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# Safer Working at Heights: Exploring the Usability of Virtual Reality for Construction Safety Training among Blue-Collar Workers in Kuwait

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**Abstract:** Virtual Reality (VR) construction safety training modules have reached a level of maturity which renders them as a serious alternative to traditional safety training modules. The purpose of this study is to investigate the usability of a particular safety training module related to "Working at heights" for blue-collar construction workers in Kuwait. A mixed study approach was applied based on a semi-quasi experimental research design, utilizing a control group/experimental group with pre-/post-test measurements, supplemented by observations. The findings indicate a statistically insignificant higher learning effectiveness of the workers exposed to the VR approach. Observations confirmed that trainees require an extended time of preparation to become familiar with moving within the virtual environment and using the related hardware. Furthermore, younger users with less work experience reported a higher usability than older users with more work experience. VR content developers are encouraged to investigate the possibilities of simplifying the virtual environment to make it more relevant for blue-collar workers, reduce the complexity of the hardware, and intensify the feeling of the consequences resulting from users' choices. Construction companies and educational institutions training construction blue-collar workers can benefit from the VR approach to safety training if they allow sufficient time for familiarization with the virtual training module.

**Keywords:** construction; safety training; working at heights; virtual reality; usability; blue-collar worker

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## 1. Introduction and Background

Traditional approaches to construction safety training, such as safety workshops, tool-box training, and safety awareness seminars, are, in general, still the most common approaches to prevent construction accidents and injuries [1]. However, despite the continuous efforts in enhancing traditional training approaches, according to the International Labor Organization report in 2015 [2], "At least 108 thousand workers are killed on site every year", a figure which represents about 30% of all occupational fatal injuries. In addition to the ILO report, the U.S. Bureau of Labor Statistics reported that in 2021, construction deaths due to falls, slips, and trips increased by 5.9% compared with 2017 [3]. The increasing trend in fatalities, specifically from heights hazards, has raised questions amongst scholars on the efficacy of the traditional training pedagogies. Thus, the limitations of traditional approaches have led to exploring alternative solutions and training modules that could outweigh the shortcomings of traditional training as an attempt to improve safety training and reducing hazards within the construction industry.

Disruptive technologies such as Virtual Reality (VR) and Augmented Reality (AR) have been found to carry a competitive advantage over traditional training approaches [4–6] within the construction industry, not to mention the advantage related to improved performance and usability reflected by engineering education students [7–9]. Based on the perception that traditional safety education does not lead to the desired learning effectiveness among construction students, VR approaches such as virtual field trip systems [10] have been developed. Some studies investigated VR approaches to safety training for workers of specific project scopes, such as rail engineering projects [11], and found, based on trainees' feedback, that the VR approach can have a positive impact on workers' behavior and the project's safety culture. Other such studies [4] used a semi-quasi experimental research design with an experimental and a control group and found significant advantages related to the VR approach for stone cladding work and for cast-in-situ concrete work, but not for general site safety.

The general low acceptance and utilization of VR approaches to construction safety training has led [12] to investigations into the users' attitudes towards using VR technology. Using the extended Technology Acceptance Model (TAM), they found that perceived usefulness and perceived ease of use are significant direct predictors of trainees' attitude towards using VR technology. Based on survey data from 248 construction workers who finished construction safety training using VR, [13] found that telepresence experienced within the virtual environment and the risk perception of the users affected their satisfaction with the VR safety training.

A systematic review of studies related to the effectiveness of construction safety training showed that (as reflected by knowledge acquisition, unsafe behavior alteration, and injury rate reduction) the effectiveness of traditional approaches is sufficiently supported by statistical evidence, the effectiveness of computer-aided technologies requires more solid evidence, and that computer-aided technologies are superior to traditional approaches regarding the representation of actual workplace situations, as they provide text-free interfaces, better user engagement, and are more cost efficient [6].

In 1998, an analysis of construction accidents in Kuwait provided evidence for the need for more effective safety training for construction workers [14]. Numbers of construction accidents and injuries have been very high throughout the years, and the construction industry in Kuwait has been identified as the most hazardous field, with falls from heights being the most common type of accident [15] as reflected by the global situation reported by the US. Bureau of Labor Statistics. In 2020, construction site problems in Kuwait, a lack of legal safety regulations, and a rise in construction fatalities were reported [16].

According to the authors' best knowledge, the effectiveness of utilizing immersive VR for working-at-height safety training as an alternative to conventional training has not been fully investigated for blue-collar workers in Kuwait. Exploring the potential of such training modules could introduce new solutions for the increasing rate of hazards within the construction industry.

*Purpose*

The purpose of this study was to investigate the perceived usability and effectiveness of virtual reality for training construction blue-collar workers in Kuwait. The training focuses on safety aspects related to working at heights.

The research questions can be summarized as follows:

1. Is there a significant difference between the awareness and knowledge retention related to working at heights before versus after the VR training?
2. Is there a significant difference between the learning effectiveness based on traditional training versus training using VR?
3. How do construction workers perceive the usability of the VR approach?

## 2. Methodology

The following section summarizes the methodological approach of the research study.

### 2.1. Sampling Approach

To answer the research questions, a semi-quasi experimental research design was applied. Several consulting companies were contacted and connections were established with five large companies that were willing to support the study. Since the main population of interest was blue-collar laborers, the authors requested the companies to only provide these.

As a result, convenience sampling, a non-probability sampling technique, was conducted, as only five of 12 companies agreed to participate. Safety engineers from the collaborating companies were requested to employ a random probability sampling technique from their workforce and prepare two groups: an experimental group, and a control group.

The following flow diagram shown in Figure 1 summarizes the sampling technique conducted.

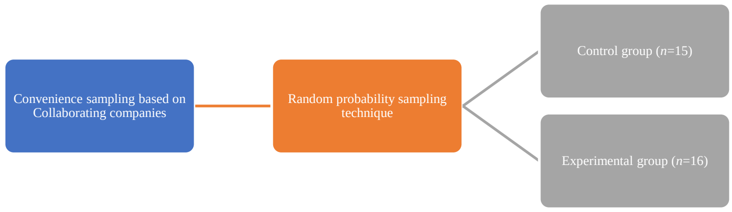


**Figure 1.** Flow diagram of sampling approach.

In the remainder of this study, the terms worker, participant, trainee, and user are used interchangeably. The construction workers spoke Arabic and all had work experience related to working at heights.

The difficulty of mobilizing construction contractors in Kuwait to provide blue-collar workers as subjects for this study resulted in the small sample size. Therefore, a mixed-study approach was chosen and the quantitative analysis was enriched with observations typical of a case study approach. Each of the following five criteria justifies a case study approach [17]:

1. The case is critical and allows testing a well-formulated theory;
2. The case is unique or extreme;
3. The case is representative or typical;
4. The case allows the analysis of a previously inaccessible phenomenon; and,
5. The case is longitudinal in nature (i.e., covering an extended period of time) and allows analysis at different points of time.

For the study carried out here, the case (i.e., safety training related to working at heights for blue-collar construction workers in Kuwait) is critical since falling from heights is the main reason for the large number of fatalities and injuries on constructions sites in Kuwait [15]. Furthermore, the case is unique since it had not been studied before. As shown in the literature review, other studies focused on different tiers of construction workers and/or different hazards. Considering the amount of construction work in the countries of the Gulf Cooperation Council (GCC), with comparable socio-economic conditions and the utilization of blue-collar construction workers, this case is also considered typical. Finally, adding systematic observations allows insights to be added that might be inaccessible through the quantitative semi-experimental approach.

### *2.2. Developing the Training Modules*

Two training modules were prepared for the research:

(1) The control group, utilizing a traditional training approach;
(2) The experimental group, utilizing a Head Mounted Display (HMD) VR approach.

Since the development of a well-established immersive VR environment requires experienced software and gaming engineers, a joint collaboration was formed with a VR service provider that already had an existing working-at-height VR training module.

#### 2.2.1. HMD VR Module

The VR environment used to train participants consisted of four scenarios related to working at heights:

1. Securing floor openings;

2. Supporting outliers of a scissor lift;
3. Handling a ladder; and,
4. Using a Personal Fall Arrest System (PFAS) consisting of body harness and lanyard.

The four scenarios circulated in a three-floor concrete building structure and a typical surrounding inner-city site environment. Using an HMD VR, users had to use a virtual tablet to take pictures, this is done by selecting the camera option that states “Take picture of hazard”, otherwise, the trainee would select the green button that states “situation is acceptable” as shown in Figure 2. After taking the picture, they would see on their virtual tablet if the identification was correct or not. They were able to move virtually on the construction site by using the teleporting function. Although physically standing supports the immersive effect of the VR training [18], it was decided to have trainees sit on a swirl chair after one trainee passed out and fell on the floor as he became extremely excited. The available audio instructions in Arabic were muted since a representative of the research team provided necessary and effective instructions. Observations were noted during the training.

**Figure 2.** Worker identifying a falling-from-height hazard using the virtual tablet.

2.2.2. Traditional Training

For the traditional training, the trainees were requested by their supervisor to sit in a classroom environment where the training was conducted. The traditional training utilized a PowerPoint slide presentation consisting of five slides: an introduction, followed by the four scenarios represented in the HMD VR. Both the traditional and VR trainings were identical in their learning outcomes.

*2.3. Pre- and Post-Test*

Since the research study aimed to investigate the potential advantages VR can have on the knowledge level of blue-collar laborers, a pre- and post-test approach was conducted.

The pre- and post-tests were identical and consisted of the four scenarios mentioned above:

1. Securing floor openings;
2. supporting outliers of scissor lift;
3. handling a ladder; and
4. Using Personal Fall Arrest System (PFAS) consisting of body harness and lanyard.

Each scenario was reflected by an image and followed by four true/false questions. Collected answers were coded 1 for correct answers and 0 for incorrect answers.

Furthermore, participants' perception of the usability of the VR approach was measured using the questionnaire-based System Usability Scale (SUS) [19] and demographic data of participants was collected. All documents, and verbal instructions with the participants, were in the Arabic language.

At the beginning of each training (i.e., the traditional and VR approach), all trainees were introduced by a company representative to the research team, and the research team explained to the participants that the collected data, and the training sessions, were not in any way related to their employment. It was ensured that all participants understood that their participation was voluntary and was to support this study.

In addition to the common Arabic language, the demographics questionnaire showed that participants had the following in common:

- No previous major accident;
- No previous experience with using VR; and,
- Low personal risk acceptance.

The System Usability Scale (SUS) consists of the following 10 questions and was found to be a robust and reliable tool to assess the system's usability [19]:

U1. I think that I would like to use this system frequently;
U2. I found the system to be unnecessarily complex;
U3. I thought the system was easy to use;
U4. I think that I would need the support of a technical person to be able to use this system;
U5. I found the various functions in this system were well integrated;
U6. I thought there was too much inconsistency in this system;
U7. I would imagine that most people would learn to use this system very quickly;
U8. I found the system very cumbersome to use;
U9. I felt very confident using the system; and,
U10. I needed to earn a lot of things before I could get going with this system.

Compared with the four levels of determining the effectiveness of a training program [20], namely, the reaction of trainees to the training (level 1), the impact on knowledge and learning (level 2), the behavior change of trainees (level 3), and the impact on measurable results (e.g., accident statistics; level 4), the data collected here are related to levels 1 and 2. Levels 3 and 4 are recommended to be included in future studies.

## 3. Results and Discussion

The results of the pre- and post-tests, along with the demographic data and SUS questionnaire, were collected using a paper-based approach and were then transferred onto Microsoft Excel for analysis. Descriptive statistics and inferential statistics were utilized. Specifically, *t*-tests were applied with a level of significance $\alpha = 0.05$, to identify any statistical differences between participants of the experimental and the control group. Furthermore, Spearman correlation was applied to analyze relationships between the perceived system usability and relevant demographic data, with correlation coefficients between 0.1 and 0.29 representing small associations, between 0.3 and 0.49 medium associations, and coefficients above 0.5 representing large associations [21].

### 3.1. Demographic Data Analysis

The demographic data of the variables that were identified to show differences are shown in Table 1. The mean values of age and injuries were slightly higher for the VR group (40.25 years and 0.63 injuries) compared with the traditional group (37.8 years and 0.47 injuries). The mean value of training conducted throughout their construction-related experience was clearly higher for the traditional group (20.07 training sessions) compared with the VR group (11.69 training sessions). Considering the lower average age of the traditional group, it is quite remarkable that participants of the traditional group had almost twice as many training sessions as the participants of the VR group. Company representatives did not provide justifications for assigning workers into the two groups, but the higher number of injuries and fewer training sessions seem to suggest that company representatives were hoping that participants of the VR group would have an opportunity to "catch up" regarding safety awareness and knowledge related to working at heights.

**Table 1.** Results of the demographic data for traditional and VR groups.

| Variable [Unit] | Traditional ($n$ = 15) | | VR ($n$ = 16) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Age [years] | 37.80 | 6.98 | 40.25 | 7.28 |
| Experience [years] | 12.07 | 6.10 | 12.81 | 7.74 |
| Training [sessions] | 20.07 | 34.34 | 11.69 | 14.61 |
| Injuries [injuries] | 0.47 | 1.02 | 0.63 | 1.41 |

### 3.2. Pre- and Post-Test Results

Results of the descriptive statistics of the pre- and post-test are shown in Table 2, with column three showing the pre-test results, column four the post-test results, and column five the difference scores (i.e., post-test scores minus pre-test scores). From the descriptive statics in Table 2, it can be seen that both the traditional group and the HMD VR group's knowledge of working-at-heights safety was very similar; in fact, the difference was only 1%. The post-test results show an improvement of 1% and 3% for the traditional and VR groups, respectively. However, it cannot be claimed that there was no significant difference in the initial knowledge level of both groups and the knowledge improvement post training without further investigating the data collected using inferential analysis.

**Table 2.** Descriptive statistics of traditional and VR group.

| Participant Groups | Measures | Pre-Test | Post-Test | Difference Score |
|---|---|---|---|---|
| Traditional | Mean | 0.69 | 0.70 | 0.01 |
| | SD | 0.14 | 0.14 | 0.16 |
| VR | Mean | 0.68 | 0.71 | 0.03 |
| | SD | 0.14 | 0.17 | 0.14 |

$t$-tests were carried out and the degree of freedom (df), $t$-value, critical $t$-value based on a confidence interval of 95% (Crit $t_{0.95}$), and the $p$-value are shown in Table 3 for the following comparisons: pre-test score Traditional (T) versus pre-test score Virtual Reality (VR) (column 2), post-test score traditional versus post-test score VR (column 3), post-test score traditional versus pre-test score traditional (column 4), post-test score VR versus pre-test score VR (column 5), difference score traditional versus difference score VR (column 6). All $t$-values were smaller than the related critical $t$-values and show that no statistically significant difference was identified. Furthermore, the negative $t$-values of the difference post-test traditional versus post-test VR, and the difference score traditional versus difference score VR reflect the larger mean values of the post-test score and difference score for the VR participants.

**Table 3.** Summary of *t*-test results (T = Traditional, VR = Virtual Reality).

| | Pre-T vs. Pre-VR | Post-T vs. Post-VR | Post-T vs. Pre-T | Post-VR vs. Pre-VR | Diff T vs. Diff VR |
|---|---|---|---|---|---|
| df | 29 | 29 | 14 | 15 | 29 |
| *t*-Value | 0.205 | −0.140 | 0.293 | 0.861 | −0.336 |
| Crit *t*0.95 | 1.699 | 1.699 | 1.761 | 1.753 | 1.699 |
| *p*-Value | 0.419 | 0.445 | 0.387 | 0.201 | 0.369 |

The pre-test scores of both groups (Traditional and VR) were found to be statistically insignificant, indicating that the participants' safety awareness and knowledge regarding falling from heights were comparable. However, the post-test scores showed a negative *t*-value for the BR group compared to the traditional group (−0.140). This suggests that the mean value of the post-test scores for the VR group was slightly higher than that of the traditional group (as indicated in Table 2), but the difference was not statistically significant (*p*-value = 0.445).

Similarly, the negative *t*-value of the difference score traditional versus difference score VR (−0.336) shows that the mean value of the difference score for the VR group was higher than the mean value of the difference score for the traditional group—albeit statistically insignificantly higher (*p*-value = 0.369). Therefore, a higher learning effectiveness of the VR approach can be seen, but without statistical significance. Both groups, traditional and VR, showed higher mean values of post-test scores than pre-test scores, albeit statistically insignificantly higher.

### *3.3. SUS Scores*

The SUS scores of the participants of both the traditional and VR group were collected as per Brooke (1996) [19]. Table 4 represents the descriptive statistics.

**Table 4.** Descriptive statistics of SUS score.

| Participant Groups | Measure | SUS Score (Percentile) |
|---|---|---|
| Traditional | Mean | 67.83 |
| | SD | 17.79 |
| VR | Mean | 59.67 |
| | SD | 17.50 |

To further comprehend the SUS scores, the percentiles were converted into an adjective scale according to [22]. Percentile scores between 0–49 were considered "Not Acceptable", scores between 50–69 were "Marginal", while scores larger than or equal to 70 were "Acceptable". The traditional training participants and the VR participants found that the training approach usability was considered "Marginal" for both. However, it is important to note that the traditional group showed a higher mean score (8.16%) difference. Even though both groups claimed marginal usability, participants seemed to prefer the traditional training approach.

For further investigation, inferential statistics were conducted to identify any significant difference between the two groups. The analysis was identical to the inferential analysis mentioned in the pre- and post-tests. Table 5 shows the findings.

**Table 5.** SUS T vs. SUS VR scores.

| | SUS T vs. SUS VR |
|---|---|
| df | 29 |
| *t*-Value | 1.243 |
| Crit *t*0.95 | 1.699 |
| *p*-Value | 0.112 |

The SUS score was statistically insignificantly higher for the traditional group than the VR group (*p*-value = 0.112). Workers' general perception of the limited usability of the VR approach was confirmed by the following observations:

(1) All VR group workers reflected difficulties with the hand controllers;
(2) Workers required extra encouragement to use the teleporting function;
(3) In total, five workers of the VR group expressed explicitly that using the VR approach was too complicated;
(4) In total, two workers of the VR group expressed explicitly that they enjoyed using the VR approach;
(5) One younger worker, although struggling much less with the VR approach than most of the other VR users, remarked: "I still like the traditional training more".

### 3.4. Correlation Analysis

In the last step, relationships between variables of the VR group were analyzed, and the Spearman correlation coefficients are shown in Table 6 for the demographic variables age (column 2), experience (column 3), training sessions (column 4), injuries (column 5), and the dependent variables pre-test VR scores, and SUS VR score.

**Table 6.** Spearman correlations—VR group.

| | Age | Experience | Training | Injuries | Pre-Test Score | SUS Score |
|---|---|---|---|---|---|---|
| Age | 1 | | | | | |
| Experience | 0.599 | 1 | | | | |
| Training | −0.076 | −0.103 | 1 | | | |
| Injuries | −0.212 | 0.093 | 0.080 | 1 | | |
| Pre-test score | −0.007 | 0.138 | 0.284 | −0.010 | 1 | |
| SUS score | −0.473 | −0.388 | 0.131 | 0.234 | −0.076 | 1 |

The only relationship with a large association was found to be between experience and age ($r_S = 0.6$), which shows that older workers usually also had more work experience. Two further relationships had a medium association, namely, between the SUS score and age ($r_S = -0.47$), and between the SUS score and experience ($r_S = -0.39$). The first of the two latter relationships shows that the older the worker, the lower the perceived system usability. Similarly, for the relationship between SUS score and experience, the more experienced the workers, the lower the perceived system usability. This finding might be related to the anecdotal evidence that older/more experienced workers are usually less familiar with digital technology, and it was confirmed by observing several occasions in which participants had difficulties to use the simulated tablet to capture virtual scenes with safety issues. It was obvious that several workers were not familiar with taking pictures using a tablet or smartphone since they were trying to push the camera button very hard. VR developers and safety training providers should discuss further whether blue-collar workers need to be required to use the virtual tablet since their primary task is not to carry out safety inspections, but to know how to deal with safety hazards.

Furthermore, the relationships between SUS score and age, and SUS score and experience, point towards a higher usability of VR safety training for younger/less experienced workers. For them, virtual experiences may include scenarios they had not experienced previously in reality. Therefore, the VR safety training would provide a safe environment to learn about safety issues and how to respond to hazards. Since this study did not include participants without experience, such as construction apprentices or unskilled candidates for construction work, it is recommended to replicate the study for participants without any experience. The SUS score can be expected to be higher for unexperienced and younger users.

Although it is understood that individual items U1 to U10 of the SUS scale are not meaningful on their own [20], considering the purpose of this study, it is justified to have a closer look at the relationships between individual items and the identified relevant independent variables, i.e., age, experience, training sessions, injuries, and the dependent variable pre-test score. This may lead to more specific findings regarding the usability of the VR approach and potential areas for improvement. The correlations are shown in Table 7 and it can be seen that numerous relationships have at least a medium association that is larger than 0.3. Here, the analysis will be limited to relationships with large associations, i.e., the relationship between:

- U1 (I think that I would like to use this system frequently) and age;
- U3 (I thought the system was easy to use) and experience;
- U3 (I thought the system was easy to use) and training; and,
- U5 (I found the various functions in this system were well integrated) and injuries.

**Table 7.** Spearman correlation between individual items of the SUS scale and independent variables.

| | Age | Experience | Training | Injuries | Pre-Test Score |
|---|---|---|---|---|---|
| U1 | −0.501 | −0.348 | 0.163 | −0.085 | 0.067 |
| U2 | −0.124 | −0.001 | 0.041 | 0.065 | −0.309 |
| U3 | −0.032 | 0.548 | −0.540 | 0.405 | −0.014 |
| U4 | 0.420 | 0.200 | −0.286 | 0.306 | −0.172 |
| U5 | 0.392 | 0.425 | 0.034 | 0.522 | −0.255 |
| U6 | −0.057 | −0.194 | −0.139 | −0.088 | −0.157 |
| U7 | −0.238 | −0.204 | 0.367 | −0.138 | −0.063 |
| U8 | 0.042 | −0.0475 | −0.239 | 0.192 | −0.451 |
| U9 | −0.467 | −0.249 | 0.021 | −0.052 | 0.110 |
| U10 | −0.030 | −0.006 | −0.474 | 0.015 | −0.276 |

The negative, large association between U1 (I think that I would like to use this system frequently) and age confirms the previous interpretation: that older users are less open to the VR approach than younger users. The positive, large association between U3 (I thought the system was easy to use) and experience seems to indicate that participants may have thought about the simulated safety challenges when evaluating how easy the system was to use (versus the ease of use of virtual tablet, hand controllers, etc.). This interpretation was confirmed by the following observations:

(1) More experienced workers more often expressed dissatisfaction with the virtual tablet and using the hand controllers than younger workers;
(2) More experienced workers verbally expressed that the virtual safety challenges were common situations which were very easy to deal with;
(3) Less experienced workers considered unacceptable scissors lift supports to be acceptable;
(4) One older worker loudly expressed his dissatisfaction at not realizing the importance of looking upwards to see the electrocution hazard resulting from the ladder touching

the electricity line by saying: “Of course I would look upward. Everybody knows that I have the best safety record”. The cause of not looking upward was obviously not related to negligence or a lack of knowledge, but it was clearly related to feeling overwhelmed with wearing the headset, and the impact of hand and body movements on the displayed virtual reality and the visual disconnection with others present in the training venue.

The negative, large association between U3 (I thought the system was easy to use) and previous safety training seems to confirm the previous finding related to age/experience: the fewer training sessions workers had (i.e., the younger they were), the easier they found navigating the tasks related to the virtual safety challenges.

The positive, large association between injuries and U5 (I found the various functions in this system were well integrated) shows that the more injuries workers had experienced, the more they realized the integration of different functions of the VR approach. This seems to confirm the complex causes of accidents that usually involve multiple factors, such as visual perception, audible perception, kinesthetic perception, stress level, physical well-being, and others, which lead to causing an accident. Users may have realized that the VR approach incorporates these factors better than traditional training. However, the following observations indicate that the overall usability of the VR approach was perceived as limited by the involved stakeholders:

(1) All five safety engineers of the five companies supporting this study observed their workers’ performance and stated that the VR approach requires significant preparation of workers regarding the virtual usage of tablets and hand controllers;
(2) The safety engineers were excited to try the VR training themselves and faced almost no difficulties;
(3) An iterative three-stage approach to the VR training (starting with a video-based introduction, continuing with familiarization with the headset and hand controllers based on a module different from “working at heights”, and finally using the module “working at heights”) led to a slightly higher level of confidence of workers, but did still not lead to an observable higher appreciation of the VR approach by workers;
(4) Necessary interventions, such as when trainees accidentally crossed the space boundary and a user code had to be re-entered by the authors of this study since it was too complicated for workers to do themselves, contributed to workers perception of limited usability of the VR approach.

In summary, these findings confirm the findings of [12], who found that the perceived usefulness and perceived ease of use are significant direct predictors of attitude toward VR technology used for construction safety training.

## 4. Conclusions and Limitations

A semi-quasi experimental research design was employed, utilizing a control group and an experimental group, along with pre- and post-tests, to assess the effectiveness of VR safety training and its usability. The research focused on “working at heights” safety training for blue-collar construction workers in Kuwait. The study adopted a mixed approach, combining quantitative analysis supplemented with observations.

The results showed a greater improvement in the mean scores between the pre- and post-tests in the VR group compared with the traditional group. However, the findings revealed a statistically insignificant higher learning effectiveness for the VR users. A medium association between perceived usability and age/work experience was identified, with older/more experienced workers perceiving the VR approach as less usable.

Although trainees found the VR approach in general interesting, for most of them, it was a stressful experience due to their lack of familiarity with using a headset, hand controllers, and a virtual tablet for taking pictures. Implementing a three-stage approach (video-based induction, familiarization with headset and hand controller, and undergoing the training) was found to reduce stress levels and to increase confidence, albeit without improving the usability as perceived by the participants. This shows that blue-collar laborers exhibit low technology and digital literacy, specifically older and more experienced individuals. Younger workers with less experience tended to rate usability higher, suggesting greater openness to technology and less resistance to change.

Representatives of the collaborating companies realized the advantage of preparing workers for working at height within a safe virtual environment. However, they observed the need for extended familiarization with the VR approach for better trainee benefits.

VR developers are advised to consider the impact of usability on trainees' learning outcomes, especially for individuals with limited technology experience. Blue-collar laborers in specific would require a simpler hardware configuration and a more immersive experience, for example, eliminating the joy sticks and utilizing hand gestures only or substituting the teleporting function with something that is more immersive and realistic.

Unfortunately, the literature lacks similar studies that target blue-collar labor and falling-from-heights hazards [23], thus comparing the results of this study with other research is not possible. Scholars are encouraged to investigate the usability of such training.

It is essential to acknowledge the study's limitations. First, the sample size used for the research was rather small, and as mentioned earlier in the paper, there was a great struggle to collaborate with companies willing to invest time during working hours. In addition to this, the VR module used was limited to four scenarios; thus, it is worth investigating how a more comprehensive and diverse VR module can affect both the effectiveness of the VR training and the usability.

A longitudinal study with a delayed post-test can provide valuable insights into knowledge retention and the potential of VR as an alternative to traditional training approaches.

Replicating this study with construction apprentices is recommended to explore if and how novice construction workers benefit from the VR approach. This may include variables such as simulation sickness, which was found in the literature to affect the performance and usability of VR [24]. Furthermore, future studies might also investigate the impact of the VR approach on behavior change and measurable results (such as accident statistics).

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