), but more study is needed.

2.4 Non-Traditional Methods of Training in Construction Safety

2.4.1 Serious Games in Construction Safety Training

Over this decade several new alternatives are proposed by researchers as being more effective and engaging than traditional tools. Use of Serious Games in construction safety training is proven to be a viable alternative (Dickinson et al., 2011, Lin et al., 2011b, Dawood et al., 2014, Chen et al., 2013). One example is a Serious Game created to educate players of health and safety regulations in trench construction, titled "Trenching Safety Game", developed by Dickinson et al. (2011). Learning content is designed by referencing an official booklet on trench safety. Three scenarios are put forward to the player to test their knowledge of the topic. The player explores the site and interacts with the environment to achieve game completion. Use of avatars and storyline in the virtual environment helps players to interact with the environment and gain knowledge from those interactions. The "Trenching Safety Game" was tested on students in three

construction trade classes. Students were asked to refer to the official guide on trench and health safety while playing. Results show active interest in students is observed towards using game technology to understand and engage with learning content. Lin et al. (2011b) developed a Serious Game to create a safety training virtual environment in which the player assumes the role of a safety inspector to identify potential hazards on the virtual construction site. A list of hazards (requiring beginner to advanced levels of knowledge) is referred to from US Washington State Labor and Industry (WA L&I) safety training materials to guide training content. Researchers model the game environment to look like an actual construction site to add realism. Use of storyline makes the game more engaging and interesting. Players can move freely in the virtual site and point out the hazards one by one. Player evaluation of the game expresses positive results regarding engagement and motivation towards learning (Lin et al., 2011b).

Dawood et al., (2014) has a different approach to the Serious Games virtual environment previously mentioned. They developed a 3D environment that changes with time, as a real-life construction site would. They call this approach 3D + time (4D). The player navigates the site and recognizes potential hazards. 4D approach to this game allows the developers to link the virtual site with the project schedule. The testing on students points out that their hazard spotting skills were reduced as the site progresses, and sites became more complex as the schedule progressed.

Chen et al., (2013) uses Building Information Modelling (BIM) to create a virtual environment like the players' current worksite. Hazard data was collected and identified through a panel of safety experts and training scenarios are developed using these hazards. The aim of the researchers is to measure the increase in hazard recognition skills in the players after gameplay. Testing shows positive results in terms of player engagement, training effectiveness, and increased safety awareness. It is clear there is great promise for Serious Games to be widely adopted by the construction industry, often with a focus on hazard recognition. There is a clear

progression from basic computer software to more recent, advanced technology to achieve greater engagement, specifically the use of Virtual Reality.

2.4.2 Use of Virtual Reality in Construction Safety Training

Burdea (2003) briefly defines Virtual Reality (VR) as a computer simulation that allows for real-time interactivity in a realistic world. VR users can interact with what would normally be static, using a computer, headset, and motion sensing controllers. This creates a highly immersive sensory experience and may enhance already engaging Serious Games for training in the construction industry and beyond. Sacks et al. (2013) developed a Virtual Reality based training module and compared it with traditional training. The study involves testing on 71 trainees. They found VR training to be more effective in maintaining the trainee's attention. Overall knowledge retention in trainees over a period of one month was found to be greater than traditional training through pre-test & post-test results. As an alternative to use of VR, Eiris et al. (2018) developed a safety training module using augmented 360-degree panoramas of real construction site photos called panoramas of reality (PARS). The training module was developed on a game engine platform. The method was adopted to tackle the issue of high computing power required to run VR headsets. The module consists of three parts: training, assessment and feedback. The players were first trained by informing them about hazards and then were asked to identify similar hazards in the assessment phase. Subsequent feedback was provided once they completed the assessment. A pretest and posttest survey were used to categorize player demographic information and their ease of use with panoramic photos and computer applications. Overall user reactions indicated positive responses from the players.

VR not only has the power to enhance training, but it can also help researchers better understand construction worker behavior in response to potential hazards. Golovina et al. (2019) used VR to gather data regarding close calls and contact collisions between construction workers and hazards like moving equipment and harmful substances using a Serious Game approach.

The players navigate the virtual site to complete a task, and the Serious Game engine recognizes when players come in close contact with moving equipment and harmful substances that should have been avoided. Close call data is recorded for such activities. The authors conclude that this kind of data was previously unavailable for research and it can be used to study close call encounters between humans and hazards on site.

Computer technology and game engines have been used to deliver construction safety using different methods and techniques (Golovina et al., 2019, Sacks et al., 2013, Chen et al., 2013). Hazard identification Serious Games are proven effective in terms of player engagement and their improved understanding of training content (Chen et al., 2013). Use of VR in training modules has been proven advantageous over traditional tools of training for similar purposes. An alternative to VR is seen in the 360-panorama training platform (PARS) used for construction site hazard identification. Use of VR for collecting close call encounter data between construction workers and on-site hazards like moving vehicles and harmful substances is a new way of collecting data in construction safety.

2.5 How Serious Games Meet Learning Objectives

2.5.1 Game Framework

Winn, B. M. (2009) noted that with the development of Serious Games that frameworks are needed to be investigated to provide a consistent, effective learning experience for different disciplines and game developers. They indicated that Serious Game design is a comparatively fresh discipline and there is a lack of popular language and an absence of normal practice in the design of Serious Games. While more research is needed, some frameworks have been proposed and will be briefly discussed as they are relevant to the development of *FallSafe*. Yusoff, A. (2010) developed a framework based on a study of pedagogy theories and Serious Game construction, which is an evolution from previous works of Garris, et al. (2002); Gilbert & Gale,

(2008b); Thompson, Berbank-Green, & Cusworth, (2007a). (Figure 2.1) is an image of the framework as an outline.

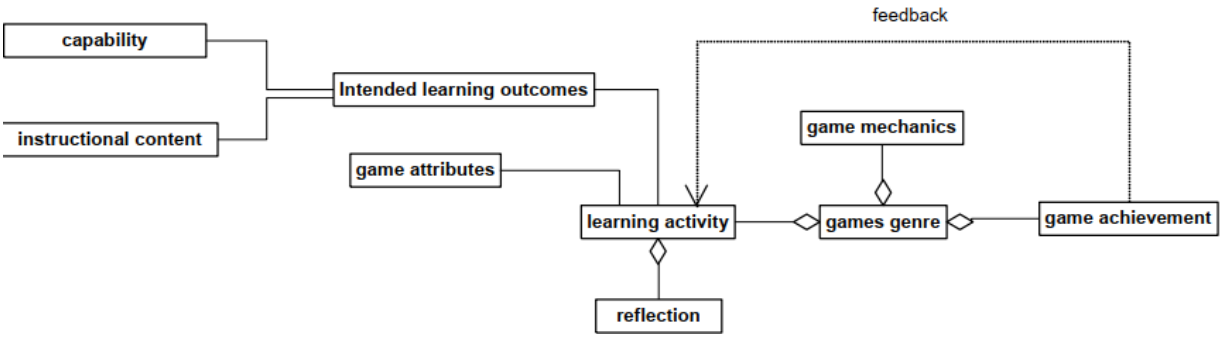

Figure 2.1: Yusoff's conceptual Serious Game framework

The ability to learn in the game is the learner's capability and the instructional content is the subject matter the learner needs to study. Both form the intended learning outcomes, which is the purpose of playing the Serious Game. Game attributes function as learning and engagement aids. Game attributes and intended learning outcomes are the components that relate to the game's learning activity. The game genre is the type or category of the game and identifies the kind of environment for the set of activities to be played within the game world. A game's mechanics are the rules and procedures that guide the player and the game response to the player's moves or actions.

Reward or game achievement is received in the form of scores/points. The learning outcomes are the goal and aims for the learner and these outcomes are associated with learning activities and game achievement. Game playing and the learning outcomes exist in two separate worlds, because game playing is an activity where the learner is totally immersed in the game world, while the outcomes are set earlier in the real world. The learner should not have to break away from the game in order to know learning objectives are met, because all the learning should

take place within the game world. Reflection is where the learner finds out learning was achieved (or not) and is made to understand the relevancy of game activity to the learning outcome. This reflection process will be made part of the game activity, in order to ensure content is learned and not just memorized. This is an effective framework, and others were referenced as well in the development of *FallSafe*.

The Design, Play, and Experience framework (figure 2.2) by Winn, B.M. (2009) proposes an iterative design process with a formal approach to Serious Game design negating the provisional approach found in Serious Game development. The layout of this framework provides a clear design path to develop our game. Winn, B. M. (2009) created the MDA framework (LeBlanc, M. 2005a) to address aspects of storytelling, user experience and influence of

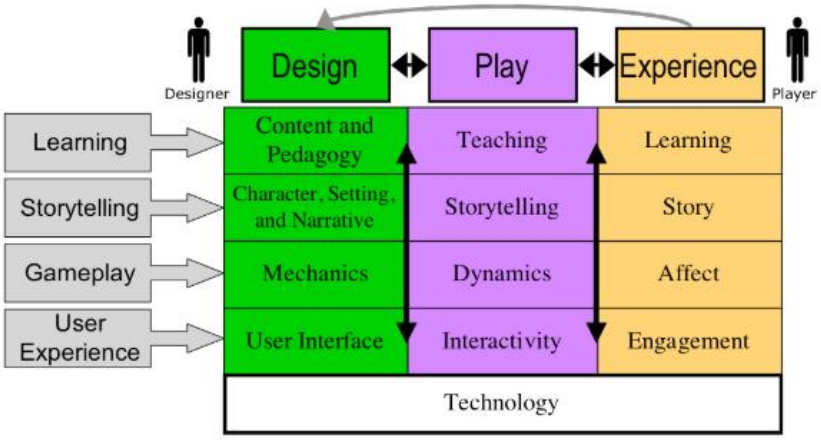

Figure 2.2: Winn's Expanded DPE framework

technology on the design to create a new framework for the design of Serious Games called the DPE (Design, Play, and Experience). The author argues that, in order to develop a game efficiently, the developer should first set objectives for the ensuing experience while taking into consideration the target audience for the game throughout the development phase. The

Expanded DPE Framework shows the components necessary to effectively delivery pedagogy using the DPE Framework. These essential components are described below:

1. The Learning Layer:

This consists of the key material or data that the developer attempts to educate the player with through the game. The author emphasizes taking time to think about and identify the learning objectives early in the design phase.

2. The Storytelling Layer:

The storytelling that takes place during play combines the tale of the designer with the relationships and decisions made by the player. The resulting experience creates the narrative of the player. All games, however, have the story of a player, which at least reflects the story of the player's game play challenges and how the player addressed them. Again, each of these important storytelling design decisions must be tempered with the desired learning outcome.

3. The Game Play Layer:

This layer consists of the mechanics, dynamics, and affect. The mechanics are the rules that define the game world's operation, what the player can do, the challenges that the player faces, and the goals of the player. The dynamics are the resulting behavior when the rules are instantiated over time with the influence of the player's interactions. The effects are the corresponding experiences or feelings obtained in the player.

4. User Experience Layer:

The user experience layer consists of the user interface the player interacts with when playing the game. "The game designer's principal goal is to create entertaining game play. The purpose of the interface is to make that entertainment accessible" (Saltzman, 2000, p. 256). The game design is accessible to the player through the user interface as the player interacts with the game directly through the user interface. A good user interface should be transparent so that the player does not have to focus their attention on how to play the game (the game controls), instead

of focusing their attention on gameplay, storyline, and learning. It is suggested by the author to start working on the topmost layer because for Serious Games, learning is the most important aspect and usually the least malleable. These four layers are supported by the underlying technology. This framework guides our study and facilitates learning.

2.6 Chapter Summary

To begin this literature review, various definitions for Serious Games as well as the definition used to guide this study are provided. A brief overview of their history is described to give the reader an idea of how recent Serious Games are developed, what their original purpose is, and the direction in which they are going. Broad applications are discussed, including corporate, healthcare, and construction safety training, where there is a great need for more engaging safety training methods. Motivation and entertainment are discussed to provide a better understanding of how Serious Games increase user engagement. Engagement and efficiency are also addressed. Current applications for Serious Games and Virtual Reality in construction safety training, with suggestions for future studies are then presented. And finally, essential components for delivering training materials through Serious Games, called the framework and game attributes, are provided. With this comprehensive overview, the reader can now understand Serious Games better and see their value as effective training tools. There is also a large knowledge gap surrounding Serious Games and their potential effects and impacts as they only recently achieved mainstream popularity and broad use in the early 2000's, thus more study is needed. All this considered, there is ample research that suggests current safety training methods are insufficient, which translates to high death and injury rates in the construction industry. Serious Games, with or without an added Virtual Reality component, have the potential to provide a training experience that is more relevant in the modern world, engaging, and effective. *FallSafe* is created to fill a great need in the construction industry. An interactive form of safety training with a specific, narrow focus within hazard recognition will be engaging and effective in terms of

transferring safety knowledge to the participants, promoting safe behavior in construction. The methodology (Chapter 3) follows and will describe in detail the creation of *FallSafe.*

Chapter 3: Development of the Serious Game

This chapter discusses the technology and implementation of game framework used to design and develop the Serious Game *Fall Safe*. The development of a game prototype is discussed in this chapter, including software and hardware components, which is then play tested to enhance user interface. Pilot testing and post-game survey results will be discussed in the Chapter 4.

3.1 Game Framework

As mentioned in the literature review, a game framework is essential to ensure consistent delivery of learning objectives across disciplines. In order to achieve learning objectives, the goal of the Serious Game must first be discussed so it can be referenced at all levels of the design process.

The Iterative Design Process (see Figure 3.1) which came from the Design, Play, and Experience Framework (Winn, B.M., 2009) is used to develop the Serious Game *FallSafe* to ensure the game can be used as an effective teaching tool.

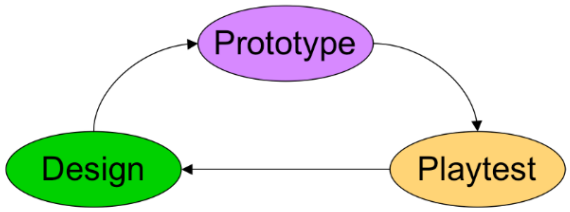

Figure 3.1: Iterative design process

The game prototype is created and put through several rounds of playtesting (beta-testing) to refine the game and enhance user experience which in turn will aid in achieving learning objectives. Note that, playtesting is separate from pilot testing which is carried out to validate

FallSafe and will be discussed in the next chapter. Playtesting *FallSafe* occurred in the form of informal game play by six players and feedback is collected through unstructured interviews, primarily to learn about user interface and gameplay experience. Some of the suggested feedback is to increase font size in the tutorial screen and adjust the height of the screen, so the player has full visibility of the surrounding environment. The tutorial screen also needed to be adjusted to move so it would always face the player. Other suggested feedback was to slow the pace of the main character when walking, and to decrease the brightness of the sunlight in the game world. Following the DPE Framework, the prototype was created, play-tested, and then there was a return to the design process to make suggested adjustments. This valuable feedback ensured the game was legible, non-straining, and gave clear instructions; playtesting enhanced the gameplay experience and user interface. Pilot Testing, to be discussed in Chapter 4, is conducted to validate the Serious Game in terms of content and pedagogy.

The Expanded Design Play Experience Framework (see Figure 3.2) above shows Learning, Storytelling, Gameplay, and User Experience, supported by Technology, as four layers that must be incorporated into each aspect of the game's design, play, and experience in order to succeed as a Serious Game. A game can be created and play tested, but would likely not deliver desired learning outcomes if, for example, learning, story, affect, and engagement were

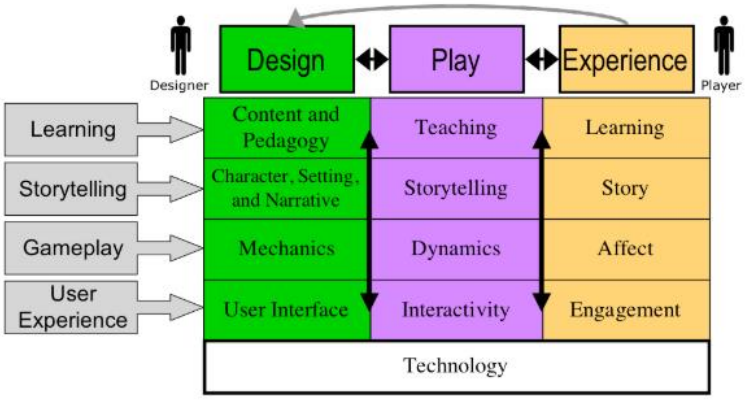

Figure 3.2: Winn's Expanded DPE framework

not present during the player's experience of the game. *FallSafe* incorporated each of the four layers at every aspect of the process of design, play, and experience

3.2 Game Overview

FallSafe is a Serious Game aimed at educating the player in the fatal hazards associated with falls in construction. The game is developed using the Unity 2019.3.14f1 3D game engine and the Oculus Rift S Headset and controllers. *FallSafe* is programmed in C# language using MS Visual Studio. *FallSafe* is playable in VR only using the headset and controller combination. It is designed with the following learning objectives from the OSHA Fall Prevention Training Guide:

1. The player must first select appropriate Personal Protection Equipment for the situation
2. Give the player an introduction to fall hazards in construction (number of fatal injuries due to falls, most violated standard for the last 9 consecutive years, mention the basic fall protection systems used in construction)
3. Educate the player about the unsafe practices related to ladder use by presenting them with a case study of a fatal injury due to fall from a ladder, followed by safe and unsafe practices for ladder use on a construction site
4. Explore a 3D model setup of a residential construction site and look for workers engaged in the unsafe practices. After the player notices an unsafe practice, they can take a note of it and answer a multiple-choice question related to that hazard. There are four scenarios (hazardous) and four sets of questions.
5. After the player has observed all the unsafe practices, they complete a comprehensive post-test (consisting of multiple-choice questions) to enhance knowledge retention.

To achieve learning objectives, *FallSafe* uses a storyline-based approach and is divided into four modules:

1. Tutorial Module (how to play the game)
2. Introduction to fall hazards & ladder safety
3. Observation of unsafe practices
4. Reinforcing Posttest/Multiple Choice Questions (to reinforce the information gained in the last two modules)

The game storyline consists of the player, a newly recruited safety intern, on the first day of their internship. A 3D model of a construction site is implemented in the game world prototype which includes the following components used to add a sense of realism to the game:

1. 3D models of animated characters (safety coordinator, workers, superintendents) with voicing that the player can interact with
2. 3D models of construction equipment, under-construction residential housing, on site office trailers
3. A tutorial screen that greets the player on game start and provides them with instructions on how to progress in the game
4. A safety briefing screen provides information regarding: Case studies of fatalities due to falls, line diagrams depicting fall hazards, quantitative data for fatalities due to falls, and best practices to adopt for fall protection in ladder safety
5. The player navigates through the game, observing 4 unsafe practices, then answering a series of multiple-choice questions
6. The game concludes at the briefing screen, where a comprehensive multiple-choice exam is given

3.3 Game Hardware

FallSafe is developed using the Virtual Reality headset (Head Mounted Display, HMD) Oculus Rift S and two motion-sensing controllers (see Figure 3.3). Rift S is selected because of its availability, cost, and easy setup compared to its older generation counterparts and is directly

supported by the Unity 3D game engine using the XR Toolkit add on module. This game is supported on Windows 10 devices.

Figure 3.3: Oculus Rift S

3.4 Game Software

FallSafe is developed using the commercially available game engine Unity 3D and the C# scripting language (using MonoBehaviour base class). Unity 3D's capabilities include adjustable graphic settings, clean user interface, and support for XR Toolkit. XR Toolkit module enables seamless integration between the Unity 3D game engine and any VR headset available on the market, making *FallSafe* playable with different hardware.

Why Unity 3D?

1. Unity 3D consists of a complete physics engine capable of simulating Newtonian physics on rigid bodies
2. The Asset Store feature allows the developer to directly import 3D models/assets into the game
3. The Animator component enables animation of in-game characters and vehicles
4. Wide online community support and active forums exist to address game development issues and queries

3.4.1 XR Toolkit

The XR Toolkit component allows *FallSafe's* Virtual Reality experience to be cross-platform compatible with other VR headsets. It enables programming the in-game interactions between the player and the game objects relatively easy using the "Direct Interactor" component (placed on the player's in-game hands, see Figure 3.5) and the "Grab Interactable" component (placed on the in-game object the player wants to interact with, see Figure 3.4).

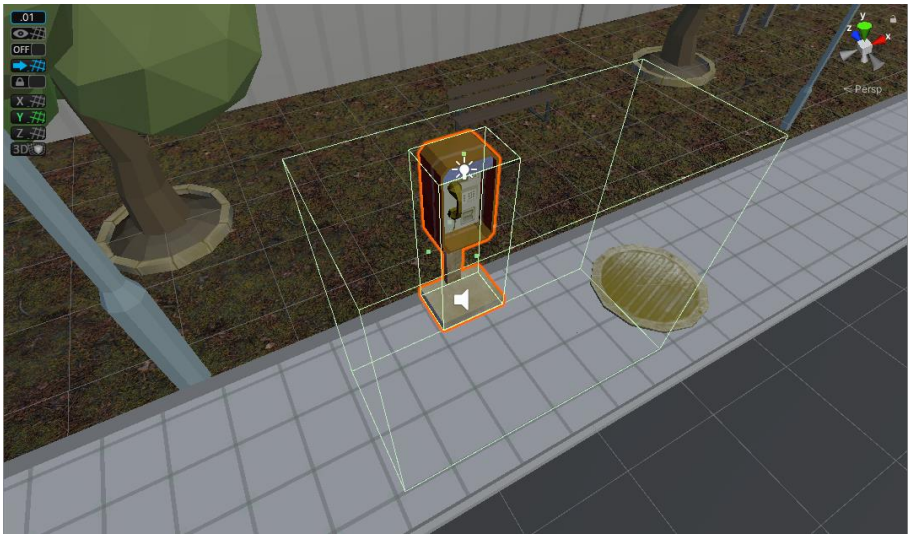

Figure 3.4: Grab Interactable component attached to the in-game phone hands

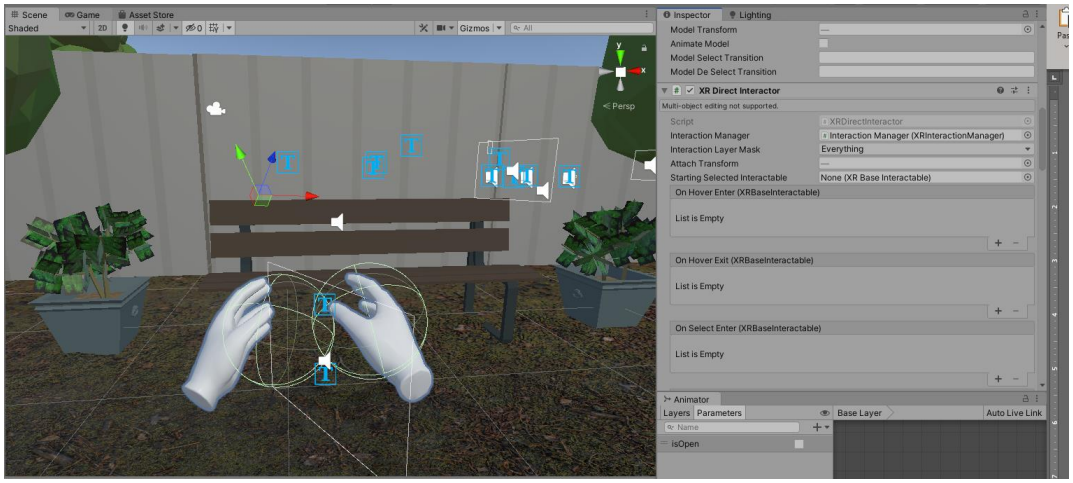

Figure 3.5*:* Direct Interactor component attached to the in-game hands hands

3.4.2 MonoBehaviour

C# scripting in Unity 3D is implemented using the MonoBehaviour base class. MonoBehaviour allows for the following features to be implemented in Unity 3D using scripts:

1. Register interactions between two game objects (collision detection)
2. Animating a game object or character
3. Movement of the player
4. Provide in-game music and to voice the characters

This class enables Unity 3D to perform its functions and run *FallSafe* as intended, it provides the player with entertainment in the form of game attributes. Different *Methods* are used in scripts to allow for greater complexity in the game. For example, the “Trigger” script uses the “OnTriggerEnter( )” (see Figure 3.6 and 3.7) method to detect collision between two game objects.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Trigger : MonoBehaviour
{

        NPCAnimations npc;

    SafetyCoordinator sc;


    BriefingScreenAnimation briefScreen;



    // Start is called before the first frame update
    void Start()
    {
            npc = FindObjectOfType<NPCAnimations>();
        briefScreen = FindObjectOfType<BriefingScreenAnimation>();
        sc = FindObjectOfType<SafetyCoordinator>();



    }

    // Update is called once per frame
    void Update()
    {

    }
```

Figure 3.6: Script Component “Trigger” using the MonoBehaviour Namespace

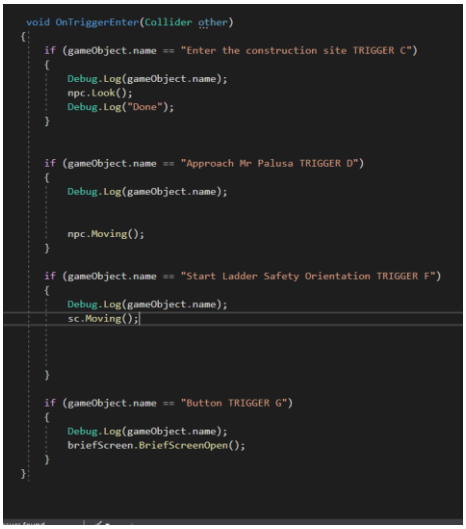

Figure 3.7: "Trigger" Script Showing the "OntriggerEnter()" method in use

The "*Talk( )*" method is used to trigger the game character animation and plays the character's voice, in the same way the "*Look( )" and "Idle( )"* functions trigger the game character to look around or stand still. Some other functions and methods used in *FallSafe* (see Table 3.1) include "*TypeSentence(string reportSentence)"* and "*OpenObjectiveWindow(Objectives objectives)"* the former performs the function to type the sentences which provide instruction for the player in the objective screen and the latter makes the objective screen visible to the player.

Function	Action
Talk()	Triggers game character talking animation
OpenObjectiveWindow(Objectives objectives)	Shows objective screen
TypeSentence(string reportSentence)	Types sentences on the objective screen
AcceptObjective(Objectives objectives)	Accepts objective presented to the player
Look()	Triggers game character looking animation
Idle()	Triggers game character idling animation

Table 3.1: List of some methods used in Fall Safe

3.4.3 Colliders and Triggers

Collider components define the shape of a game object to register physical collisions. They act as a switch for events. For example, when the player touches the phone game object, the phone's collider component registers a collision with player's hand collider component. Unity 3D's physics engine detects this collision and plays a phone conversation audio file. Colliders, triggers and XR toolkit are setup in Unity 3D to enable player interaction with the game objects to trigger events. The collider (see Figure 3.8) is triggered when player enters the site and the animation of the site superintendent (see Figure 3.9) walking towards the player is played.

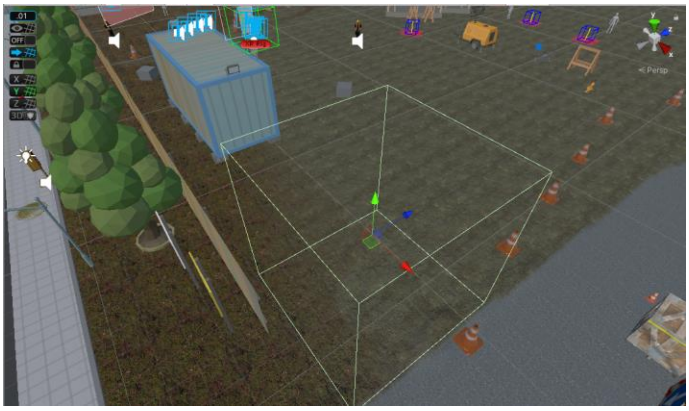

Figure 3.8: Box Colliders, green cube shows the boundry of collision detection

Figure 3.9: 3D Model of site superitendant

3.4.4 In Game Navigation

In game navigation is programmed using scripting. The rig component (see Figure 3.10) mimics the virtual presence of the player in the game world. Player can traverse the game world with the "*Continuous Movement*" script (see Figure 3.11 and Figure 3.12) which uses the "*Move( )*" method to give the player character movement.

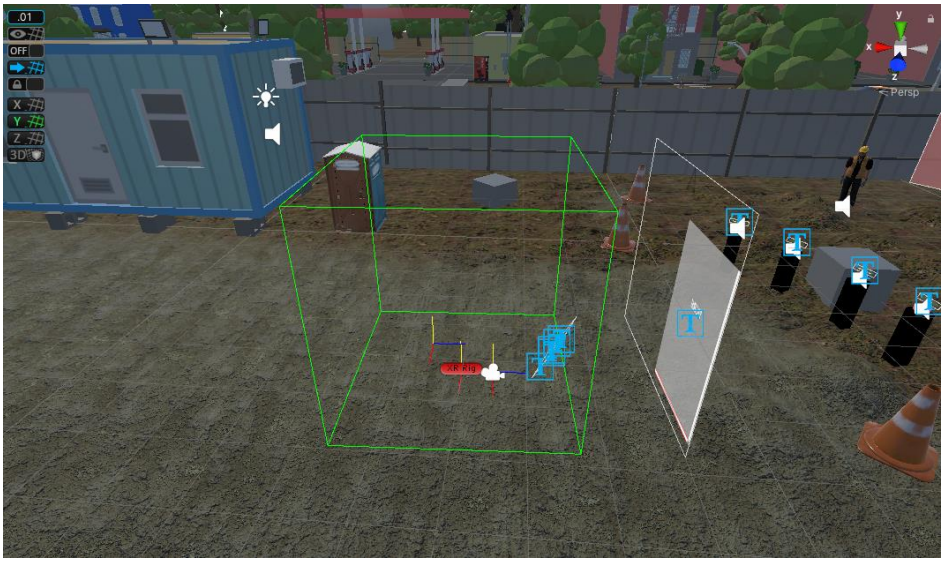

Figure 3.10: The rig represents the positioning of the player in the gameworld

"*Continious Movement*" script takes input from the left or right controller joystick and moves the player in the game world. The player can simply look in a certain direction and move in that direction using the joystick. This feature is implemented to enable ease of movement.

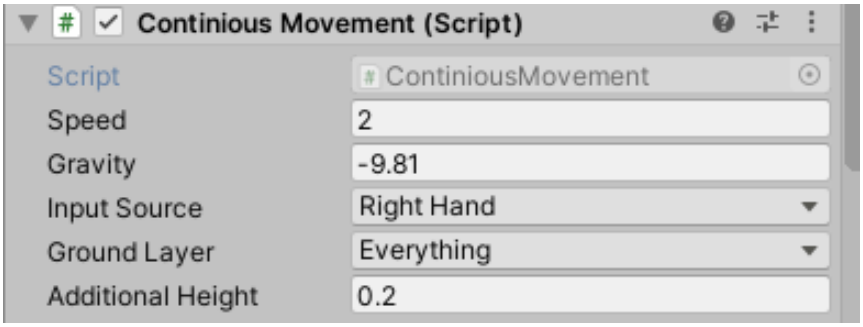

Figure 3.11: Script for Continous Movement (Unity UI Inscpector Window)

The “*Continious Movement*” script is attached to the player component (see Figure 3.10). The player movement speed and controller input selection is done in the Unity 3D UI (see Figure 3.11).

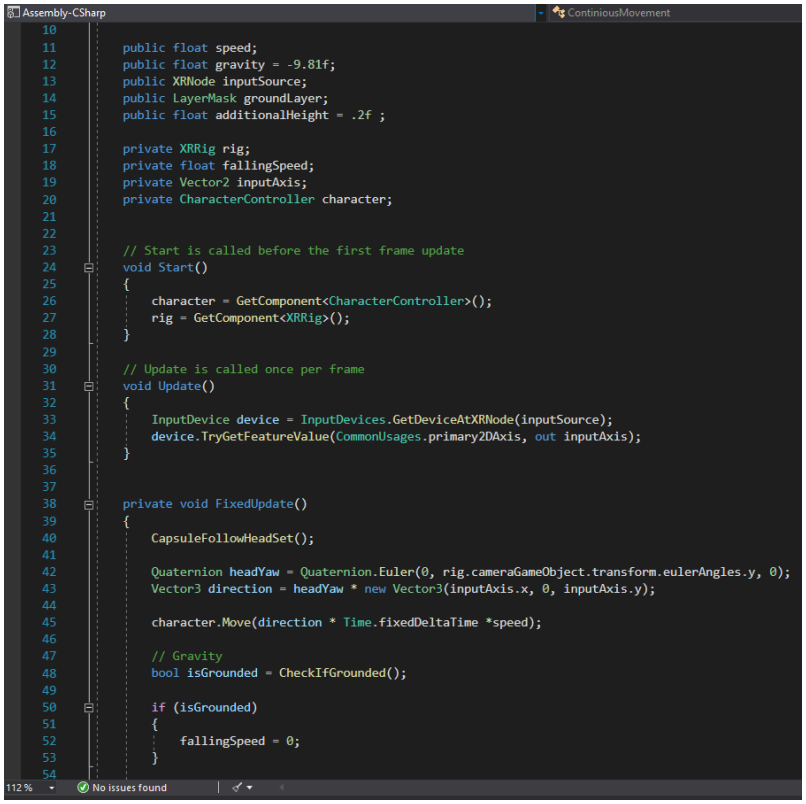

Figure 3.12: Script for Continous Movement in MS Visual Studio

3.4.5 Storyline & Game Progression

The game world is modelled around an active construction site consisting of residential housing. The wood framing is currently under construction and there are workers throughout the site. The game starts with the player (safety intern) present on the sidewalk outside the construction site. On game runtime, the player is given specific instructions through the tutorial screen (see Figure 3.13) to get them familiarized with the game controls, and moves through character interactions, briefing screens, and tasks to progress through the game.

Figure 3.13: In-game tutorial screen provides navigation instructions to the player

A tracking system is used to record tasks the player must complete for the game storyline to progress. The tracking system consists of:

1. A script using Breadth-first search (BFS) algorithm (see Figure 3.14) to traverse the task list in any order defined by the game developer. This provides the player with a list of tasks and the order in which they need to be completed to progress in the game. For example, the player needs to approach the phone first and then enter the construction site. If the player enters the construction site first, then the task “Press phone to Dial” will remain incomplete.

```
void Start()
{
    QuestEvent a = quest.AddQuestEvent("1", "Walk to the phone",A);
    QuestEvent b = quest.AddQuestEvent("2", "Press phone to Dail",B);
    QuestEvent c = quest.AddQuestEvent("3", "Enter the Construction Site",C);  // Mr. palusa stops idling and starts looking around
    QuestEvent d = quest.AddQuestEvent("4", "Approach Mr Palusa", D); // Mr. Palusa stops looking around and approaches the player
    QuestEvent e = quest.AddQuestEvent("5", "Talk with Mr Palusa",E);
    QuestEvent f = quest.AddQuestEvent("6", "Approach Ladder Safety ToolBox Briefing Area", F);
    QuestEvent g = quest.AddQuestEvent("7", "Press the button to Start the Safety Briefing", G);



    quest.AddPath(a.GetId(), b.GetId());
    quest.AddPath(b.GetId(), c.GetId());
    quest.AddPath(c.GetId(), d.GetId());
    quest.AddPath(d.GetId(), e.GetId());
    quest.AddPath(e.GetId(), f.GetId());
    quest.AddPath(f.GetId(), g.GetId());


    quest.BFS(a.GetId());
```

Figure 3.14: Implementing the Breadth-first search (BFS) using C#

2. Audio - Visual aids and sensory feedback: A hovering red cylinder (see Figure 3.15) directs the player to the location of the next task to be completed. The player moves towards the red cylinder to progress through the game. Only one cylinder is visible at a time due to the linear nature of the game. The player must move within close range of the red cylinder to trigger the box collider associated with the current task. Doing so will register the current task as completed and will turn the cylinder color from red to green (see Figure 3.16).

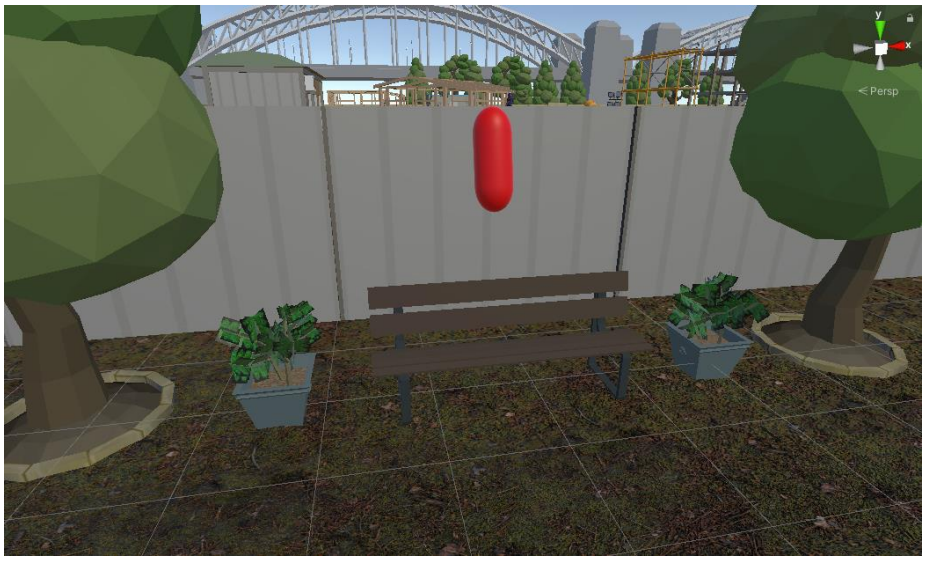

Figure 3.15: Red cylinder provides location of current task

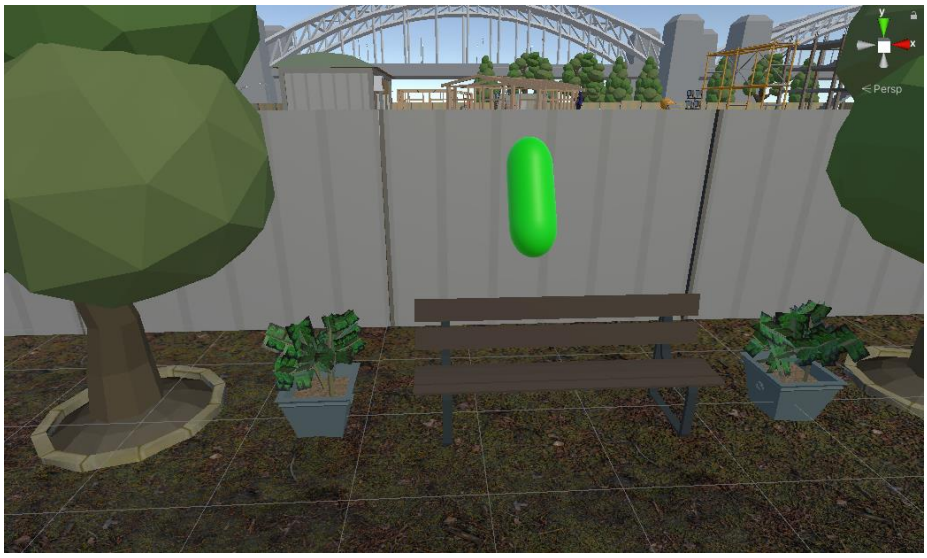

Figure 3.16: Red cylinder turns to color green when a task is registered completed

A sound will play when the cylinder changes color from red to green, and the handheld controllers will vibrate (haptic feedback) to inform the player when they complete a task. Audio - Visual aids and sensory feedback supplement player interaction with the game world making the gameplay engaging. When the player completes four tasks, they are instructed to navigate back to the briefing screen to take a comprehensive test to complete the game

3.5 Learning in *FallSafe*: Game Storyline and Modules

Learning in *FallSafe* takes place when the game teaches the desired learning objectives (from OSHA Fall Prevention) in an engaging manner, through storyline and other attributes, and the player retains what they have learned through reinforcing multiple-choice questions.

In *FallSafe, the* player must complete four modules:

1. Tutorial Module
2. Introduction Module
3. Observation Module
4. Reinforcing Module

3.5.1. Tutorial and Introduction Modules

The Tutorial Module is brief and exists to familiarize the player with the game controls and how to navigate through the game world. This information serves to instruct the player how to play and interact in the game. The Introduction module consists of the following components:

1. Introduction Storyline
2. Interactive buttons that trigger the safety training
3. The briefing screen
4. Character animation and voicing of the safety coordinator that simulates a one-to-one toolbox talk

Figure 3.17: Tutorial Screen

On runtime, the game starts with the player present outside the sidewalk adjacent to a construction site. The Tutorial screen (see Figure 3.17) provides instructions to the player regarding navigating the game world and interaction, including how to use the controllers. The tutorial screen is anchored to the player's position and is programmed to always face the player.

Player's interactions with the game world are accompanied by audio-visual clues (through VR headset speakers) and haptic feedback (through the controllers) to reinforce the interaction events. In the starting moments, the player is prompted to approach a location that contains construction Personal Protection Equipment (PPE). Instructions are given to the player to collect and equip the PPE (see Figure 3.18). This brief interaction was added to highlight the importance of use of PPE when at a construction site.

Figure 3.18: PPE collection setup

The player is then instructed to interact with a payphone present on the sidewalk. The purpose of this interaction is for the player to call the construction site office and let them know of the player's location so the supervisor can open the gate. Once interaction event is completed the site gate opens and the tutorial screen instructs the player to go inside the site. The tracking system makes sure that all player interaction events (interacting with the phone, collecting the PPE) takes place in a predetermined order.

Upon entering the site, the player is then instructed through the tutorial screen to meet with site superintendent. Upon initiating the interaction event with the superintendent, the character is animated, and the associated voice clip is played. The character greets the player and gives them an introduction of the 3 modules: Introduction, Observation, and Reinforcing (see Figure 3.19). The player is then instructed to see the site safety coordinator to proceed further.

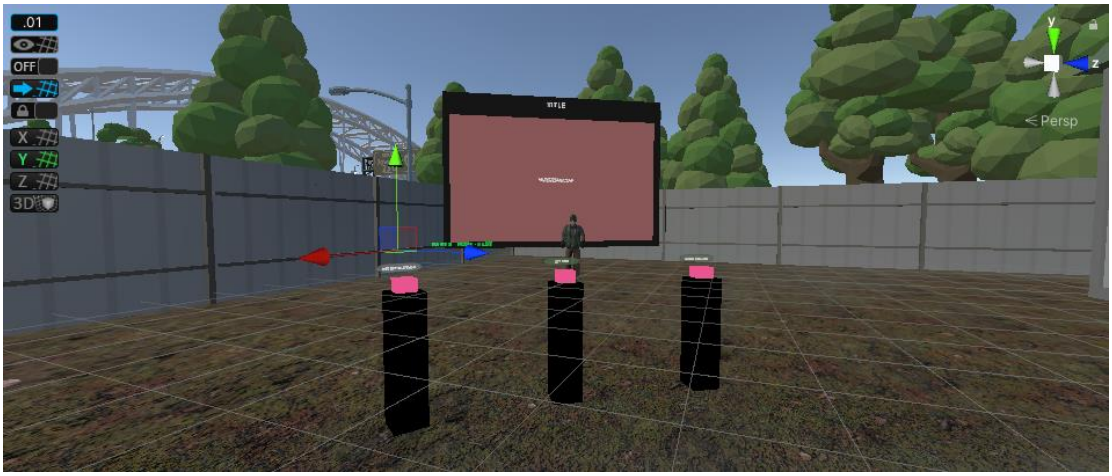

Figure 3.19: Briefing screen setup with buttons to start the briefing

The player then navigates towards the briefing screen and the safety coordinator character is animated to walk in front of the screen and greet the player. The briefing mimics the "Toolbox Talks" presented in the OSHA Fall Prevention Training Guide. The safety coordinator prompts the player to press the introduction button to start the safety briefing. Upon pressing the button, a briefing screen appears and gives the introduction module, which includes information

regarding fatal injuries due to falls in construction. The player is then instructed to press the ladder safety module button. A briefing is given of ladder safety content from OSHA, including proper inspection and use of ladders. There is also an example presented at the beginning of the briefing that describes an accident that occurred as a result of unsafe ladder use. This makes the hazards the player must find in the game recognizable, as it depicts this scenario. The player is then prompted to move through the site to see if they can observe any unsafe practices, which commences the Observation Module.

3.5.2. Observation Module

The player then moves on to the Observation Module, which effectively delivers learning content through life-like hazardous scenarios. Throughout the construction site are four workers engaged in unsafe practices. The player moves freely about the construction site and does not have to find the unsafe practices in a particular order but must find all four.

The player may first observe a worker using a stepladder as scaffolding (see Figure 3.20), the player then moves toward the unsafe practice and from a safe distance will point toward the worker. An information screen appears at the player's right hand (Heads Up Display, or, "HUD") and the name of the worker and a description of the scenario are presented, the player is then asked if this is a safe or unsafe practice. The player will select "yes" (if the player selects no, they are corrected) and a multiple-choice question appears. Upon answering the multiple-choice question correctly (question is asked until answered correctly), the player reports the unsafe behavior to the, the unsafe practice is marked as observed (a green cube will appear, different from the hovering red/green "pills" that hover throughout the game for navigation purposes), and the first task is complete.

FallSafe is positively reinforcing; it employs a points system to reward players for answering multiple choice questions correctly, satisfying needs such as recognition and achievement, which motivates the player to continue to engage in game play.

Figure 3.20: Hazard 1 – Worker using step ladder as scaffolding

This same process is repeat with three more unsafe behaviors observable on site. They include: a worker standing on the top rung of a ladder (Figure 3.21), a worker using an extension ladder improperly (Figure 3.22), and a worker near a ladder where the base is too far

Figure 3.21: Hazard 2 – Worker standing on top rung of ladder

from the edge of the wall (Figure 3.23). Upon observing and reporting the four hazards, the player is prompted to return to the briefing screen to complete the fourth module.

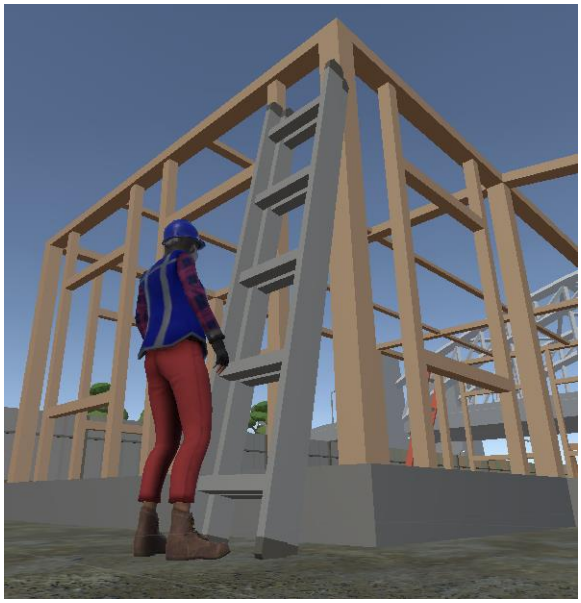

Figure 3.22: Hazard 3 – Worker not using full length of extension ladder

Figure 3.23: Hazard 4 – Base of ladder is too far from the edge of horizontal surface

3.5.3. Reinforcing Module and Game Completion

The final module is the Reinforcing Module, where the player will take a comprehensive multiple-choice question exam covering all the desired learning objectives present in the previous two modules. If a question is answered incorrectly, the question is posed again, and the player cannot proceed through the exam until all questions are answered correctly. When all the questions are answered correctly, the player meets the learning objectives, and the game has successfully taught the player one of the OSHA “Toolbox Talks” for ladder safety. The player is congratulated and told they have finished their first day on site as a safety intern, and *FallSafe* is then completed.

3.6 Chapter Summary

This methodology serves to primarily describe in detail how *FallSafe* was created from a game designer’s perspective. It includes the Serious Game framework used, which is the Design, Play, Experience Framework (Winn, B.M., 2009). Following is a brief overview of the game storyline, and hardware components used for Virtual Reality. Software and programming components into the game is described in detail, with special attention to colliders that trigger actions in the game. In game navigation, storyline progression, and how learning takes place in the game is also described, moving the reader from the very beginning stages of game design through delivery of learning objectives to conclusion of the game. In the following Chapter, Pilot Testing of the game is discussed, which is carried out to ensure *FallSafe* delivers the intended safety contents and succeeds as a construction safety training Serious Game.

Chapter 4 – Pilot Testing & Results

4.1. Overview of Pilot Testing

As is mentioned previously, playtesting is conducted to enhance user experience, gameplay, and confirm intended learning outcomes are met. This chapter describes the pilot testing of *FallSafe*, which is conducted to validate the Serious Game. Six students from Michigan State University's Construction Management graduate program with varying levels of construction safety knowledge volunteered to pilot-test the game and filled out a feedback survey; the entire process takes about one hour. This study is approved by Michigan State University IRB and participants receive a research briefing and sign their respective consent forms before commencing the study. Instruction for game set up and play is given to the participants. Participants are instructed to play the game for 30 minutes, then fill out the feedback survey.

4.2. Pilot Testing Results Analysis

There are several parts to the feedback survey that participants completed. A brief questionnaire is created to collect basic demographic information (see Figure 4.1) and gain

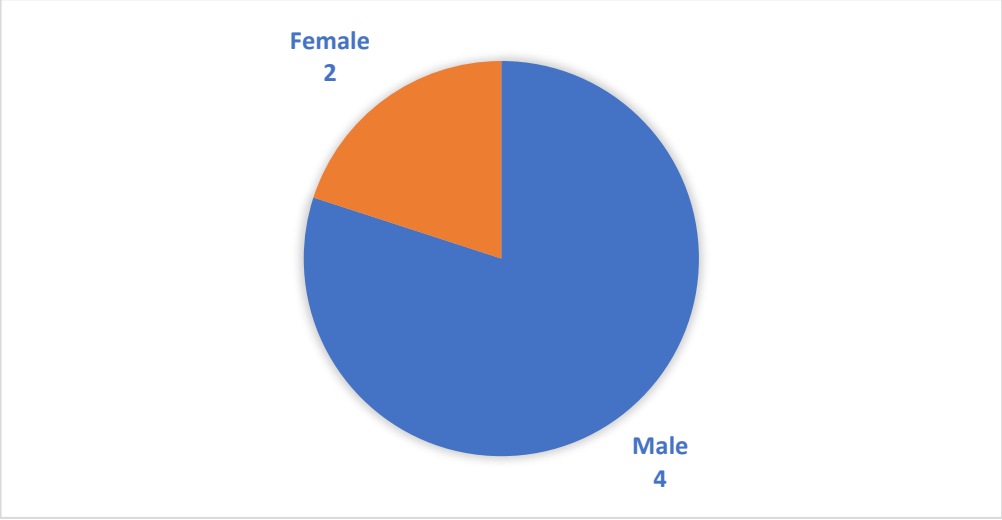

Figure 4.1: Participant gender distribution

understanding of user's knowledge/experience level with the hardware (see Figure 4.2) and content used and (see Figure 4.3). Results of the demographic survey are pictured in pie charts below.

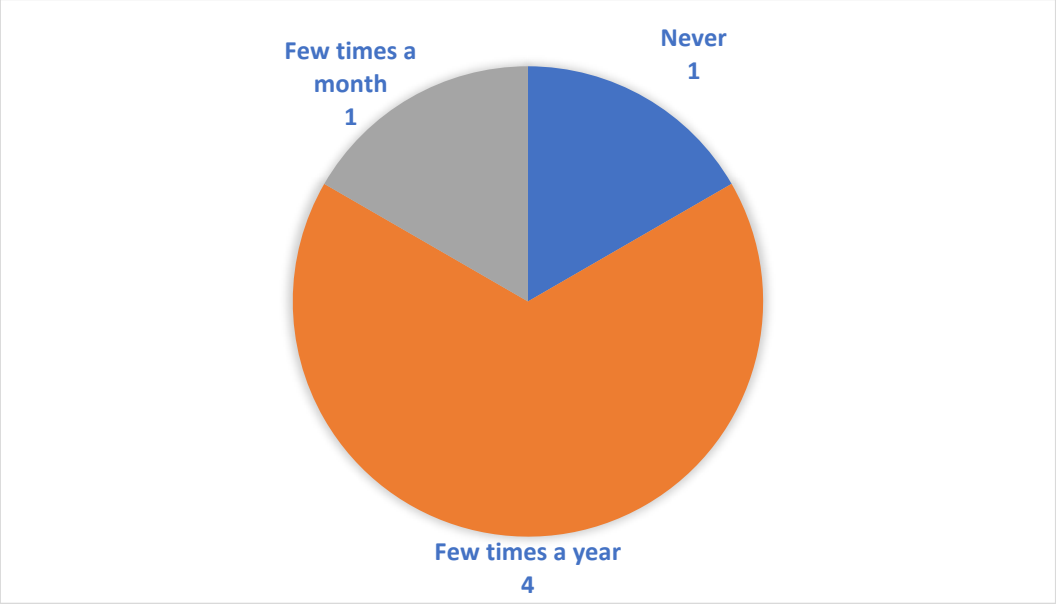

Figure 4.2: Participant's experience with using Virtual Reality

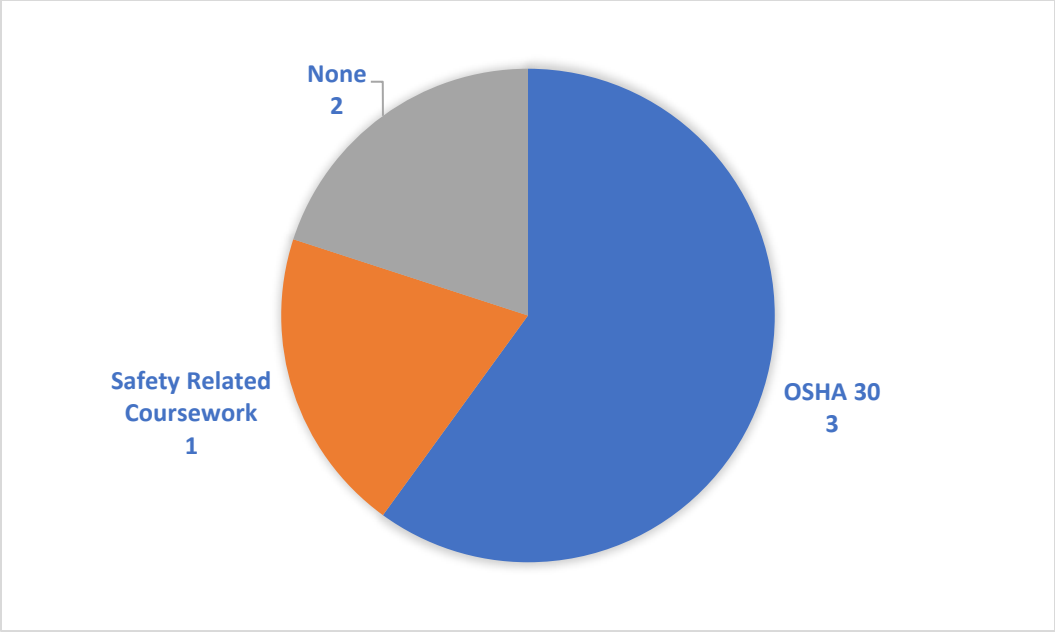

Figure 4.3: Participant's construction safety experience

The second part of the survey asked three open ended questions for feedback on *FallSafe*. The feedback and suggestions are noted and will be used to create enhanced versions of *FallSafe* in the future. The questions posed to participants and samples of their direct responses include:

1. What are the best features of *FallSafe*? Why?

One participant responded stating the tutorial screen “provided clear instruction throughout the game”, and another participant noted that the red/green “capsule system used for navigation was helpful” assisting participants in navigating through the game as intended. “The storyline of the game intrigued me”, is a positive response received from a participant regarding engagement and realism. “The briefing screen (that provided safety contents and fall data) was a good feature” is another positive comment from a participant.

2. What are your least favorite features of *FallSafe*? Why?

“In game character movement could have been smoother” is one response from a participant. Another participant notes, “There could be more (in-game) character interactions to help the game feel more realistic”. Character animation is also a least favorite feature, with multiple participants pointing out that animation of the 3D characters could be more realistic.

3. What are your suggestions for improving *FallSafe*?

One participant suggests adding both safe and hazardous scenarios to enhance realism. “There could be a map attached to the tutorial screen” is a great suggestion provided that would enhance in-game navigation, as many video games have this feature. “Add more modules” is suggested by multiple participants. One participant suggested adding both more modules and more unsafe practices to add complexity to the game.

Question 4 poses ten statements that were scored by participants using a 1 - 5 Likert scale to understand their experience using *FallSafe*, with 1 representing “strongly disagree” and 5 representing “strongly agree”. See Table 4.1 that displays the results from question 4.

	Survey Questions	Responses
1.	Instructions provided in the Serious Game were clear	66% rated 4 and above 33% rated 3
2.	The Serious Game controls were easy to use	66% rated 4 33% rated 5
3.	I felt comfortable using the VR headset and controllers	83% rated 4 17% rated 3
4.	I felt disoriented while playing the Serious Game	83% rated 4 17% rated 3
5.	I was aware of the unsafe practices present in the Serious Game	66% rated 4 33% rated 3
6.	The Serious Game intrigues your learning interest in construction safety	100% rated 5
7.	The Serious Game motivates you to refresh your knowledge in construction safety	83% rated 5 17% rated 4
8.	The Serious Game provides an engaging method of delivering construction safety	100% rated 5
9.	The learning experience is enhanced by the Serious Game	100% rated 5
10.	The Serious Game is engaging compared to traditional safety learning experience	66% rated 5 33% rated 4

Table 4.1: Feedback survey question 4 survey results

The short answer feedback questions (1-3) and question 4 share some commonalities regarding the user's experience of *FallSafe*. In question 1, several participants comment on ease of use, which is reflected in the statements, "Instructions provided in the Serious Game were clear", where 66% of participants rated 4 (agree) and above, and "The Serious Game controls were easy to use" rated 4 by 66% of participants. In question 2, participants comment on the animation of the Serious Game among their least favorite features, perhaps contributing to a rating of 4 (agree) by 83% of participants for the statement, "I felt disoriented while playing the Serious Game" and also a rating of 4 (agree) by 83% for the statement, "I felt comfortable using the VR headset and controllers". However, these two statements may not be related, this is conjecture based on responses to question 2.

"The Serious Game intrigues your learning interest in construction safety" is rated 5 (strongly agree) by 100% of participants and is also commented on in question 1, with one participant commenting on *FallSafe* having an intriguing storyline. Other statements rated 5 by all participants include, "The Serious Game provides an engaging method of delivering construction safety", and "The learning experience is enhanced by the Serious Game". Overall, most responses in questions 1- 4 reflect positive interaction and experiences with *FallSafe*.

Since engagement is the primary concern for the purpose of validating *FallSafe,* question 5 asked participants to score 31 questions using the User Engagement Scale (UES) to measure engagement provided by *FallSafe*. O'Brien (2018) defines user engagement (UE) as, "a quality of user experience characterized by the depth of an actor's cognitive, temporal., affective and behavioral investment when interacting with a digital system." Engagement is about more than just attention or interaction; it is a state of complete involvement in something. The UES is found to be an effective tool for measuring engagement in a variety of digital media including Serious Games and asks a series of 31 questions based on six dimensions:

1. FA: Focused attention, feeling absorbed in the interaction and losing track of time (7 items). For example, participants who report a high score for “I lost myself in this experience” rate the game as highly engaging in terms of Focused Attention.
2. PU: Perceived usability, negative affect experienced as a result of the interaction and the degree of control and effort expended (8 items). These questions ask if the experience was taxing, demanding, frustrating, etc., reflecting a negative experience with perceived useability if scored higher.
3. AE: Aesthetic appeal., the attractiveness and visual appeal of the interface (5 items). These questions are straight forward and ask about visual attraction to the game.
4. EN: Endurability, the overall success of the interaction and users’ willingness to recommend an application to others or engage with it in future (5 items). For example, “I would recommend the Serious Game to my family and friends”, a higher score for this statement would indicate the experience is memorable, or positive overall.
5. NO: Novelty, curiosity, and interest in the interactive task (3 items). “I continued to use this game out of curiosity” was one of our questions, and if it is scored higher this indicates the player experienced curiosity and interest while playing the game.
6. FI: Felt involvement, the sense of being “drawn in” and having fun (3 items). These questions reflect enjoyment of the game by the participant.

The last 3 dimensions, Endurability (EN), Novelty (NO), and Felt Involvement (FI) are grouped together in one category, Reward Factor (RW), for the revised, or short-form, UES (O’Brien, 2018) which has proven to be effective.

The specific dimension is not mentioned next to the questions in the survey, and the questions are randomized so that questions are not grouped by dimension, to avoid confusion between similar questions.

While the UES provides us with valuable insight regarding engagement of *FallSafe*, the sample population (6 participants) is too small to produce any statistically significant results, thus participants scores are not be compared but averaged as an overall picture of engagement among a small group of student volunteers. Scores range from 1 (strongly disagree) to 5 (strongly agree). Since a large number of questions are asked, scores are shown as averages according to the four dimensions measured to give us an overall picture of participant's responses (see Table 4.2).

User Engagement Scale Dimensions	Average scores of all six participants out of 5
Focused Attention	4.11
Perceived Usability	2.67
Aesthetic Appeal	3.79
Reward Factor	4.096

Table 4.2: User Engagement Scale (UES) average results

Focused Attention scored 4.11 on average, indicating players fells absorbed in the experience, or may have lost track of time as a result of high engagement. This may reflect positive feedback from questions 1-4 such as, "The storyline of the game intrigued me". Perceived Usability scored 2.67, which indicates there were some more negative interactions players had with the game. In the feedback questions some players reported feeling disoriented, this could relate to perceived usability. For Aesthetic Appeal., participants scored the game 3.79, indicating slightly more pleasing than neutral feelings about game visuals. Better animation and graphics are common feedback suggestions from questions 1-4. Reward Factor, which includes

Endurability, Novelty, and Felt Involvement, scored 4.096, indicating players had a positive experience with the game and found it engaging. This is also suggested by many of the scores for question four, including participants scoring 5/5 for “The Serious Game provides an engaging method of delivering construction safety”, “The learning experience is enhanced by the Serious Game”, and “The Serious Game intrigues your learning interest in construction safety”. The results of questions 1-5 suggest *FallSafe* is an engaging and effective method of teaching construction safety training when tested among a small group of student volunteers with various levels of safety training.

4.3. Chapter Summary & Discussion of Results

This chapter describes pilot testing and results of pilot testing the construction safety training game *FallSafe*. Pilot testing is conducted to validate the Serious Game. The findings from pilot testing FallSafe indicate that players found the Serious Game engaging and effective at delivering training content. Responses to short answer questions 1-3 suggest participants felt that the game presents clear instructions, is easy to navigate, and has an intriguing storyline. Suggestions for improvements from the short answer portion of the feedback survey that can be made regarding the appearance of the animation and adding character interactions can easily be attended to in future editions of the game with lesser time constraint. Excellent suggestions were given for enhancing the complexity of the game in the form of adding both safe and unsafe practices and a map for in-game navigation.

Question 4 of the feedback survey asked users to score ten questions with a 5-point Likert scale. All participants agreed that use of *FallSafe* as a medium of teaching construction safety is intriguing, engaging and enhances their learning experience. Following positive responses depicted the comfort level of participants in using the game controls. Participants rated *FallSafe* highly as a motivating in refreshing their safety knowledge. Many participants felt slight disorientation after playing *FallSafe* and this might be due to prolonged use of the Virtual Reality

headset. Overall Question 4 recorded positive responses from the participants, this shows that *FallSafe* is well received within the player group.

Lastly, the UES consisting of 31 questions with a 5-point Likert scale also recorded positive responses and is evident from the participant average scores (see Table 4.2). The purpose of the UES is to measure engagement provided by *FallSafe.* 31 questions answered by the participants are categorized into 4 factors namely Focused Attention (sense of feeling absorbed while playing *FallSafe),* Perceived Usability (was the experience taxing?), Aesthetic Appeal (was the experience pleasant graphically?) and Reward Factor (Involvement, Novelty). From the scores it is clear that the participants felt absorbed in the game experience. Neutral response is recorded for usability suggesting that improvements can be made in making the game experience less taxing and demanding. This factor relates more to the use of VR rather than the experience playing *FallSafe*. Aesthetic appeal scores show that the graphics, animations, and text in *FallSafe* added to the engaging experience, but there is a further room for improvement. Participants felt that their time playing *FallSafe* is rewarding and they would return for a similar type of experience as is depicted by a high Reward Factor score.

FallSafe provides a promising experience that is engaging and interactive. Improvements can be made to further enhance its experience as is evident from participant feedback. Results prove that *FallSafe* is a refreshing method of delivering construction safety content and players are absorbed in the experience which motivates and intrigues their learning interest towards construction safety.

Chapter 5 – Conclusion

Current safety training in construction is found to be ineffective and lacks engagement, which is necessary for learning to take place. To address the shortcomings of traditional safety training, the use of an engaging and interactive medium to deliver construction safety training is called for. Serious Games implemented in Virtual Reality provide an engaging, realistic, and affordable alternative to passive training methods and on-site instruction as they create an opportunity for hands-on learning to take place in a safe environment. New methods of delivering construction safety training content are necessary to prevent loss of life and property; this is the motivation for this thesis, to create a modern and effective teaching tool for the field of construction safety in the form of an innovative Serious Game implemented in Virtual Reality, titled, *FallSafe*.

The purpose of this thesis is to develop, and pilot test a construction safety training Serious Game that is effective and engaging. *FallSafe* meets these requirements successfully, as is evident from the pilot testing conducted on a group of students from a graduate level Construction Management program. Participant feedback is positive and the method of delivering safety training content through the medium of Serious Game is validated. Use of Virtual Reality technology, first-person perspective, and narrative storyline adds a layer of realism to *FallSafe* that had not previously been demonstrated in construction safety training. Combined use of Serious Games with Virtual Reality helped create a realistic story-based training module that invoked interest and learning desire within the participants.

A review of current literature shows interesting developments in the use of Serious Games. From their beginnings as tools to teach military strategy and preparedness, Serious Games now have a broad range of successful applications from training healthcare professionals to teaching children art history from home to current applications in the field of construction safety

training. Studies suggest current construction safety training methods, when compared to Serious Games and E-Learning in general, are ineffective due to the use of passive methods such as lectures, which are not motivating or engaging. Serious Games offer an alternative suitable for the needs of adult learners and have the potential to save great costs for firms and society in terms of loss of life and property. Serious Games began as considerably basic computer applications and now contain many elements of traditional and innovative video games, such as intriguing storyline, entertainment through character interaction and narrative, and use of Virtual Reality, while inducing self-motivation in players to effectively retain learning objectives. There are several construction safety training games already in existence, and for all Serious Games to be successful, they must have a suitable framework to deliver training content, as is implemented in *FallSafe*. In addition to framework and innovative game features, software and hardware components are necessary to support these features and make the learning content and game world come to life.

The Unity 3D game engine proves to be a great platform to develop *FallSafe* due to its seamless support for major Virtual Reality headsets available on the market. The Oculus Rift S VR headset and hand controls allow the player to use typical hand movements in the game and look in any direction, contributing to realism and an enhanced first-person perspective. The XR module support by Unity 3D makes Virtual Reality integration convenient and saved time on development. The DPE framework enables *FallSafe* to meet its learning requirements and the Serious Game is enhanced by playtesting the game prototype several times throughout its development cycle. Following these steps ensured that the player could complete the game with minimum effort, as feedback on items such as text size was corrected early on.

Finally, pilot testing of the game is conducted to validate *FallSafe.* Participant feedback after playing *FallSafe* was overall positive, with players reporting *FallSafe* as a viable tool for teaching construction safety training. Participants reported clear instructions and an enjoyable

storyline, with suggestions for enhanced graphics and a greater variety of modules and character interactions. Should *FallSafe* continue to be developed, these suggestions could easily be addressed with a larger budget and lesser time constraints, and *FallSafe* would be ready to test among a larger sample size in preparation for implementation with future construction trainees.

5.1 Contributions

A comprehensive review of literature regarding Serious Games and traditional tools for learning demonstrates that Serious Games are effective training tools because they engage the learner better than passive methods and deliver hands-on training experiences in a safe environment. They are economical because they do not require training using on-site materials, which reduces the risk of injury and property loss. While some construction safety Serious Games exist, *FallSafe* is unique in that it utilizes first-person perspective and storyline to deliver training content. Virtual Reality is implemented to enhance engagement and realism, contributing to effective and engaging delivery of safety training content. Both components had not previously been utilized to create a construction safety training game, thus *FallSafe* is created to meet this need and is validated as engaging and effective at delivering training content.

This research is also unique in that it deploys the DPE framework to successfully design a Serious Game in the discipline of construction safety education. The DPE framework had not been previously used to design a Serious Game in the field of construction. The use of DPE framework makes this research interdisciplinary and delivers an engaging Serious Game that meets its learning objectives. This research proves that the DPE framework can be implemented successfully to design a Serious Game in construction. An overarching view of how the development of *FallSafe* is carried out is illustrated (see Appendix D) in the form of a flowchart. Practitioners in construction education and professionals working in construction can refer to this as a short guide to develop a Serious Game in different fields of construction safety. The flowchart depicts the process that was undertaken while developing *FallSafe* from start to finish.

Literature shows that there is a rising trend in fatal injuries in construction due to falls, construction safety training is taught through mediums which are passive and unengaging. These shortcomings in delivering safety training are among the major factors that contribute to high rates of injury. Engaging means of safety training show greater knowledge retention along with reduced accidents, injuries and illness. *FallSafe* addresses these shortcomings by providing an engaging, interactive and effective method of delivering construction safety education and that is evident from the pilot-testing. *FallSafe* could lead to a Serious Game that is widely utilized by trainees to prevent accidents and injuries on site through more effective safety training and that is the contribution of this research to the construction industry.

5.2 Limitations

Due to time constraints only one safety talk from OSHA 3666- 04 2014 Fall Prevention Training Guide was presented. In the introductory safety briefing in the game, one of the "Toolbox Talks" is given by a site safety coordinator: Safe Use of Ladders. Safe Use of Scaffolding and the Roofing Safety "Toolbox Talks" can be added for this game to fulfill all the learning requirements for the OSHA Fall Prevention Training Guide. The main game features the player interacts with are the workers engaged in unsafe behaviors. Workers engaged in safe practices with different equipment can also be added to reinforce safety measures that will be present on an actual site to enhance realism of the game. Due to comments regarding animation, better graphics should be considered in future versions. Despite limited modules, *FallSafe* shows great promise as an effective and engaging form of construction safety training.

5.3 Future Direction

5.3.1 Possibilities for *FallSafe*

Future direction of this study can be directed towards making improvements to the existing Serious Game by adding more game features to further enhance engagement. Subtle

learning objectives should be a goal so that there is effortless flow for the player and learning takes place implicitly. While multiple choice questions are an effective method to retain knowledge, it maintains a similar teaching style to lecture and exams present in passive teaching methods. A variety of different safety modules, such as fall protection training or trenching, could be added to create a game that is specific to different fields of construction or for a more well-rounded training experience, depending on training needs.

The main game features the player interacts with are the workers engaged in unsafe behaviors. Workers engaged in safe practices with different equipment can also be added to reinforce safety measures that will be present on an actual site to enhance realism of the game. Due to comments regarding animation, better graphics should be considered in future versions. Despite limited modules, *FallSafe* shows great promise as an effective and engaging form of construction safety training.

5.3.2 Future Direction: Research

A comparison study with a large (N > 100) sample size can be undertaken between participants undergoing traditional safety training versus playing *FallSafe*. This will provide empirical evidence to test the hypotheses: Serious Games increase students understanding of safety training contents better than conventional training tools. Perhaps studies will follow that validate *FallSafe* as a viable training tool that can become the new standard for delivering engaging and effective construction safety training content.

APPENDICES

APPENDIX A: Research Participant Information and Consent Form

Research Participant Information and Consent Form

Study Title: Pilot Testing of a Construction Safety Serious Game
Researcher and Title: Mrudul Patil
Department and Institution: School of Planning, Design & Construction
Contact Information: patilmru@msu.edu
Sponsor: Dr Mohamed El-Gafy

BRIEF SUMMARY

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation including why you might or might not want to participate, and to empower you to make an informed decision. You should feel free to discuss and ask the researchers any questions you may have.

You are being asked to participate in a research study that involves pilot testing of a Virtual Reality based training module. Your participation in this study will take about 1 Hour. You will be given a short briefing prior to the playtesting to obtain background information about the research. Researcher will provide guidance through the playtesting. After testing, you will need to fill out a survey to provide your feedback on the training module.

Your participation in this research study will be from home. You will be sent a testing kit that will contain: 1 Virtual Reality headset with 2 controllers and a laptop containing the training module software. The testing kit will be delivered to you by mail. Communication between researcher and the participant through the study will take place by means of video conferencing.

The most likely risks of participating in this study are slight disorientation and fatigue from using the Virtual Reality headset (if used at long stretches of 1 hour or more).

You may not directly benefit from your participation in this study. However, your participation in this study may contribute to your understanding of virtual reality applications used to promote construction safety and may provide a different perspective on how construction safety is delivered.

PURPOSE OF RESEARCH

The purpose of this research study is to get participant feedback through a feedback survey on the virtual reality training module. The feedback survey will help the researcher to make essential changes to the training module so that a full-scale implementation can be made possible in the future. It will also measure user engagement through a user engagement scale provided in the survey

WHAT YOU WILL BE ASKED TO DO

The research study will take place in the following order

- Briefing prior to playtesting – 20 minutes

Background information related to the research will be described to the participant in brief. Instructions to setup and playtest the serious game will be provided by the researcher.

- Playtesting – 30 minutes
  Participant will be asked to wear the Virtual Reality headset and playtest the training module using the left- and right-hand controllers. During this time, researcher will provide guidance to the participant till the playtesting concludes. If you feel any discomfort during the playthrough, please take off the headset.

- Filling out the feedback survey will conclude the research study – 10 minutes
  Participant is free to skip any questions that he/she would prefer not to answer.

POTENTIAL BENEFITS

You may not benefit personally from being in this study. However, we hope that, in the future, other people might benefit from this study because an engaging form of delivering safety training will promote safety awareness among peers.

POTENTIAL RISKS

The most likely risks of participating in this study are slight disorientation and fatigue from using the Virtual Reality headset (if used at long stretches of 1 hour or more).

PRIVACY AND CONFIDENTIALITY

The consent forms and feedback survey data from each participant will be stripped of identifiers to maintain anonymity and will be stored with the researcher securely for duration of 4 months. The data will not be used for any purposes other than this research. Video recording of participant playtesting will be stored for a duration of 4 months on a personal secure electronic device owned by the researcher and will be destroyed after that period.

YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

You have the right to say no to participate in the research. You can stop at any time after it has already started. There will be no consequences if you stop and you will not be criticized. You will not lose any benefits that you normally receive.

COSTS AND COMPENSATION FOR BEING IN THE STUDY

You will not receive money or any other form of compensation for participating in this study.

FUTURE RESEARCH

Your feedback survey data collected as part of the research, even if information that identifies you is removed, will not be used or distributed for future research studies.

CONTACT INFORMATION

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher (Mrudul Patil at 517-898-9541, or email patilmru@msu.edu or regular mail at 920 S Washington Av, Lansing, MI 48910.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

DOCUMENTATION OF INFORMED CONSENT.

Your signature below means that you voluntarily agree to participate in this research study.

_____ _____

Signature Date

You will be given a copy of this form to keep.

APPENDIX B: Feedback Survey

1. What is your gender?

   [ ] Male [ ] Female

2. How often do you play Virtual reality games?

   [ ] Never

   [ ] A few times every year

   [ ] A few times every month

   [ ] Several times a week

   [ ] Everyday

3. Construction Safety Experience

   [ ] OSHA 30

   [ ] OSHA 10

   [ ] Safety Related Coursework

   [ ] Other : _____

   [ ] None

4. What are the best features of the Serious game? Why?

   -
   -
   -

5. What are your least favorite features of the Serious game? Why?

   -
   -
   -

6. What are your suggestions for improving the Serious game?

7. Score the survey questions on 1 – 5

Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

- Instructions provided in the Serious game were clear - [ ]
- The Serious game controls were easy to use - [ ]
- I felt comfortable using the VR headset and controllers - [ ]
- I felt disoriented while playing the Serious game - [ ]
- I was aware of the unsafe practices present in the Serious game - [ ]
- The Serious game intrigues your learning interest in construction safety - [ ]

- The Serious game motivates you to refresh your knowledge in construction safety - [ ]
- The Serious game provides an engaging method of delivering construction safety - [ ]
- The learning experience is enhanced by the Serious game - [ ]
- The Serious game is engaging compared to traditional safety learning experience - [ ]

8. Score the User Engagement Scale (UES) on 1 - 5

Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

- Using the Serious game was worthwhile - [ ]
- I lost myself in this experience - [ ]
- The screen layout of Serious game was visually pleasing. - [ ]
- I could not do some of the things I needed to do while using the Serious game - [ ]
- I was so involved in this experience that I lost track of time - [ ]
- I felt frustrated while using this Serious game - [ ]
- My experience was rewarding. - [ ]
- Using this Serious game was taxing - [ ]
- I liked the graphics and images of the Serious game - [ ]
- This experience did not work out the way I had planned. - [ ]
- This experience was demanding - [ ]
- The content of the Serious game incited my curiosity. - [ ]
- I was absorbed in this experience - [ ]
- I felt in control while using this Serious game - [ ]
- I continued to use the Serious game out of curiosity. - [ ]
- I blocked out things around me when I was using the Serious game - [ ]
- This Serious game was attractive - [ ]
- When I was using Serious game , I lost track of the world around me - [ ]

- I felt involved in this experience. - [ ]
- I found this Serious game confusing to use - [ ]
- This experience was fun. - [ ]
- I felt discouraged while using this Serious game - [ ]
- During this experience I let myself go - [ ]
- I was really drawn into this experience. - [ ]
- Serious game appealed to visual senses. - [ ]
- The time I spent using Serious game just slipped away - [ ]
- I would recommend the Serious game to my family and friends - [ ]
- This Serious game was aesthetically appealing - [ ]
- I felt annoyed while using Serious game - [ ]
- I consider my experience a success. - [ ]

APPENDIX C: IRB Exempt Determination Document

MICHIGAN STATE
UNIVERSITY

EXEMPT DETERMINATION
Revised Common Rule

August 26, 2020

To: Mohamed Anwar El-Gafy

Re: **MSU Study ID:** STUDY00004983
Principal Investigator: Mohamed Anwar El-Gafy
Category: Exempt 1
Exempt Determination Date: 8/26/2020
Limited IRB Review: Not Required.

Title: Development and Pilot Testing of A Serious Game for Construction Fall Protection Awareness Training

This study has been determined to be exempt under 45 CFR 46.104(d) 1.

Principal Investigator (PI) Responsibilities: The PI assumes the responsibilities for the protection of human subjects in this study as outlined in Human Research Protection Program (HRPP) Manual Section 8-1, Exemptions.

Institutional restrictions to in-person human subject research activities conducted by MSU employees, MSU students, or agents of MSU are in place, but MSU is phasing in human research that has the potential for in-person interactions with participants, using a Tier approach. Restrictions to in-person interactions with human research participants by MSU employees, MSU students, or agents of MSU are in place until the activity is permitted under a Tier and a Human Research Plan for a Safe Return is approved. Visit http://hrpp.msu.edu/COVID-19/index.html for the restrictions, Tiers, forms, and the process.

Continuing Review: Exempt studies do not need to be renewed.

Modifications: In general, investigators are not required to submit changes to the Michigan State University (MSU) Institutional Review Board (IRB) once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the study is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Please contact the HRPP office if you have any questions about whether a change must be submitted for IRB review and approval.

Office of Regulatory Affairs
Human Research Protection Program

4000 Collins Road
Suite 136
Lansing, MI 48910

517-355-2180
Fax: 517-432-4503
Email: irb@msu.edu
www.hrpp.msu.edu

New Funding: If new external funding is obtained for an active study that had been determined exempt, a new initial IRB submission will be required, with limited exceptions. If you are unsure if a new initial IRB submission is required, contact the HRPP office. IRB review of the new submission must be completed before new funds can be spent on human research activities, as the new funding source may have additional or different requirements.

Reportable Events: If issues should arise during the conduct of the research, such as unanticipated problems that may involve risks to subjects or others, or any problem that may increase the risk to the human subjects and change the category of review, notify the IRB office promptly. Any complaints from participants that may change the level of review from exempt to expedited or full review must be reported to the IRB. Please report new information through the study's workspace and contact the IRB office with any urgent events. Please visit the Human Research Protection Program (HRPP) website to obtain more information, including reporting timelines.

Personnel Changes: After determination of the exempt status, the PI is responsible for maintaining records of personnel changes and appropriate training. The PI is not required to notify the IRB of personnel changes on exempt research. However, he or she may wish to submit personnel changes to the IRB for recordkeeping purposes (e.g. communication with the Graduate School) and may submit such requests by submitting a Modification request. If there is a change in PI, the new PI must confirm acceptance of the PI Assurance form and the previous PI must submit the Supplemental Form to Change the Principal Investigator with the Modification request (available at hrpp.msu.edu).

Closure: Investigators are not required to notify the IRB when the research study can be closed. However, the PI can choose to notify the IRB when the study can be closed and is especially recommended when the PI leaves the university. Closure indicates that research activities with human subjects are no longer ongoing, have stopped, and are complete. Human research activities are complete when investigators are no longer obtaining information or biospecimens about a living person through interaction or intervention with the individual, obtaining identifiable private information or identifiable biospecimens about a living person, and/or using, studying, analyzing, or generating identifiable private information or identifiable biospecimens about a living person.

For More Information: See HRPP Manual, including Section 8-1, Exemptions (available at hrpp.msu.edu).

Contact Information: If we can be of further assistance or if you have questions, please contact us at 517-355-2180 or via email at IRB@msu.edu. Please visit hrpp.msu.edu to access the HRPP Manual, templates, etc.

Exemption Category. The full regulatory text from 45 CFR 46.104(d) for the exempt research categories is included below. [1234]

Exempt 1. Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Exempt 2. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:

> (i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
>
> (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
>
> (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

Exempt 3. (i) Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses (including data entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection and at least one of the following criteria is met:

> (A) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
>
> (B) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
>
> (C) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

(ii) For the purpose of this provision, benign behavioral interventions are brief in duration, harmless, painless, not physically invasive, not likely to have a significant adverse lasting impact on the subjects, and the investigator has no reason to think the subjects will find the interventions offensive or embarrassing. Provided all such criteria are met, examples of such benign behavioral interventions would include having the subjects play an online game, having them solve puzzles under various noise conditions, or having them decide how to allocate a nominal amount of received cash between themselves and someone else.

(iii) If the research involves deceiving the subjects regarding the nature or purposes of the research, this exemption is not applicable unless the subject authorizes the deception through a prospective agreement to participate in research in circumstances in which the subject is informed that he or she will be unaware of or misled regarding the nature or purposes of the research.

Exempt 4. Secondary research for which consent is not required: Secondary research uses of identifiable private information or identifiable biospecimens, if at least one of the following criteria is met:

(i) The identifiable private information or identifiable biospecimens are publicly available;

(ii) Information, which may include information about biospecimens, is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained directly or through identifiers linked to the subjects, the investigator does not contact the subjects, and the investigator will not re-identify subjects;

(iii) The research involves only information collection and analysis involving the investigator's use of identifiable health information when that use is regulated under 45 CFR parts 160 and 164, subparts A and E, for the purposes of ``health care operations'' or ``research'' as those terms are defined at 45 CFR 164.501 or for ``public health activities and purposes'' as described under 45 CFR 164.512(b); or

(iv) The research is conducted by, or on behalf of, a Federal department or agency using government-generated or government-collected information obtained for nonresearch activities, if the research generates identifiable private information that is or will be maintained on information technology that is subject to and in compliance with section 208(b) of the E-Government Act of 2002, 44 U.S.C. 3501 note, if all of the identifiable private information collected, used, or generated as part of the activity will be maintained in systems of records subject to the Privacy Act of 1974, 5 U.S.C. 552a, and, if applicable, the information used in the research was collected subject to the Paperwork Reduction Act of 1995, 44 U.S.C. 3501 et seq.

Exempt 5. Research and demonstration projects that are conducted or supported by a Federal department or agency, or otherwise subject to the approval of

department or agency heads (or the approval of the heads of bureaus or other subordinate agencies that have been delegated authority to conduct the research and demonstration projects), and that are designed to study, evaluate, improve, or otherwise examine public benefit or service programs, including procedures for obtaining benefits or services under those programs, possible changes in or alternatives to those programs or procedures, or possible changes in methods or levels of payment for benefits or services under those programs. Such projects include, but are not limited to, internal studies by Federal employees, and studies under contracts or consulting arrangements, cooperative agreements, or grants. Exempt projects also include waivers of otherwise mandatory requirements using authorities such as sections 1115 and 1115A of the Social Security Act, as amended. (i) Each Federal department or agency conducting or supporting the research and demonstration projects must establish, on a publicly accessible Federal Web site or in such other manner as the department or agency head may determine, a list of the research and demonstration projects that the Federal department or agency conducts or supports under this provision. The research or demonstration project must be published on this list prior to commencing the research involving human subjects.

Exempt 6. Taste and food quality evaluation and consumer acceptance studies: (i) If wholesome foods without additives are consumed, or (ii) If a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

Exempt 7. Storage or maintenance for secondary research for which broad consent is required: Storage or maintenance of identifiable private information or identifiable biospecimens for potential secondary research use if an IRB conducts a limited IRB review and makes the determinations required by 45 CFR 46.111(a)(8).

Exempt 8. Secondary research for which broad consent is required: Research involving the use of identifiable private information or identifiable biospecimens for secondary research use, if the following criteria are met:

> (i) Broad consent for the storage, maintenance, and secondary research use of the identifiable private information or identifiable biospecimens was obtained in accordance with 45 CFR 46.116(a)(1) through (4), (a)(6), and (d);
>
> (ii) Documentation of informed consent or waiver of documentation of consent was obtained in accordance with 45 CFR 46.117;
>
> (iii) An IRB conducts a limited IRB review and makes the determination required by 45 CFR 46.111(a)(7) and makes the determination that the research to be conducted is within the scope of the broad consent referenced in paragraph (d)(8)(i) of this section; and

(iv) The investigator does not include returning individual research results to subjects as part of the study plan. This provision does not prevent an investigator from abiding by any legal requirements to return individual research results.

[1]Exempt categories (1), (2), (3), (4), (5), (7), and (8) cannot be applied to activities that are FDA-regulated.

[2] Each of the exemptions at this section may be applied to research subject to subpart B (Additional Protections for Pregnant Women, Human Fetuses and Neonates Involved in Research) if the conditions of the exemption are met.

[3] The exemptions at this section do not apply to research subject to subpart C (Additional Protections for Research Involving Prisoners), except for research aimed at involving a broader subject population that only incidentally includes prisoners.

[4] Exemptions (1), (4), (5), (6), (7), and (8) of this section may be applied to research subject to subpart D (Additional Protections for Children Involved as Subjects in Research) if the conditions of the exemption are met. Exempt (2)(i) and (ii) only may apply to research subject to subpart D involving educational tests or the observation of public behavior when the investigator(s) do not participate in the activities being observed. Exempt (2)(iii) may not be applied to research subject to subpart D.

APPENDIX D: Overview of Serious Game Development: *FallSafe*

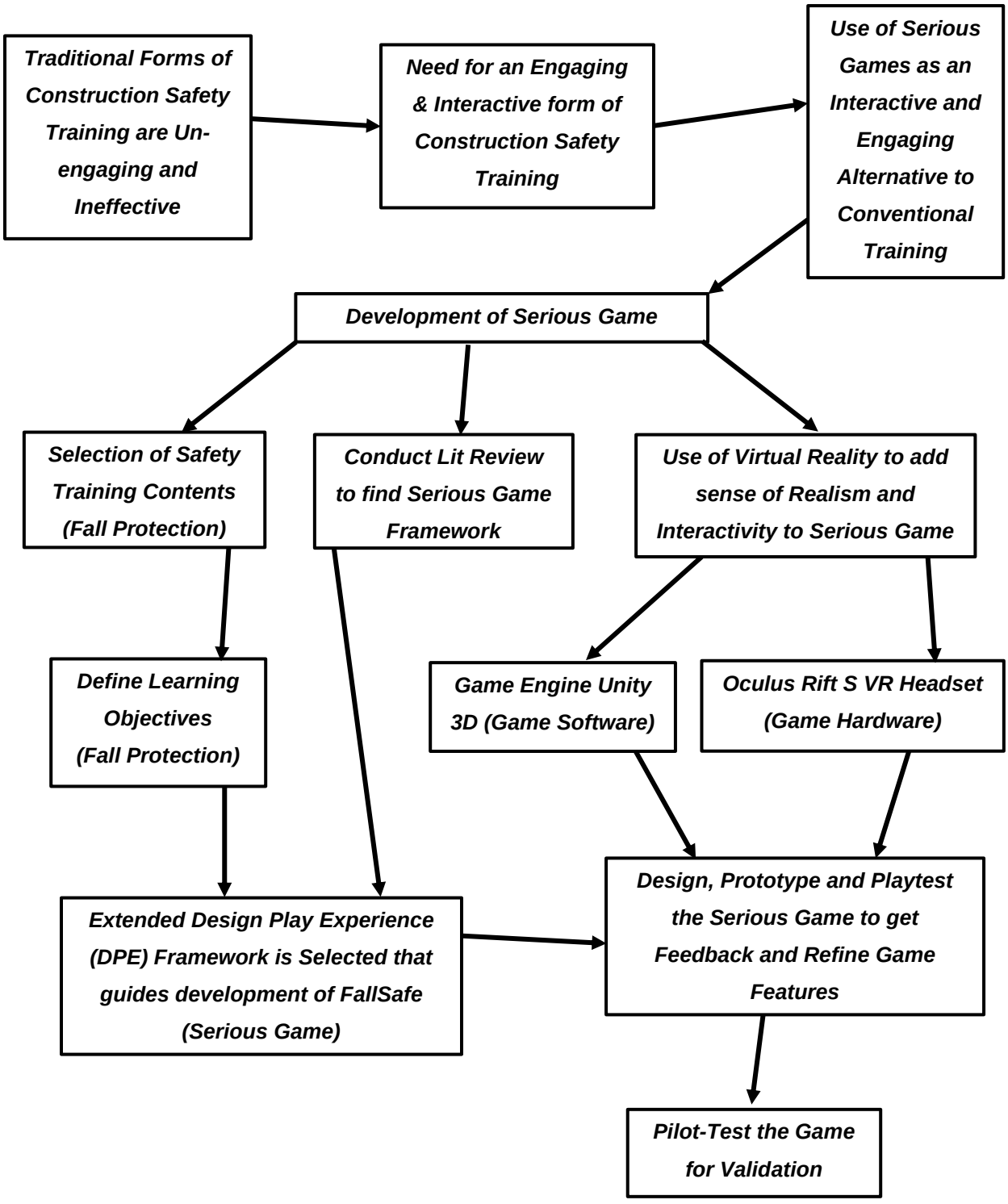

Figure A.1: Overview of Serious Game Development: *FallSafe*

REFERENCES

REFERENCES

Abt, C. C. (1970). Serious Games: the art and science of games that simulate life. Viking Press, New York.

Antonova, A., and Ekambaram, A. (2011). “Serious Games in the context of organizational knowledge management practices.” *Proceedings of the 12th European Conference on Knowledge Management: ECKM2011,* Academic Conferences Limited, (Vol. 1, p. 28).

Bente, G., and Breuer, J. (2010). “Why so serious? On the Relation of Serious Games and Learning.” Eludamos - Journal for Computer Game Culture, 4(1), 7–24.

Bergeron B. (2006). *Developing Serious Games*. Charles River Media, Hingham.

Boyle, E., & Connolly, T. (2008). “A review of theories of player enjoyment in playing computer games.” *2nd European Conference on Games Based Learning*, Barcelona, Spain (59-68).

Bryson, S. (1996). “Virtual Reality in scientific visualization.” Communications of the ACM, 39(5), 62-71.

Burdea, G. C., & Coiffet, P. (2003). *Virtual Reality technology*. John Wiley & Sons.
Bureau of Labor Statistics (2020). Wikipedia. Retrieved 18 February 2020, from https://en.wikipedia.org/wiki/Bureau_of_Labor_Statistics.

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., and Islam, G. (2006). “Relative Effectiveness of Worker Safety and Health Training Methods.” American Journal of Public Health, 96(2), 315–324.

Chen, A., Golparvar-Fard, M., and Kleiner, B. (2013). “Design and development of SAVES: A construction safety training augmented virtuality environment for hazard recognition and severity identification.” *Proc., 2013 ASCE International Workshop on Computing in Civil Engineering*, Los Angeles, 841–848.

Clark, D. B., Tanner-smith, E. E., and Killingsworth, S. S. (2016). “Digital Games , Design , and Learning : A Systematic Review and Meta-Analysis.” 86(1), 79–122.

Cohen, A., Colligan, M. J., Sinclair, R., Newman, J., and Schuler, R. (1998). “Assessing occupational safety and health training: A literature review.” Cincinnati, OH: National Institutes of Health, (June), 1–174.

Colligan, M. J., and Cohen, A. (2004). “The Role of Training in Promoting Workplace Safety and Health.” *The Psychology of Workplace Safety*, Barling, J., and Frone, M. R, eds., American Psychological Association, Washington, D.C., 223–248.

Connolly, T., Stansfield, M., and Hainey, T. (2008). “Development of a general framework for evaluating games-based learning.” *Proc., 2nd European Conference on Games-based Learning*, Barcelona, Spain, 105–114.

Csikszentmihalyi, M. (2009). *Flow: the psychology of optimal experience*. Harper Row, New York.
Dawood, N., Miller, G., Patacas, J., and Kassem, M. (2014). “Construction Health and Safety Training: the Utilisation of 4D Enabled Serious Games.” J*ournal of Information Technology in Construction (ITcon)*, 19(19), 326–335.

DeKanter, N. (2005). “Gaming redefines interactivity for learning.” *TechTrends*, 49(3), 26–31.
Dickinson, J. K., Woodard, P., Canas, R., Ahamed, S., and Lockston, D. (2011). “Game-based trench safety education: Development and lessons learned.” *Electronic Journal of Information Technology in Construction*, 118–132.

Dickey, M. D. (2005). “Engaging by design: How engagement strategies in popular computer and video games can inform instructional design.” *Educational technology research and development*, 53(2), 67-83.

Djaouti1&2, D., Alvarez, J., Jessel, J. P., & Rampnoux, O. (2012). *Origins of Serious Games*. IRIT, Toulouse III University, France.

Druley, K. (2019). “OSHA’s Top 10 most-cited violations for fiscal year 2019”. *Safety+Health Magazine*, published by the National Safety Council.

Eiris, R., Gheisari, M., and Esmaeili, B. (2018). “Pars: Using augmented 360-degree panoramas of reality for construction safety training.” *International Journal of Environmental Research and Public Health*, 15(11).

Erhel, S., and Jamet, E. (2013). “Computers & Education Digital game-based learning : Impact of instructions and feedback on motivation and learning effectiveness.” *Computers & Education*, Elsevier Ltd, 67, 156–167.

Everett, J.G. and Frank, P.B. (1996). “Costs of accidents and injuries due to the construction industry.” *Journal of Construction Engineering and Management*, 122(2): 158–64.

“First-person (video games).” Wikipedia (2020). Retrieved 25 March 2020 from https://en.wikipedia.org/wiki/First-person_(video_games).

Froschauer, J., Arends, M., Goldfarb, D., & Merkl, D. (2011, May). “Towards an online multiplayer Serious Game providing a joyful experience in learning art history.” *2011 Third International Conference on Games and Virtual Worlds for Serious Applications,* IEEE, pp. 160-163.

Gampell, A. V., Gaillard, J. C., & Parsons, M. (2019). “On the use of participatory methodologies for video game research: Exploring disaster risk reduction in video games.” *Methodological Innovations*, 12(3).

Gao, Y., González, V. A., & Yiu, T. W. (2017). “Serious Games vs. traditional tools in construction safety training: a review.” *LC3 2017*, *1*, 4-7.

Garris, R., Ahlers, R., and Driskell, J. E. (2002). “Games, motivation, and learning: A research and practice model.” *Simulation and Gaming,* 33(4), 441–467.

Gee, J.P. (2003). What video games have to teach us about learning and literacy. Palgrave Macmillan, New York.

Gilbert, L., & Gale, V. (2008). “Front-end analysis.” *Principle of E-Learning Systems Engineering*, 77-101.

Girard, C., Ecalle, J., & Magnan, A. (2013). “Serious Games as new educational tools: how effective are they? A meta-analysis of recent studies.” *Journal of computer assisted learning*, 29(3), 207-219.

Golovina, O., Kazanci, C., Teizer, J., and König, M. (2019). “Using Serious Games in Virtual Reality for automated close call and contact collision analysis in construction safety.” *Proc., 36th International Symposium on Automation and Robotics in Construction*, ISARC 2019, Alberta, Canada, 967–974.

Grossard, C., Grynspan, O., Serret, S., Jouen, A. L., Bailly, K., & Cohen, D. (2017). “Serious Games to teach social interactions and emotions to individuals with autism spectrum disorders (ASD).” *Computers & Education*, *113*, 195-211.

Guo, H., Li, H., Chan, G., and Skitmore, M. (2012). “Using game technologies to improve the safety of construction plant operations.” *Accident Analysis and Prevention*, Elsevier Ltd, 48, 204–213.

Hake, R. R. (1998). “Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses.” *American journal of Physics*, 66(1), 64-74.

Hallowell, M. (2010). “Cost-effectiveness of construction safety programme elements.” *Construction Management and Economics*, *28*(1), 25-34.

Ho, C. L., and Dzeng, R. J. (2010). “Construction safety training via e-Learning: Learning effectiveness and user satisfaction.” *Computers and Education*, Elsevier Ltd, 55(2), 858–867.

Hu, K., Rahmandad, H., Smith-Jackson, T., and Winchester, W. (2011). “Factors influencing the risk of falls in the construction industry: a review of the evidence.” *Construction Management and Economics*, 29(4), 397–416.

LeBlanc, M. (2005a). “Game Design and Tuning Workshop.” *International Academic Conference on the Future of Game Design and Technology*, FuturePlay, East Lansing, MI.

Lin, K. Y., Son, J. W., and Rojas, E. M. (2011). “A pilot study of a 3D game environment for construction safety education.” *Electronic Journal of Information Technology in Construction*, 69–83.

Lingard, H. (2010). “Construction Safety Management.” *Construction Management and Economics*, 28(2), 213–214.

Loosemore, M., and Malouf, N. (2019). “Safety training and positive safety attitude formation in the Australian construction industry.” *Safety Science*, 113, 233–243.

Mayo, M. J. (2007). “Games for science and engineering education.” *Communications of the ACM*, 50(7), 30.

Meera, P., McLain, M. L., Bijlani, K., Jayakrishnan, R., & Rao, B. R. (2016). “Serious Game on flood risk management.” *Emerging research in computing, information, communication and applications*, Springer, New Delhi, pp. 197-206.

Michael, D., & Chen, S. (2006). Serious Games: Games that Educate, Train, and Inform, Course Technology. Cengage Learning.

O’Brien, H. L., Cairns, P., & Hall, M. (2018). “A practical approach to measuring user engagement with the refined user engagement scale (UES) and new UES short form.” *International Journal of Human-Computer Studies*, *112*, 28-39.

“Occupational Safety and Health Administration.” (2020). Wikipedia. Retrieved 18 February 2020 from https://en.wikipedia.org/wiki/Occupational_Safety_and_Health_Administration.

Prensky, M. (2001). “Digital Natives, Digital Immigrants.” *On the Horizon*, 9(5), 1–6.
Sacks, R., Perlman, A., and Barak, R. (2013). “Construction safety training using immersive Virtual Reality.” *Construction Management and Economics*, 31(9), 1005–1017.

Saltzman, Marc. (2000). *Game Design: Secrets of the Sages, Second Edition*. Indianapolis, IN: Macmillan Publishing, 256.

Shamsudin, N. M., Mahmood, N. H. Ni., Rahim, A. R. A., Mohamad, S. F., and Masrom, M. (2018). “Current Practices of Construction Safety Training Methods.” *Advanced Science Letters,* 24(4), 2433–2436.

Susi, T., Johannesson, M., & Backlund, P. (2007). “Serious Games: An overview.” School of Humanities and Informatics, University of Skövde, Sweden.

“The Bible Videogame: David” Kickstarter (2017). Retrieved 2 October 2020 from

https://www.kickstarter.com/projects/1622773351/the-bible-videogame-david.

Thompson, J., Berbank-Green, B., & Cusworth, N. (2007). Game design: Principles, practice, and techniques-the ultimate guide for the aspiring game designer. John Wiley & Sons.

U.S. Bureau of Labor Statistics (2019). “Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data.” Retrieved 15 March 2020 from https://www.bls.gov/iif/oshcfoi1.htm.

U.S. Bureau of Labor Statistics (2018). “TABLE A-9. Fatal occupational injuries by event or exposure for all fatal injuries and major private industry(1)sector, all United States, 2018.” Retrieved 18 February 2020 from https://www.bls.gov/iif/oshwc/cfoi/cftb0330.htm.

United States Department of Labor (2020). “Commonly Used Statistics.” Occupational Safety and Health Administration. Retrieved 18 February 2020 from https://www.osha.gov/data/commonstats.

United States Department of Labor (2020). “Duty to have fall protection.” Occupational Safety and Health Administration. Retrieved 18 February 2020 from https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.501.

Wakkary, R., Hatala, M., Muise, K., Tanenbaum, K., Corness, G., Mohabbati, B., & Budd, J. (2009). “Kurio: a museum guide for families.” *Proc., 3rd International Conference on Tangible and Embedded Interaction,* Cambridge, UK, 215-222.

Wilkins, J. R. (2011). “Construction workers’ perceptions of health and safety training programmes.” *Construction Management and Economics,* 29(10), 1017–1026.

Wilkinson, P. (2016). “A brief history of Serious Games.” *Entertainment computing and Serious Games* (pp. 17-41). Springer, Cham.

Winn, B. M. (2009). “The design, play, and experience framework.” *Handbook of research on effective electronic gaming in education*, IGI Global., pp. 1010-1024.

Yusoff, A. (2010). “A Conceptual Framework for Serious Games and its Validation.” University of Southampton, School of Electronics and Computer Science, PhD Thesis (October).

Yusoff, A., Crowder, R., and Gilbert, L. (2010). "Validation of Serious Games Attributes Using the Technology Acceptance Model," *2010 Second International Conference on Games and Virtual Worlds for Serious Applications*, 45-51.

Zyda, M. (2005). From visual simulation to Virtual Reality to games. *Computer*, 38(9), 25-32.