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Using Immersive Storytelling to Improve Engagement and Motivation During Fall Prevention Training

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Abstract

Construction continues to have one of the highest rates of injuries and fatalities of any industry in the U.S. Fall accidents are the leading cause of fatalities in construction, particularly in the residential sector. Construction employers often use training programs to try to reduce falls, but current programs often produce low engagement and motivation among trainees. To improve engagement and motivation, this project developed fall hazard training for residential construction featuring immersive storytelling. A study was developed to assess how the inclusion of storytelling-driven narratives affects safety training engagement and motivation. A between-subject experimental design with two training approaches: 1) virtual human storytelling-driven narratives and 2) non-storytelling narratives – was employed to evaluate trainee engagement and motivation. Data was collected using behavioral eye-tracking metrics, a hazard identification survey, and self-efficacy and motivation questionnaires. While it was found that no significant statistical differences were detected in the cognitive and emotional dimensions of engagement and motivation, the behavioral dimension benefited how workers' attention was directed in some fall hazard scenarios.

Key Findings

1. Immersive storytelling during the training provides behavioral engagement and motivation benefits in directing workers' attention in some fall hazard scenarios.
2. Immersive storytelling training is not statistically different from traditional virtual reality training regarding the cognitive and emotional dimensions of motivation and engagement.
3. The research team recommends using immersive storytelling in future training interventions to improve trainees' behavioral engagement and motivation.

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Introduction

Construction continues to be one of the most dangerous industries in the United States, incurring over 20 percent of all workplace fatalities (OSHA, 2023). Construction workers are 5.5 times more likely to suffer a fatal injury than workers in other industries (Al-Bayati et al., 2023). Among OSHA's "Construction Focus Four" hazards (fall, electrocution, struck-by, and caught-by/between), falls are the largest source of fatalities and injuries (Al-Bayati and York 2019; Harris et al., 2023). OSHA's accident inspection records indicate that a significant proportion of these fatalities and injuries are caused by falls from working on unprotected elevated surfaces (e.g., roofs, ramps, pits), ladders, floor openings, and scaffolds (Janicak, 1998; Hu et al., 2011). Fall accidents that do not result in a direct death often require lengthy, costly recovery periods and cause distress, suffering, and pain for the persons involved. Fall accidents also affect profits, causing delays and cash flow issues (Hu et al., 2011). Due to these significant effects, educational and training initiatives have become common to help at-risk workers identify and reduce fall hazards on construction sites.

Construction training programs aim to reduce safety incidents by preparing personnel to make safety-conscious decisions through greater awareness, understanding, and recognition of hazards (Demirkesen & Arditi, 2015). Often, training sessions are performed offsite (for example, in the contractor trailer, at a remote office, or within online learning platforms) using standardized learning materials (e.g., OSHA 10-hour or 30-hour courses) and delivered by a certified instructor. These sessions predominantly use lecture-based associated techniques, including texts, images, videos, slide presentations, or pamphlets, to communicate safety information without exposing workers to actual hazardous conditions (Cherrett et al., 2009).

Although lecture-based training is widespread in construction, several studies have identified significant issues with this traditional approach. One major limitation is their passive nature, as learners become observers of the safety information the instructor delivers. These passive methods (e.g., texts, images, videos) have consistently demonstrated low effectiveness in delivering educational content, as they do not engage workers in learning (Burke et al., 2006; Wilkins, 2011; Zuluaga et al., 2016).

To overcome the passivity of traditional training, a growing body of researchers is investigating the use of virtual environments to provide hands-on, context-based, and activity-oriented interactions and to facilitate safety training and education (Li et al., 2018). While a large proportion of the existing literature focuses on using 3D-modeled environments to provide immersive safety training interventions (e.g., Yu et al., 2022; Rokooei et al., 2023), these digitally produced environments have been found to generate unrealistic workplace hazard scenarios (Eiris et al., 2020-a). Because of this limitation of 3D-modeled safety training, 360-degree panorama-based technologies have been increasingly used by researchers. These panorama-based approaches allow delivery of interactive safety simulations while offering a high sense of presence (i.e., feeling of being in a location when physically being somewhere else), realistic visualizations, and the capability of adding layers of information (e.g., text, signifiers, audio) over the obtained background images and videos (Eiris et al., 2018; Eiris et al., 2020b; Eiris et al., 2021a).

Although an increasing number of researchers using virtual environments to provide active, engaging safety training, exiting literature lacks to demonstrate a clear understanding of the methods used increase engagement and motivation. Learner engagement is the students' or trainees' behavioral, cognitive, and emotional involvement during a learning activity (Lester. 2013). Prior studies have found that academic achievement, motivation, satisfaction, and persistence are attained when students or trainees are engaged. (Halverson & Graham, 2019). Because of the benefits of learner engagement, there is a need to investigate how virtual environments can be designed to increase trainee engagement and motivation. While the behavioral and cognitive dimensions of engagement in safety training have been somewhat explored, the emotional dimension of engagement requires further investigation.

This project focuses on evaluating immersive storytelling as a technique to increase learner engagement and motivation within 360-degree panoramic virtual environments. A 360-degree panorama platform was developed for fall hazards in the residential construction industry to understand how the inclusion of storytelling during safety training influences engagement across behaviors, cognition, and emotions. A between-subjects experimental design was completed with two conditions – (1) immersive storytelling and (2) immersive non-storytelling. A total of 42 residential industry professionals experienced the 360-degree panorama platform. Data were collected from surveys and eye-tracking metrics to understand engagement and motivation across behavioral, cognitive, and emotional dimensions. The residential construction industry was selected for this study due to the large proportion of fall accidents suffered by workers in the construction industry (Kang et al., 2017).

Related Work

Learning Engagement and Motivation in Virtual Environments.

Student or trainee engagement and motivation is key for any effective safety training intervention. In the education sciences literature, student or trainee engagement and motivation is defined as a meta-construct composed of three dimensions: 1) behavioral – time and attention allocated to a learning task, 2) cognitive – strategies for obtaining and producing meaning out of learning materials, and 3) emotional – interest and perceptional responses from a learning activity (Fredricks & McColskey, 2012; Henrie et al., 2015). When engagement is achieved, motivation to learn the content is developed (Lester, 2013; Henrie et al., 2015). Virtual environments in the construction literature are often highlighted as a method to improve overall engagement and motivation during training or learning (e.g., Wang et al., 2018; Zhang et al., 2022). Explanatory factors in virtual environments that cause this engagement and motivation effects are related to the interactive nature of teaching materials for self-learning and the increased sense-of-presence from the immersive learning settings (Li et al., 2018; Eiris et al., 2020-a). Behavioral and cognitive outcomes of engagement and motivation during safety training are starting to be explored. For example, Lee et al. (2022) evaluated behavioral engagement and motivation through hazard attentional allocation of trainees in 360-degree panorama virtual environments using eye-tracking metrics. The authors found that the dynamic and static nature of the hazards visualized affected the engagement and motivation of trainers while identifying hazards. In another study, Pham et al., (2018) evaluated cognitive engagement and motivation through using learning questionaries' in a web-based 360-degree panorama-based field trip. The study found that student engagement and motivation during learning were similar in virtual environments compared to traditional field trips for construction safety learning. Although several studies indirectly consider learner engagement and motivation, the dimension constructs (i.e., behaviors, cognition, emotions) defined by educational sciences remain largely unexplored as explanations of the effectiveness of safety training approaches. In particular, the emotional dimension of engagement and motivation remains to be investigated within safety training applications in virtual environments.

Storytelling in Construction Training and Virtual Environments.

One method used in traditional and virtual construction training to support learner engagement and motivation is storytelling. Storytelling refers to the art of conveying knowledge through appealing and memorable narratives (McDowell, 2021). Within traditional training, storytelling typically occurs within interventions such as discussions, toolbox talks, or seminars. Such narrative approaches are commonly used across the construction industry to provide real-world stories of near misses, workplace incidents, and professional experiences that resemble daily practices on the construction job site (Kaskutas et al., 2013). As listeners follow a story, a mental simulation of the narrative events is produced that enables learners to internalize story contents, helping them acquire knowledge, empathize with story characters and emotions, situations, and experiences, and recognize proper and improper professional practices (Bliss and Dalto, 2018). Despite the benefits of using storytelling in training, this technique does not provide the means to visualize accident conditions (e.g., locations, people involved, hazard events). This limitation in traditional training centered on storytelling is being addressed by utilizing 360-degree panorama-based virtual environments.

Current literature on immersive storytelling leverage 360-degree panorama virtual environments to provide visually contextualized safety information narratives in an interactive manner (Eiris & Gheisari, 2023). Preliminary results of implementing such a technique in safety training suggest that trainees obtain similar learning from storytelling-based materials compared to traditional OSHA-10-hour interventions (Eiris et al., 2020-a). Often, virtual humans appear in these storytelling approaches to guide the attention of story listeners during the digital experience (Eiris et al., 2021). A virtual human is defined as a digital replica of a person that allow trainees to observe high-risk operations (e.g., working on the top step of a ladder, working at heights without a harness, working at unsecured elevated edges) without exposing real people to physical danger (Eiris et al., 2017). The use of virtual humans within storytelling experiences in building science applications has been found to increase learner engagement and motivation (Eiris et al., 2021). However, the use of storytelling and virtual humans within immersive storytelling safety training to enhance engagement and motivation has not been explored.

Fall Hazards in Residential Construction.

Residential projects experience the highest fall incident rates among any construction project type (Kang et al., 2017). Fall protection compliance has been documented to be exceptionally low in residential building construction (Johnson et al., 1998). The construction occupations mainly affected by fall hazards – laborers, carpenters, and roofers – often fail to use or incorrectly use fall-protection measures and equipment (Dong et al., 2014; Kang, 2018; Al-Bayati and York, 2019). Moreover, safety training in the residential construction sector has been found to be inadequate, as the knowledge delivered does not always match conventional practices. It is often superficial and rarely contains high-engagement training methods (e.g., hands-on, interactive, reality-based) due to cost constraints (Hung et al., 2013; Evanoff et al., 2016).

In addition to these challenges, much of the training done for fall hazards is still passive. Prior studies have found that workers often do not feel engaged or motivated by training materials (Hung et al., 2013). For example, workers have highlighted that "a lot of times, videos, they get really kind of boring, to be honest, and they would be like the same thing as reading, you kind of just skim through stuff, even though it's important stuff" (Hung et al., 2013). Therefore, fall hazards in the residential sector provide a critical venue to explore the use of immersive storytelling to increase engagement and motivation.

Motivation And Knowledge Gap

Fostering trainee engagement and motivation is important for enhancing the effectiveness of learning interventions. Learners who are engaged and motivated by instructional approaches have been shown to have increased knowledge, interest, and persistence of content learning (Lester, 2013; Henrie et al., 2015), all of which are critical for topics such as construction safety that are often perceived as boring and present difficulties in facilitating efficient knowledge transfer (Le et al., 2015; Zuluaga et al., 2016). Although significant research has been done to leverage virtual environments to create engagement and motivation across some dimensions (i.e., behavioral and cognitive), approaches to increase emotional engagement remain to be explored. To address this knowledge gap, this project used an immersive storytelling approach to engage and motivate learners during safety training. The primary aim for using immersive storytelling in safety training was to improve engagement and motivation while emphasizing emotions due to its inherent benefits for empathy connection with the recipient (Bliss and Dalto, 2018).

Research Objectives And Scope

This research project aims to improve the engagement and motivation of construction workers toward safety training by developing and validating immersive storytelling as a training technique. Immersive storytelling is centered on using 360-degree panoramas and virtual humans as story narrators, enabling learners to observe, understand, and empathize with fall hazard-related stories of accidents in residential construction sites. To address the identified knowledge gap, we completed two research objectives:

- *Objective 1:* Develop an immersive storytelling platform based on realistic narratives of residential construction accidents for safety training.
- *Objective 2:* Assess the effectiveness of immersive storytelling across behavioral, cognitive, and emotional dimensions of engagement and motivation.

OSHA, NIOSH, and CPWR report that fall hazards – such as ladders, scaffolds, floor openings, and unprotected edges – continue to be prevalent in the residential sector. Because of that, our Research Objective 1 was completed into two phases. In the first, recent fall fatalities in the residential sector were identified from reports in the OSHA Fatality and Catastrophe Investigation Summaries (FCIS), the NIOSH Fatality Assessment and Control Evaluation (FACE) Program, and CPWR's stopconstructionfalls.com fatality map databases. Incident narratives were collected and analyzed to understand the common hazard types and the way these occur on job sites. This collected data guided the process of capturing 360-degree images from construction sites and the creation of stories. The researchers visited multiple locations in Michigan to capture scenes similar to the ones described in the accident data collected. Training content in the form of story narratives and storyboards were created to connect the 360-degree images with the narratives. A focus group with four safety experts was conducted to refine the contents of the storyboards and the story narratives into validated training materials. In the second phase, the immersive storytelling platform was developed, including creation of narrative voice-overs, 360-degree panorama environments, and virtual humans. These elements were created and interconnected to each other using the Unity game engine. A combination of software such as IBM Text-to-Speech, Reallusion Character Creator 4, and Adobe Mixamo were used to create the animated virtual humans. The Unity game engine was leveraged to deliver the voice-over narrations and the virtual human within the 360-degree images to create an interactive, immersive training storytelling experience.

For Research Objective 2, a comparative evaluation was conducted to assess two 360-degree panorama-based virtual environments for safety training – immersive storytelling and immersive non-storytelling – in a between-subjects study. The created safety training materials in Research Objective 1 were used to train 42 residential workers and measure their reactions to the two experimental conditions using survey and eye-tracking metrics.

Research Objective 1 – Develop Immersive Storytelling Platform.

Phase I – Creation of fall incident visual narratives: Data was collected from the OSHA Fatality and Catastrophe Investigation Summaries (FCIS), the NIOSH Fatality Assessment and Control Evaluation (FACE) Program, CPWR's stopconstructionfalls.com fatality map databases to define the fall incident narrative scope. Data about the most recent fatality cases was obtained from these databases using the following process:

- *OSHA's FCIS:* The following parameters were used for filtering – (1) the North American Industry Classification System (NAICS) code for residential building construction as "23611"; (2) the keyword "Fall"; (3) the "fatality-only" filter; and (4) the time range "Jan. 2016 to Apr. 2022."
- *NIOSH's FACE:* The following parameters were used for filtering – constrained to the case-studies to the category of "Falls-Construction-Residential."
- *stopconstructionfalls.com:* The following parameters were used for filtering using the interactive map – (1) Injury Type as "Falls, Slips, Trips"; (2) Focus Four Category as "Fall to Lower Level", the (3) Years of Occurrence "2016-2022"; and the (4) Construction Subsector to "Only Residential Companies."

A total of 193 reports were found for analysis. Initially, the data was reviewed for completeness and relatedness. From this analysis, 36 data points were discarded, as they either had large amounts of data missing, were not construction-related, or were not fall accidents. The remaining 157 data points were further analyzed and classified based on the type of fall accident, type of occupation of the victim, type of project where the accident occurred, and location. Tables 1, 2, 3, and 4 display the analysis results.

From the analysis, it was found that most fatal fall accidents occurred from working on elevated surfaces with unprotected edges (36%), ladders (23%), scaffolds (18%), and floor openings (14%) (Table 1). Other fall accidents are present within the databases (e.g., slips & trips, collapsed stands, non-specified), but these represent only a small percentage of all the data (10%).

Table 1. Frequency of Falls by Category

Types of Falls	**Frequency (Counts)**	**Percentage**
Unprotected Edge	56	36%
Ladders	36	23%
Scaffold	28	18%
Floor Opening	22	14%
Other Falls (Slips & Trip, Collapsed Stand, Non-Specified Falls)	17	10%
Total	**157**	**100%**

The analysis also showed that most fatal fall accidents affected occupations such as laborers (21%), carpenters (20%), roofers (10%), painters (8%), construction trades (4%), and other construction roles (e.g., managers, inspectors, glazier) (10%) (Table 2). However, a considerable percentage of the data points collected did not specify the occupation of the accident victim (27%).

Table 2. Frequency of Falls by Occupation

Occupation	**Frequency (Counts)**	**Percentage**
Laborer	33	21%
Carpenter	31	20%
Roofer	15	10%
Painter	12	8%
Construction Trade	7	4%
Others (Managers, Inspectors, Glaziers)	4	10%
Non-Specified	42	27%
Total	**157**	**100%**

Furthermore, the analysis showed that the largest number of fatal fall accidents occurred in single-family/duplex dwellings (33%) and multi-family residential buildings (17%) (Table 3). A large percentage of the accident report did not specify the type of project (49%), and a minor portion of the accident occurred in mobile homes (1%).

Table 3. Frequency of Falls by Project Type

Project Type	**Frequency (Counts)**	**Percentage**
Single Family or Duplex	52	33%
Multi-family Residential	27	17%
Other (Non-Specified)	77	49%
Mobile Home	1	1%
Total	**157**	**100%**

Finally, it was found that most fatal fall accidents happened outside the building (84%) in places such as roofs, scaffolds, or trusses. A lower percentage of the accidents occurred inside the buildings (13%) or were non-specified (3%).

Table 4. Frequency of Falls by Location

Project Location	**Frequency (Counts)**	**Percentage**
Outside (e.g., Roof, Scaffold, Truss)	132	84%
Inside	21	13%
Non-Specified	4	3%
Total	157	100%

Based on the identified trends, 360-degree images from real-world locations in Michigan were captured using advanced high-precision 360-degree cameras. The data analysis from the databases served as the basis to select the constructions to be captured using the following information found: (1) type of fall accident; (2) type of occupation; (3) type of project, and (4) location of the accident. These four parameters guided the selection of the site visited by the team for capturing 360-degree images to find similar real-world site potential hazards. A total of nine site visits were completed in four Michigan communities (Detroit, Houghton, Marquette, and Southfield). The team visited seven single-family/duplex dwellings and two multi-family residential buildings. Between April 2022 and June 2022, more than 360 images were captured that illustrated potential fall hazards from the analyzed accidents data category types – unprotected edges, ladders, scaffolds, and floor openings. Figure 1 shows the data collection process across the visited sites. A sample is displayed for some of the hazard conditions described by the databases, including incorrect step ladder usage, improper access points to scaffolds, unprotected edges, and floor openings.

Figure 1: The capturing process of 360-degree panoramas

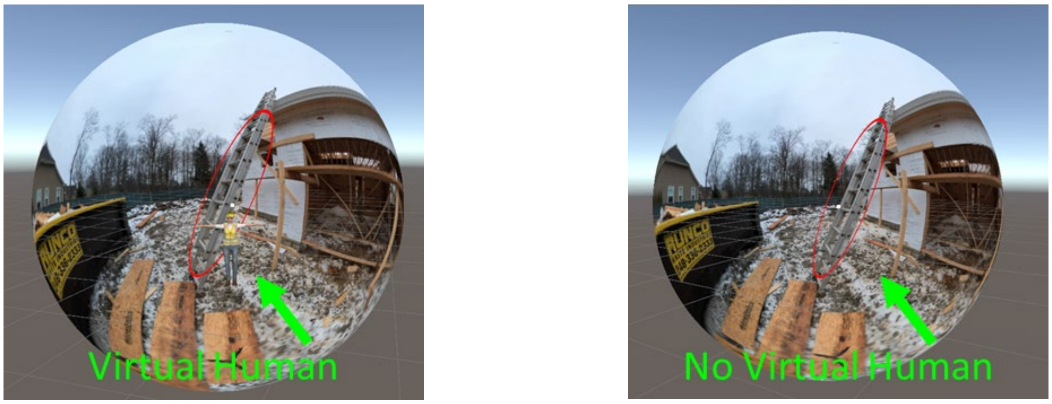
Stories narratives and storyboards were developed under each of the following categories: (1) ladders, (2) scaffolds, (3) floor openings, and (4) working at elevated surfaces. A "Hero's Journey" narrative structure was used to build the story around these four hazards. Storyboards were created for each narrative with the pre-planned movements and dialogue associated with the virtual human, as shown in Figure 2. This crafting process was completed for all four narratives with their visual representation of fall hazards. Additionally, a set of images were selected to perform the assessment of the hazard identification within the immersive training experience. Similarly, a set of control, non-storytelling storyboards were created that do not contain a virtual human. A safety advisory board of four industry professionals with at least five years of experience in the residential construction industry, validated these draft created materials through a focus group Zoom online discussion on August 2022. The focus group with the advisory board helped to guarantee that the training content is accurate and representative of hazards in the residential sector. The outcome of this phase was a validated set of four-story narratives and storyboards for the storytelling condition, four non-storytelling storyboards, and a set of assessment 360-degree images for each of the most prevalent types of fall hazards (ladders, scaffolds, floor openings, unprotected edges) in the residential industry.

Figure 2. Sample Story Narrative and Storyboard for Scaffolds.

(a) Training (b) Assessment

<u>Phase II – Development of the Immersive Storytelling Fall Hazard Training Platform:</u> The created narratives from phase I were developed into an interactive training platform. The Unity game engine was employed for interconnecting the storytelling narratives voice-overs, 360-degree panorama environments, and animated virtual humans to represent safety-related challenges on real projects. Within the game engine, coding scripts were created to enable the exploration of the story using audio recordings, animations, and multiple 360-degree images. The creation of the virtual humans for this game engine were done with the software Reallusion Character Creator 4 and Adobe Mixamo. Over sixteen individual scenes with audio voice-over clips, custom virtual human models and animations, and real-world residential construction 360-degree panoramas were created within the game engine. The non-storytelling version of the training was developed by removing the virtual human from the scenes and using the narratives from the non-storytelling storyboards. As shown in Figure 3, the storytelling (Figure 3-a) and non-storytelling (Figure 3-b) versions of the fall hazard safety training developed in Unity contained similar visual augmentations, but the storytelling version had a virtual human (highlighted with a green arrow) and a more comprehensive story narrative. On the other hand, the non-storytelling version only had visual augmentations and a more straightforward, short voice-over outlining the OSHA regulation for the hazard present in the virtual location.

Figure 3. Immersive Safety Training Content within the Unity® Game Engine for Connecting the Storytelling Narratives Voice-Overs, 360-degree Panoramas, and Virtual Humans.



(a) Immersive Storytelling (b) Immersive Non-Storytelling

Within the immersive platform, participants were trained about fall hazards using a structured two-step session: Training and Assessment (Figure 4). The Training Session (Figure 4-a) focuses on leveraging the 360-degree panoramas, the virtual human narrations, and the augmentations contained in virtual space to facilitate the retrieval and retention of safety-related information. The trainees were allowed to observe the safety content in the panoramic spaces by looking around using the head-mounted display. Initially, the trainees were shown a hazard demonstration within the environment to visually understand the potential source of the accident in the location. Following, the hazard solution was demonstrated directly in the 360-degree environment using augmentations and voice-overs. In the Assessment Session (Figure 4-b) the trainees concentrated on exploring 360-degree panoramas to evaluate their safety knowledge as acquired during the Training Session. During this Assessment Session, trainees are asked to identify hazards in a series of 360-degree images that do not contain virtual human narrators or show any types of augmentation. There, the hazard recognition is left entirely to the trainee. A 360-degree panorama image similar to the one observed in the hazard demonstration was shown to understand the learning gains from the trainee.

(a) Training Session (b) Assessment Session

Figure 4. Training and Assessment Session within Immersive Platform

<u>Research Objective 2 – Assess the Influence of Immersive Storytelling</u>

To evaluate the influence of immersive storytelling, a between-subjects experimental design was employed. Figure 5 illustrates an example of the two conditions used in this experimental approach for working on elevated surfaces. A total of four training scenarios were created, covering ladders, scaffolds, floor openings, and working on elevated surfaces. For each of these scenarios, the two conditions – control and experimental – had the following components:

- ***(a) Control Condition – Immersive Non-Storytelling*:** A version of the immersive 360-degree panorama training platform where construction workers visualized the hazards without the storytelling component. Information was presented through signifiers and accompanying audio. No virtual humans were used to narrate any of the text descriptions. Audios were simple descriptions without a narrative story line.
- ***(b) Experimental Condition – Immersive Storytelling:*** A version of the immersive 360-degree panorama platform where construction workers followed a storytelling experience narrated by a virtual human. The content was analogous to the control condition, but the delivery method was centered on the stories narrated by the virtual human.

Figure 5. Working on Elevated Surface Example for Control and Experimental Condition.

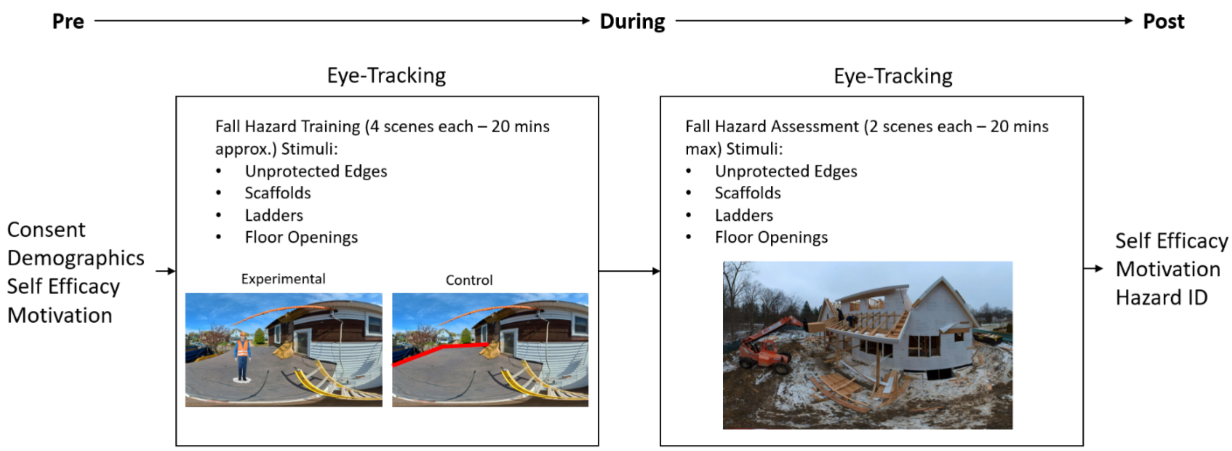
(a) Control Condition – Immersive Non-Storytelling

(b) Experimental Condition – Immersive Storytelling Condition

<u>Research Methodology:</u> Figure 6 illustrates the overall research methodology for the between-subjects experiments in this project. Before being exposed to the training materials, each participant completed a set of surveys (Table 5). Subsequently, trainees used a head-mounted display (HTC Vive Pro 2) to performed two sessions: a training session, and assessment session. First, during the training session, each participant was exposed to only one of the two training conditions (control or experimental). The participants within their assigned conditions (control or experimental) learned about residential fall hazards using a 360-degree panorama platform. Four

topics (ladders, scaffolds, floor openings, working on unprotected elevated surfaces) were covered during the training sessions that lasted for approximately 20 minutes. Second, each participant completed an assessment session, where a fall hazard identification activity took place. To complete the assessment session, trainees observed 360-degree images (analogous to the ones observed during training, but different) to recognize safety hazards. While performing the assessment session on each condition, eye-tracking sensors embedded in the head-mounted display recorded their eye movements. After completing the experiment, the another set of surveys was completed by the participants (Table 5).

Figure 6. Experimental Methodology for Project



An IRB (#1873063-2) for this project was obtained by the Michigan Technological University. All data collected from trainees was fully anonymized based on IRB protocols developed for this study. A total of 42 residential workers data sets was collected to complete this evaluation. Participants were randomly assigned to each experimental condition while maintaining an equal balance of participants across conditions (21 participants in the control condition and 21 participants in the experimental condition). Each participant received a $20 gift card for their participation in the study. The total duration of the study, including the surveys, was approximately 50 minutes. The metric outlined in Table 5 were collected from each worker participant.

Table 5. Study Metrics

Dimension	Metric	Description	Collection
Behavioral	Fixation Count on Hazard Content	The number of times a worker to look at the story hazard contents during the intervention.	During Training and Assessment Sessions
	Dwell Time on Hazard Content	Time worker spent hazing at the story hazard contents during the intervention	During Training and Assessment Sessions
Cognitive	Test Hazard Identification	Hazards were recognized by a worker in a paper-based test after the intervention.	Post-Assessment Session

Emotional	Self-Efficacy	Worker perception of how well or poorly learning occurred during the intervention (adapted version of Self-Efficacy Scale – Chen et al., 2001)	Pre-Training and Post-Assessment
	Motivation	Worker perception of their motivation (intrinsic and extrinsic) to perform training interventions (adapted version of the Academic Motivation Scale – Guay et al., 2000)	Pre-Training and Post-Assessment

The proposed hypotheses tested in this project were formulated as follows:

Behavioral Hypotheses:

$HB1_o$: The mean fixation count for participants under the immersive storytelling and immersive non-storytelling are equal

$HB1_a$: The mean fixation count for participants under the immersive storytelling and immersive non-storytelling are not equal

$HB2_o$: The mean dwell time for participants under the immersive storytelling and immersive non-storytelling are equal

$HB2_a$: The mean dwell time for participants under the immersive storytelling and immersive non-storytelling are not equal

Cognitive Hypothesis:

$HC1_o$: The mean hazard identification score for participants under the immersive storytelling and immersive non-storytelling are equal

$HC1_a$: The mean hazard identification score for participants under the immersive storytelling and immersive non-storytelling are not equal

Emotional Hypothesis:

$HE1_o$: The mean self-efficacy score for participants under the immersive storytelling and immersive non-storytelling are equal

$HE1_a$: The mean self-efficacy score for participants under the immersive storytelling and immersive non-storytelling are not equal

$HE2_o$: The mean motivation score for participants under the immersive storytelling and immersive non-storytelling are equal

$HE2_a$: The mean motivation score for participants under the immersive storytelling and immersive non-storytelling are not equal

Experiment Analysis and Results

A total of 42 residential workers participated in this study. The workers were predominantly male (93%), with a low percentage of female (7%). Most participants self-identified as White American (71%), followed by African American (14%), Hispanic (10%), and Do Not Wish to Specify (5%). The average age of the participants was 35 years (standard deviation 12 years). Half of the participants had obtained a high school diploma (50%), while others had some college (12%), a bachelor's degree (15%), or a trade certificate (23%). A large percentage of the participants indicated that they had over 5 years of experience (43%), with others indicated that they had 2-to-5 years (22%), 1-to-2 years (15%), or less than one year (20%). Over half of the participants had obtained either OSHA-10-hour or OSHA-30-hr training (67%).

Using the data collected from the experiment, the behavioral dimension of engagement and motivation was evaluated using eye-tracking metrics. Table 6 show the results from the analysis of the eye-tracking data in terms of fixation count (i.e., number of times a worker looked at the story hazard contents) and dwell time (i.e., time worker spent hazing at the story hazard contents) for the assessment session of each experimental condition. The analysis was performed with descriptive and inferential statist [Grab your reader's attention with a great quote from the document or use this space to emphasize a key point. To place this text box anywhere on the page, just drag it.]
ics for each area of interest (AOI) contained in each 360-degree panorama image. Each AOI represented a fall hazard within the virtual environment. Before performing inferential statistical analysis, a Shapiro-Wilks test was performed to investigate normality in each of the data samples. Corresponding inferential statistics test were performed based on the normality of each set of samples (i.e., if both samples were normal – T-Test was done, if one or the two samples were non-normal, Mann Whitney U Test was done). Overall, there was a correspondence between fixation counts and dwell times (i.e., the more fixations the longer the time participants observed the area of interest. Moreover, there was a great variability across experimental conditions in terms of which condition produced higher rates of fixation counts and dwell times with following observed patterns:

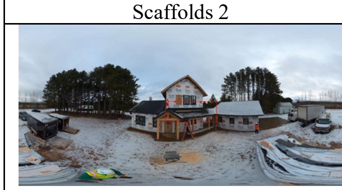
- *Control Condition Higher Fixation Count and Dwell Time* – Ladders 1 AOI-0; Opening 1 AOI-1; Scaffolds 2 AOI-0; Unprotected Edges 1 AOI-0; Unprotected Edges 2 AOI-2 – Total 5/11 AOIs
- *Experimental Condition Higher Fixation Count and Dwell Time* – Ladders 1 AOI-1; Ladders 2 AOI-0; Opening 1 AOI-0; Opening 2 AOI-0; Scaffolds 1 AOI-0; Unprotected Edges AOI-0 – Total 6/11 AOIs

Although some descriptive statistical difference was observed, most of the results from inferential comparison across experimental conditions were not statistically significant. Therefore, our null hypotheses ($HB1_o$ & $HB2_o$) that fixation count and dwell time across most AOIs cannot be rejected. Only one of the comparisons yielded a significant difference on Ladders 1 AOI-1 (Stepladder and Bucket Hazard), with higher numbers of fixations and dwell time for the immersive storytelling condition. Therefore, in Ladders 1 AOI-1 our null hypothesis of equal means for fixation count and dwell time was rejected. These results indicate that the immersive storytelling condition is particularly engaging and motivation within the behavioral dimension for AOIs hazards that contain stepladders and buckets being improperly used.

Table 6. Behavioral Results for Experiment

Scene	Area of Interest (AOI)	Fixation Count (#) Mean (S.D.)		Significant - P-Val (T-Test/Mann)	Dwell Time (milsec) Mean (S.D.)		Significant - P-Val (T-Test/Mann Whitney U)
		Control	Experimental		Control	Experimental	
	AOI-0	68.7 (135.6)	18.7 (135.6)	No – 0.11 > 0.05 (Mann Whitey U)	5900 (9859)	1442 (2506)	No – 0.48 > 0.05 (Mann Whitey U)

Table 6. Behavioral Results for Experiment (continued)

 Ladders 1	AOI-1	178.5 (79.1)	263.7 (108.3)	Yes – 0.006 < 0.05 (T-Test)	22379 (9936)	30336 (8986)	Yes – 0.009 < 0.05 (T-Test)
 Ladders 2	AOI-0	262.7 (110.1)	268.1 (82.6)	No – 0.55 > 0.05 (Mann Whitey U)	29765 (7365)	30890 (9270)	No – 0.67 > 0.05 (Mann Whitey U)
 Opening 1	AOI-0	37.2 (39.6)	37.9 (25.7)	No – 0.47 > 0.05 (Mann Whitey U)	3437 (2937)	4635 (3354)	No – 0.18 > 0.05 (Mann Whitey U)
	AOI-1	67.1 (46.1)	64.5 (39.4)	No – 0.83 > 0.05 (Mann Whitey U)	8295 (3436)	8707 (5072)	No – 0.76 > 0.05 (T-Test)
 Opening 2	AOI-0	267.0 (108.3)	267.8 (121.8)	No – 0.96 > 0.05 (Mann Whitey U)	26158 (8616)	23930 (7405)	No – 0.45 > 0.05 (T-Test)
 Scaffolds 1	AOI-0	44.4 (33.6)	59.9 (39.1)	No – 0.17 > 0.05 (T-Test)	5640 (4551)	6529 (3766)	No – 0.34 > 0.05 (Mann Whitey U)
 Scaffolds 2	AOI-0	150.8 (104.1)	146.1 (91.4)	No – 0.97 > 0.05 (Mann Whitey U)	15859 (6429)	15635 (7088)	No – 0.91 > 0.05 (T-Test)
 Unprotected Edges 1	AOI-0	127.5 (67.6)	94.8 (54.4)	No – 0.07 > 0.05 (Mann Whitey U)	9820 (4057)	11816 (4696)	No – 0.15 > 0.05 (T-Test)
 Unprotected Edges 2	AOI-0	196.2 (120.8)	224.9 (103.8)	No – 0.24 > 0.05 (Mann Whitey U)	21702 (8218)	23822 (9682)	No – 0.46 > 0.05 (T-Test)
	AOI-1	25.2 (29.9)	15.0 (17.2)	No – 0.29 > 0.05 (Mann Whitey U)	2992 (3534)	1564 (2016)	No – 0.19 > 0.05 (Mann Whitey U)

Data collected for the cognitive and emotional dimensions of engagement and motivation were also evaluated, with Table 6 showing the descriptive and inferential analysis results. Initially, cognitive engagement and motivation was evaluated by comparing the hazard identification scores across the experimental conditions of this study. These hazard identification scores were computed by grading the paper-based post-experimental test, where four hazard scenarios were presented to the participants. Each participant was assigned a percentage score of the number of correct answers for this test (0% is the lowest score, and 100% the highest). No descriptive or statistical differences were observed for hazard identification scores across conditions. Therefore, the null hypothesis for the cognitive dimension that hazard identification means equal across conditions ($HC1_o$) cannot be rejected**.** This result indicates that the immersive storytelling and the immersive non-storytelling condition provide similar cognitive engagement and motivation for participants.

For the emotional dimension of engagement and motivation, the two collected survey scales of self-efficacy and motivation were analyzed. For each of these scales, a composite score was calculated by aggregating the responses provided by the participants and dividing it by the total number of questions. The descriptive statistics show an increase for both control and experimental conditions pre/post-experiment. However, no statistically significant differences were found for self-efficacy or motivation across control or experimental condition after a Kruskal-Wallis analysis. Therefore, the null hypotheses for the emotional dimensions that self-efficacy and motivation means are equal across conditions ($HE1_o$ & $HE2_o$) cannot be rejected**.** This result indicates the immersive storytelling and the immersive non-storytelling condition provide similar emotional engagement and motivation for participants.

Table 7. Cognitive (Hazard Identification) & Emotional (Motivation and Self-Efficacy) Results

Variables	Conditions				Stats Analysis	
	Control		Experimental		Kruskal-Wallis/Mann Whitney U	
	Mean (S.D.)					
	Pre	Post	Pre	Post	p-val	Sign?
Hazard Identification*	-	0.82 (0.28)	-	0.82 (0.25)	0.88	No
Self-Efficacy**	4.43 (0.54)	4.41 (0.55)	4.58 (0.39)	4.37 (1.09)	0.14	No
Motivation***	4.19 (0.71)	4.26 (0.85)	3.96 (0.52)	3.97 (0.58)	0.34	No

* The hazard identification score represents an aggregated score from 0% to 100%
** The self-efficacy scale ranges from 1-Strongly Disagree to 5-Strongly Agree
*** The motivation scale ranges from 1-Not At All to 7-Exactly

Final Remarks

This project proposed immersive storytelling as an alternative to tradition immersive virtual reality training as a method to increase engagement and motivation of trainees. To evaluate the differences in engagement and motivation, two safety training conditions were employed in a between-subjects experiment – immersive storytelling & immersive non-storytelling. A total of 42 residential construction workers experienced one of the two condition using a head-mounted display that showed them a training and assessment session for fall hazards (ladders, openings, scaffolds, unprotected edges). The workers' engagement and motivation across behavioral, cognitive, and emotional dimensions were measured with pre- and post-experiment surveys and eye-tracking data. Descriptive and statistical differences were evaluated from the data across the experimental dimension. It was found that behavioral engagement and motivation were statistically different only for hazards containing improperly used stepladders and buckets. No significant differences were found in cognitive or emotional engagement and motivation across the experimental condition of this study. These results indicate that immersive storytelling provides some behavioral engagement and motivation benefits to direct workers' attention during training in some specific scenarios. However, the influence of immersive storytelling on cognitive or emotional perspectives is not significantly different from traditional virtual reality training. The research team recommends that immersive storytelling should be considered to when the goal of the training intervention is to improve behavioral engagement and motivation. In addition, if future researchers aim to improve the cognitive and emotional dimensions of engagement and motivation, the research team found that either immersive storytelling or traditional virtual reality can provide positive effects on trainees. Ultimately, the research team concluded that immersive storytelling is an effective learning method and a valid alternative from traditional virtual reality training for interventions within the residential construction sector.

Publications & Presentations Based on this Project

- Isingizwe, J., & Eiris, R. (2022). Fall Hazards Immersive Storytelling for Residential Constructions. Poster Presented at the College of Engineering Graduate Research Symposium, Houghton, MI
- Isingizwe, J., Eiris, R., & Al-Bayati, A. (2023). Immersive Storytelling Safety Training To Enhance Trainee Engagement: Comparison of Expert and Novice Fall Hazards in the Residential Construction Sector. ASCE Computing in Civil Engineering (*Under Preparation*).
- Isingizwe, J., Eiris, R., & Al-Bayati, A. (2024). Immersive Storytelling Safety Training To Enhance Trainee Engagement: Pilot Study for Fall Hazards in the Residential Construction Sector. ASCE Construction Research Congress (CRC) 2024, Des Moines, Iowa, March 20-23, 2024 (*Abstract Accepted – Full Paper Under Review*)

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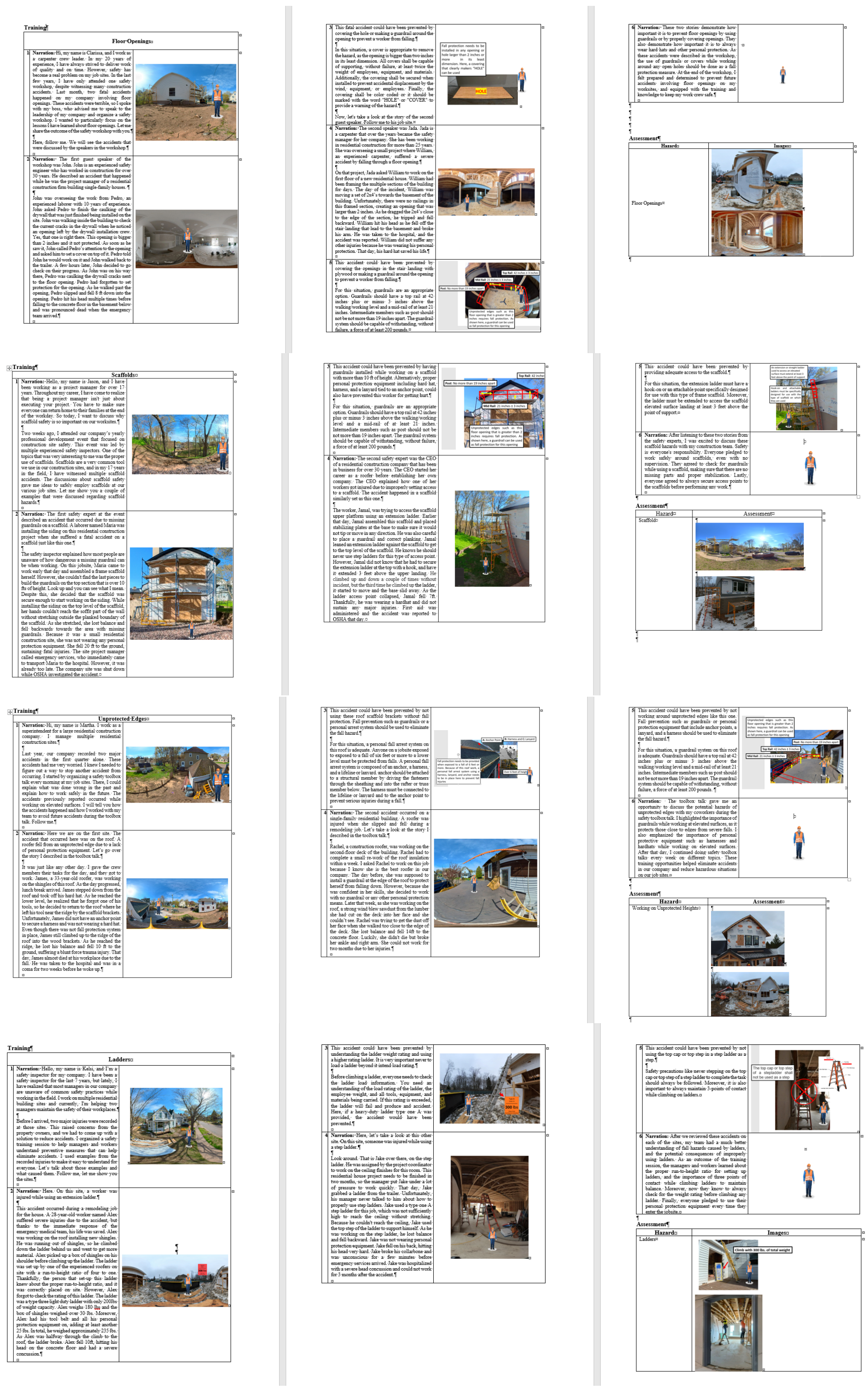
APPENDIX

Narrative Storyboards – Experimental Condition (Immersive Storytelling).



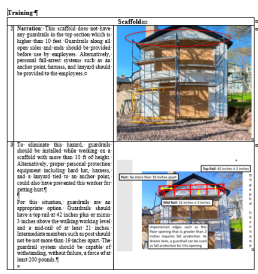
Narrative Storyboards – Experimental Condition (Immersive Storytelling).


Training

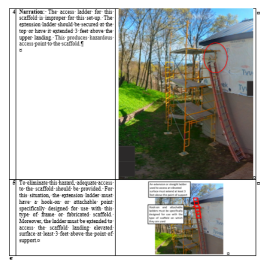
	Floor Openings	
2	**Narration:** This opening is bigger than 2 inches and it is not protected. Either a covering should be placed on it or guardrails should be placed around to protect anyone from falling into the opening.	
3	To eliminate this hazard, a covering for the hole or a guardrail around the opening should be set in place. In this situation, a cover is appropriate to remove the hazard, as the opening is bigger than two inches in its least dimension. All covers shall be capable of supporting, without failure, at least twice the weight of employees, equipment, and materials. Additionally, the covering shall be secured when installed to prevent accidental displacement by the wind, equipment, or employees. Finally, the covering shall be color coded or it should be marked with the word "HOLE" or "COVER" to provide a warning of the hazard.	Fall protection needs to be installed in any opening or hole larger than 2 inches or more in its least dimension. Here, a covering that clearly makers "HOLE" can be used HOLE
4	**Narration:** The around the stairs is bigger than 2 inches. There are no railings in the framed sections, which creates the opening. Either a covering should be placed on it or guardrails should be placed around to protect anyone from falling into the opening.	
5	To eliminate this hazard, a covering for the hole or a guardrail around the opening should be set in place. For this situation, guardrails are an appropriate option. Guardrails should have a top rail at 42 inches plus or minus 3 inches above the walking/working level and a mid-rail of at least 21 inches. Intermediate members such as post should not be not more than 19 inches apart. The guardrail system should be capable of withstanding, without failure, a force of at least 200 pounds.	Top Rail: 42 inches ± 3 inches Mid Rail: 21 inches ± 3 inches Post: No more than 19 inches apart Unprotected edges such as this floor opening that is greater than 2 inches requires fall protection. As shown here, a guardrail can be used as fall protection for this opening


Assessment

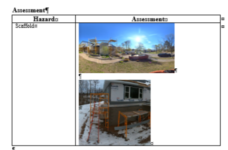
Hazard	Images
Floor Openings	


Training

	Scaffolds	
2	**Narration:** This scaffold does not have any guardrails in the top section which is higher than 10 feet. Guardrails along all open sides and ends should be provided before use by employees. Alternatively, personal fall-arrest systems such as an anchor point, harness, and lanyard should be provided to the employees.	
3	To eliminate this hazard, guardrails should be installed while working on a scaffold with more than 10 ft of height. Alternatively, proper personal protection equipment including hard hat, harness, and a lanyard tied to an anchor point, could also have prevented this worker for getting hurt. For this situation, guardrails are an appropriate option. Guardrails should have a top rail at 42 inches plus or minus 3 inches above the walking/working level and a mid-rail of at least 21 inches. Intermediate members such as post should not be not more than 19 inches apart. The guardrail system should be capable of withstanding, without failure, a force of at least 200 pounds.	Top Rail: 42 inches ± 3 inches Post: No more than 19 inches apart Mid Rail: 21 inches ± 3 inches Unprotected edges such as this floor opening that is greater than 2 inches requires fall protection. As shown here, a guardrail can be used as fall protection for this opening



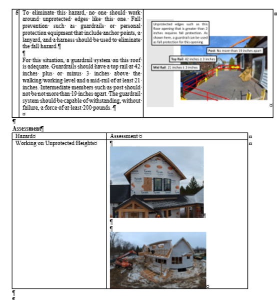
4	**Narration:** The access ladder for this scaffold is improper for this set-up. The extension ladder should be secured at the top or have it extended 3 feet above the upper landing. This produces hazardous access point to the scaffold.	
5	To eliminate this hazard, adequate access to the scaffold should be provided. For this situation, the extension ladder must have a hook-on or attachable point specifically designed for use with this type of frame or fabricated scaffold. Moreover, the ladder must be extended to access the scaffold landing elevated surface at least 3 feet above the point of support.	


Assessment

Hazard	Assessment
Scaffolds	


Training

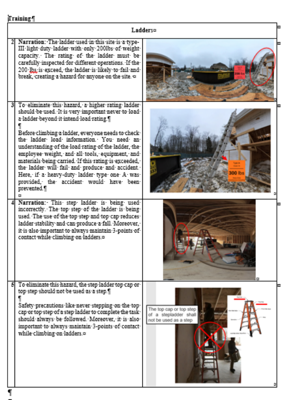
	Unprotected Edges	
2	**Narration:** This roof has no anchor point to perform roofing work. Additionally, personal protection equipment such as lanyard and harness are required to be provided to the employees to tie to the anchor point. The lack of anchor point produces a hazardous situation on this roof. Alternative there could be a guardrail to prevent falls. However, there are not guardrails in this roof.	
3	To eliminate this hazard, these roof scaffold brackets should not be used without fall protection. Fall prevention such as guardrails or personal protection equipment should be used to eliminate the fall hazard. For this situation, personal fall arrest system on this roof is adequate. Anyone on a jobsite exposed to a fall of six feet or more to a lower level must be protected from falls. A personal fall arrest system is composed of an anchor, a harness, and a lifeline or lanyard. anchor should be attached to a structural member by driving the fasteners through the sheathing and into the rafter or truss member below. The harness must be connected to the lifeline or lanyard and to the anchor point to prevent serious injuries during a fall.	
4	**Narration:** This roof has no guardrails or any other fall protection measures, creating an unprotected edge. The unprotected edge is a hazardous situation that can produce a fall for an employee.	



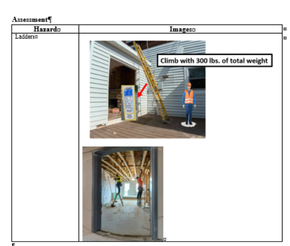
5	To eliminate this hazard, no one should work around unprotected edges like this one. Fall prevention such as guardrails or personal protection equipment that include anchor points, a lanyard, and a harness should be used to eliminate the fall hazard. For this situation, a guardrail system on this roof is adequate. Guardrails should have a top rail at 42 inches plus or minus 3 inches above the walking/working level and a mid-rail of at least 21 inches. Intermediate members such as post should not be not more than 19 inches apart. The guardrail system should be capable of withstanding, without failure, a force of at least 200 pounds.	

Assessment

Hazard	Assessment
Working on Unprotected Heights	


Training

	Ladders	
2	**Narration:** The ladder used in this site is a type-III light duty ladder with only 200lbs of weight capacity. The rating of the ladder must be carefully inspected for different operations. If the 200 lbs is exceed, the ladder is likely to fail and break, creating a hazard for anyone on the site.	
3	To eliminate this hazard, a higher rating ladder should be used. It is very important never to load a ladder beyond it intend load rating. Before climbing a ladder, everyone needs to check the ladder load information. You need an understanding of the load rating of the ladder, the employee weight, and all tools, equipment, and materials being carried. If this rating is exceeded, the ladder will fail and produce and accident. Here, if a heavy-duty ladder type one A was provided, the accident would have been prevented.	
4	**Narration:** This step ladder is being used incorrectly. The top step of the ladder is being used. The use of the top step and top cap reduces ladder stability and can produce a fall. Moreover, it is also important to always maintain 3-points of contact while climbing on ladders.	
5	To eliminate this hazard, the step ladder top cap or top step should not be used as a step. Safety precautions like never stepping on the top cap or top step of a step ladder to complete the task should always be followed. Moreover, it is also important to always maintain 3-points of contact while climbing on ladders.	The top cap or top step of a stepladder shall not be used as a step


Assessment

Hazard	Images
Ladders	Climb with 300 lbs. of total weight

Image Selection for Training and Assessment Sessions.

Image Selection for Training and Assessment Sessions continued.

Github Repository.
https://github.com/Eiris/Storytelling-Behaviors-Project (To request access please email PI Eiris at reiris@mtu.edu or reiris@asu.edu)