

# Telepresence in Construction Sites: Usability Study of a VR-Based Environment for Working in Heights

Olmo A. Moreno F.<sup>1</sup>, Nicholas Cartocci<sup>1</sup>, Antonios E. Gkikakis<sup>1</sup>, Gabriele Giurin<sup>1</sup>, Marco Carega<sup>1</sup>, Yonas T. Tefera<sup>1</sup>, Nikhil Deshpande<sup>2</sup>, Francesca M. Fabiani<sup>3</sup>, Darwin G. Caldwell<sup>1</sup>, and Jesus Ortiz<sup>1</sup>

**Abstract**—Workers in the construction industry are constantly exposed to injuries and fatal hazards. Contributing factors, such as lack of safety knowledge, ineffective training, and inadequate supervision, increase the risk of accidents. Virtual reality environments with telepresence capabilities provide a potential solution to training employees when they are not located in a physical location. This study explores the use of immersive training technologies at a construction site. We propose a virtual reality-based environment that replicates assembly tasks for temporary work equipment at a typical construction site. We conducted a user study with fourteen participants to evaluate the environment in terms of presence, immersion, intrinsic motivation, user experience, usability, and motion sickness. Results indicated that while the participants found the virtual environment immersive, usable, engaging, and aesthetically pleasing, they faced challenges in task effectiveness and experienced eye-related discomfort and fatigue.

## I. INTRODUCTION

Working at height (WAH) is widely recognised as one of the most hazardous activities across various industries [1], [2], [3], requiring strict safety protocols and compliance measures to mitigate risks such as falls, equipment failure and environmental risk. In 2021, the Italian Workers' Compensation Authority reported that 253,947 incidents were related to falls, of which 476 resulted in death causality [4]. Some factors that could contribute to workers' injuries include a lack of safety knowledge, careless worker attitudes, and ineffective training [5].

Before undertaking any work-at-height tasks, employees must obtain the necessary qualifications through training programs that cover critical safety aspects. To address these challenges, this study explores advancements in immersive assembly actions by integrating and assessing mixed reality and telepresence technologies in the context of WAH. Specifically, we focus on virtual reality (VR) training models when a worker performs generic assembly tasks at a construction site.

<sup>1</sup>O. A. Moreno F., N. Cartocci, A. E. Gkikakis, G. Giurin, M. Carega, Y. Tefera, D. G. Caldwell, and J. Ortiz are with Advanced Robotics Department, Istituto Italiano di Tecnologia, Via Morego 30, 16163, Genova, Italy {olmo.moreno, nicholas.cartocci, antonios.gkikakis, gabriele.giurin, marco.carega, yonas.tefera, darwin.caldwell, jesus.ortiz}@iit.it

<sup>2</sup>N. Deshpande is with School of Computer Science, University of Nottingham, Wollaton Road, Nottingham, NG8 1BB, UK nikhil.deshpande@nottingham.ac.uk

<sup>3</sup>F. M. Fabiani is with Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, P.le Pastore 6, 00144 Rome, Italy fr.fabiani@inail.it

This paper presents the development and assessment of an environment that could be used in VR-based training; however, this study does not provide an educational methodology for worker training. We evaluate VR elements such as presence, user experience, usability, immersion, motion sickness, and simulator realism.

### A. Motivation

The VICARIOS Mixed Reality and Simulations Lab, in collaboration with the Wearable Robots, Exoskeletons, and Exosuits Laboratory (XoLab) at the Istituto Italiano di Tecnologia (IIT), has partnered with the Italian Workers' Compensation Authority (INAIL) to develop novel solutions for enhancing worker safety. A key aspect of this initiative is enabling a safe, interactive, and immersive environment through telepresence, allowing workers to perform assembly tasks remotely. This approach ensures that workers can practice in high-risk environments (i.e. work at height in construction sites) without physical danger. The academic contribution of this work relies on integrating and assessing mixed reality and telepresence technologies in the context of WAH, addressing a critical gap in how the user responds to VR-based environments for construction sites. To the best of our knowledge, this study is the first to propose a hypothetical, generic assembly tasks for VR in a construction site. We believe that it is important for private and public entities to reduce the number of fatal and nonfatal causalities during WAH activities by testing disruptive technologies.

### B. State of the art

Several approaches have been proposed to study the impact of VR systems on WAH training employees [6]. Regarding fall hazard prevention, in [7] and [8] is discussed the evaluation of proprioceptive training using VR environments on the level of postural stability. Tehrani et al. in [9] presents an assessment of mental fatigue in VR environments. Then, in [5] and [10] is presented the design and development of a VR application and simulation for safety training. Finally, in [11] is conducted a usability assessment for a VR safety training module. The outline of this work follows the next order. Section II defines the system characteristics of the VR hardware, the virtual environment, and the assessment metrics used in this study. Next, Section III describes the participant group and the experimental design of the study. The results and discussion of the participants' activities are presented in Section IV. Finally, Section V presents the conclusions and future work.

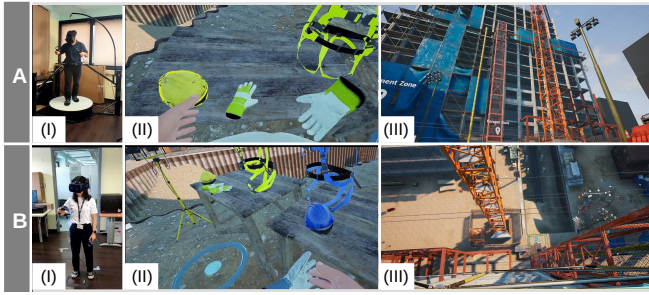


Fig. 1: Participants performing the assembly activity in the virtual environment. A: (I) Participant 1, (II) equipment zone, and (III) building and lift. B: (I) Participant 2, (II) equipment zone, and (III) view from the top of the building.

## II. METHODS AND MATERIALS

### A. System description

1) *Hardware specifications:* The proposed system uses the HTC Vive Pro Eye VR headset and the motion controllers, which includes an integrated Tobii Eye Tracking system with an accuracy of  $0.5\text{--}1.1^\circ$  and a trackable field of view (FOV) of  $110^\circ$ . The system operates on a computer running Windows 10 with an Nvidia GeForce GTX 1080 graphics card. Additionally, the system uses the Cyberith Virtualizer for locomotion and safety during falling experiments (see Fig. 1).

2) *Virtual environment:* The VR environment was developed using Unreal Engine (UE), which provides an immersive user experience. It consists of two sections: a) training room and b) construction site. In the training room, users can watch a short video of the assembly activity performed (see Fig. 2-AI). Then, there is an action element (highlighted area where material must be placed) where the user trains the assembly activity, and a poster on the wall depicts how to use the motion controls (see Fig. 2-AII). Lastly, there is a material container in which the user selects the parts of the work equipment to be assembled (see Fig. 2-AIII). At the construction site, there is an equipment zone to grab tools or safety equipment (see Fig. 2-CI), an assembly zone, which is 7 storey building (32m) where the user assembles the work equipment (see Fig. 2-CII), and a coffee area where the user interacts with a coffee machine (see Fig. 2-BI). The VR environment operates under the following scenarios: i) a clear day (see Fig. 2-CII) and ii) a rainy dark night (see Fig. 2-CIII).

### B. Assessment metrics

The standardised assessment metrics in this study were chosen from the user-centred evaluation framework for Wearable Robotics Devices (WRD), a research methodology platform offered by the Interactive Usability Toolbox (IUT) [12]; and also the VR evaluation tool framework proposed by Bareišytė in [13]. The scale of Cronbach's alpha coefficient of reliability is defined in [14].

**IGroup Presence Questionnaire (IPQ)** is designed to assess the subjective experience of presence within virtual

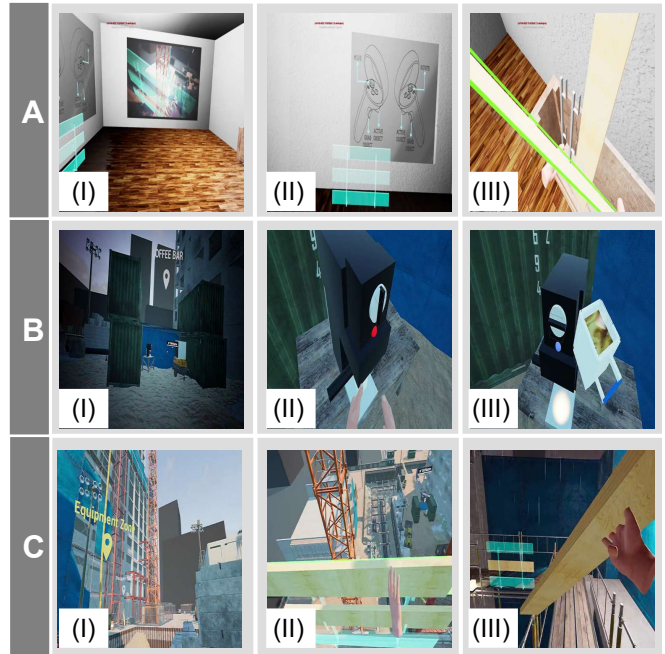


Fig. 2: Virtual reality environment: training room and construction site. A: Training room: (I) video screen, (II) action element, and (III) material container. B: Coffee area: (I) coffee room, (II) coffee machine, and (III) full coffee cup. C: Construction site: (I) equipment zone, (II) building on a clear day, and (III) building on a rainy dark night.

environments. It includes 14 items in a 7-option Likert scale (from not at all true to completely true) that measure three independent components: a) spatial presence, b) involvement, and c) judgments of realness. Participants respond to a series of statements related to their experiences in the virtual environment [15].

**Intrinsic Motivation Inventory (IMI)** is a 12-item multi-dimensional measure designed to assess individuals' intrinsic motivation across various tasks using a 7-option Likert scale (from not all true to very true). It evaluates dimensions such as interest-enjoyment, perceived competence, effort, and pressure-tension, providing a comprehensive view of motivation [16].

**Single Usability Metric (SUM)** is a standardised 3-item and 5-option Likert scale metric designed to encapsulate multiple usability dimensions into one score, simplifying usability assessments. It integrates three common metrics: task completion rates, average time on task, and post-task satisfaction [17].

**System Usability Scale (SUS)** is a 10-item evaluation tool with a 5-option Likert scale (from strongly disagree to strongly agree), developed to assess the usability of various systems. The SUS generates a score ranging from 0 to 100, with higher scores indicating better perceived usability [18].

**Usability Metric for User Experience (UMUX)** is a 4-item survey with a 7-option Likert scale (from strongly disagree to strongly agree) designed to assess the perceived usability of applications. After scoring, the individual item

scores are recoded and summed to derive a final score, which can be expressed as a percentage from 0 to 100 [19].

**User Fatigue Survey (UFS)** is 8-item tool designed to evaluate eye-related discomfort and fatigue experienced by participants during visual tasks. It includes questions addressing aspects such as eyes tiredness, clarity of vision, and sensations of pain or dryness. Participants rate their symptoms on a scale from 0 (no problem) to 3 (severe problem) [20].

**Virtual Reality System Usability Questionnaire (VR-SUQ)** is a 9-item tool with a 5-point Likert scale (from strongly disagree to strongly agree) developed to evaluate the perceived usability of virtual reality (VR) systems by addressing their unique characteristics. It encompasses various usability aspects, such as effectiveness, efficiency, and user satisfaction, and was designed specifically for VR environments [21].

### III. EXPERIMENTAL EVALUATION

#### A. Participants

Fourteen healthy subjects (age:  $28.29 \pm 4.95$  years) with no history of musculoskeletal disorders were included, allowing them to safely perform the assigned tasks. Among the participants, 7 wore glasses when watching a screen; none presented with hearing difficulties. Only 28.57% of the participants had previous experience with VR systems. The data collection process was approved by the Ethics Committee of the Liguria Region under protocol IIT ADVR TELE01.

#### B. Experiment design

The experimental design is shown in Fig. 3 which consists of monitoring and assessment of four virtual activities: a) Training, b) Assembly 1, c) Assembly 2, and d) Assembly 3. All activities were performed using a visual headset with motion controllers and VR environment. In the training activity, participants learned how to operate the virtual materials using the motion controllers by watching a short video displayed on a screen. The main objective is to habituate the participant to the VR environment and provide them with a general understanding of the single work equipment assembly activity. The participant then settles on the construction site. Initially, assembly activities were initiated next to the equipment zone (the initial point). First, they must approach the coffee area and prepare and drink a hot cup of coffee using the coffee machine. The purpose of this activity was to allow participants to adjust their visual headset and motion controllers before starting the work equipment assembly task. Then, the participant moves towards the assembly zone, takes the elevator to go on the top of it. Next, the participant must find the material container and the action element. The last element indicates where the material should be placed. Each material container had five assembly pieces, and each assembly activity had two action elements. When the participant completes the second assembly task, before addressing the next material container, the assembly task is interrupted, indicating the end of the

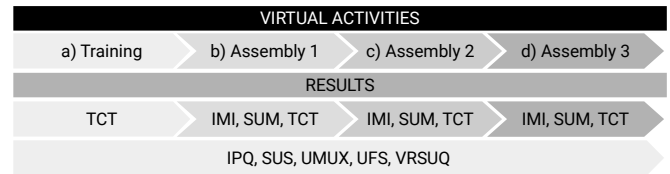


Fig. 3: Experimental design structure. The experiment comprised virtual activities. Results were registered after each assembly task and after completing the experiment.

activity. The results collected after training were the task completion time (TCT). At the end of each assembly activity, TCT was recorded, and participants were asked to answer the following surveys: IMI and SUM. Finally, when participants completed the experiment, they were asked to answer the next evaluations: IPQ, SUS, UMUX, UFS, and VRSUQ. Participants were asked to remove the headset and motion controllers after finishing each assembly task to report the questionnaires.

### IV. RESULTS AND DISCUSSION

The average participant time for the experiment was 53m. The results are presented in two levels: a) post-activity results and b) post-experiment results. All statistical studies were executed with 14 participants ( $n = 14$ ). Results IV-A.1, IV-A.2, IV-B.1, IV-B.2, IV-B.3, IV-B.4, and IV-B.5 are categorized as subjective results, while IV-A.3 are objective results.

#### A. Post activity

1) *Intrinsic Motivation Inventory*: Fig. 4 depicts the IMI results obtained after each assembly task. The scale's internal consistency was measured using Cronbach's alpha, which was found to be  $\alpha = 0.777$ . Task 3 obtained the highest scores in the effort/importance (E/I) dimension with a mean value of  $5.464 \pm 1.262$ , in interest/enjoyment (I/E) with a mean value of  $6.142 \pm 0.101$ , and perceived competence (P-Co) with a mean value of  $5.392 \pm 0.151$ . Task 1 reported the highest perceived choice (P-Ch) score with a mean value of  $5.821 \pm 0.959$ . Participants reported the highest rating in pressure/tension (P/T) in Task 2, with a mean value of  $4.107 \pm 0.353$ . Finally, the value/usefulness (V/U) dimension obtained the highest score in Task 1, with a mean value of  $6.285 \pm 0$ . According to the effort/importance dimension, we can infer that participants progressively found importance in assembly activities. In the same way, the enjoy/interest dimension presented an increasing slope along the three tasks, suggesting that the participants enjoyed the task performance. Perceived choice dimension results define engagement with the task, and participants' scores suggest that they felt slightly forced to complete the activities. The perceived competence dimension results were generally the second lowest, which suggests that participants felt not confident enough to complete the tasks. In the pressure/tension dimension, the results were the lowest among all dimensions, indicating that the participants did not experience

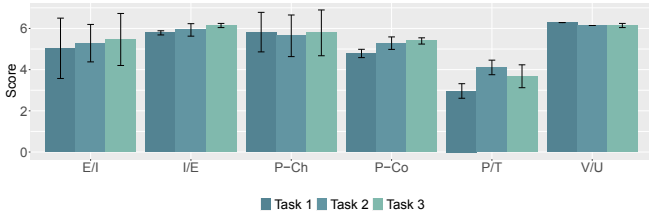


Fig. 4: Intrinsic Motivation Inventory results. E/I: Effort/Importance, I/E: Interest/Enjoyment, P-Ch: Perceived choice, PC: Perceived competence, P/T: Pressure/Tension, V/U: Value/Usefulness.



Fig. 5: Single Usability Metric, results of the three virtual assembly activities.

excessive tension during the assembly activities. Finally, the value/usefulness dimension was the highest rated among the three tasks, indicating that participants perceived the activities as meaningful.

2) *Single Usability Metric*: The computed Cronbach’s alpha for the dataset was  $\alpha = 0.795$ , indicating excellent internal reliability. Fig. 5 shows the SUM results for the three assembly activities. The highest rated activity in the task ease attribute was Task 1 with a mean value of  $3.714 \pm 1.204$ ; in the satisfaction attribute, Task 2 and Task 3 were the highest rated with a mean value of  $4.214 \pm 0.801$  and  $4.214 \pm 0.892$ , respectively; lastly, in time on task attribute, the top rated activity was Task 1 with a mean value of  $3.857 \pm 1.027$ . Friedman test was conducted on each group of attributes to determine whether task ease, satisfaction, and task on time scores differed between the first, second, and third trials. The results show no significant difference in any of the three groups,  $X^2(2) = 1.2$ ,  $p = 0.5488$  (task ease),  $X^2(2) = 0.5$ ,  $p = 0.778$  (satisfaction), and  $X^2(2) = 2.545$ ,  $p = 0.280$  (time on task). Therefore, we fail to reject the null hypothesis and conclude that there is no difference for each group of attribute scores (task ease, satisfaction and time on task) between the first, second, and third assembly activities.

Participants reported Task 1 with the highest rating (11.866/15). Although the scores are close among each other, it is notable that Task 2 (11.466/15) and Task 3 (11.600/15) scores were lower than the first one. This suggests that as the experiment progressed, participants experienced less ease, satisfaction, and less time.

3) *Task Completion Time*: Figure 6 presents the recorded times of seven activities during the experimental protocol. As described in Sec. III-B, there was a training phase to allow the user to adapt to the VR environment, followed

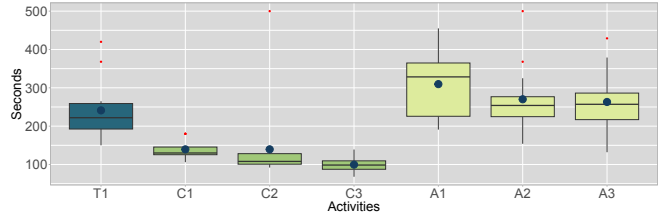


Fig. 6: Time on Task results, Mean value is represented by the dark circle on the plot.

by a coffee-making task and an assembly task. The training phase had a duration with a mean value of  $241.14s \pm 74.06$ . Coffee-making in Task 3 registered the lowest time with a mean value of  $99.57s \pm 17.65$ , which is a difference of  $40.0s$  compared with Task 1, which registered a mean value of  $139.5s \pm 23.89$ . Task 3 obtained the lowest time with a mean value of  $263.0s \pm 75.45$ , which is a difference of  $46.64s$  compared with Task 1, which registered a mean value of  $309.64s \pm 86.6$ . Friedman test was conducted on each activity time to determine whether time scores differed between the first, second, and third trials. The results show no significant difference in any of the three activities,  $X^2(2) = 5.333$ ,  $p = 0.069$ . Therefore, we did not reject the null hypothesis and concluded that no time difference was found between assembly activities.

## B. Post experiment

1) *IGroup Presence Questionnaire*: Table I presents the IPQ results. The scale’s internal consistency was measured using Cronbach’s alpha, which was found to be  $\alpha = 0.519$ . The confidence interval was 0.95. The following attributes are ranked according to the rated score, from the highest to the lowest, and for each attribute it is mention the qualitative grading scale proposed by Melo in [22]. The highest ranked score was “Presence” with a qualitative score as excellent; then, “Spatial presence” with a qualitative score as unacceptable; followed by “Involvement” with a qualitative score as unacceptable; finally, “Experienced realism” with a qualitative score as unacceptable. The results suggest that the VR system effectively created a convincing immersive experience, allowing users to feel engaged. However, the spatial presence was slightly lower than the general presence, suggesting that some elements may have reminded participants that they were in a simulation. Involvement proposes that participants may experience distractions, cognitive load, or external factors. Finally, the virtual environment did not feel completely realistic to the participants. Nomenclature for Table I: LB: lower bond, and UB: upper bond.

TABLE I: IGroup Presence Questionnaire

Attribute	Mean	SD	LB	UB
Presence	5.285	0.913	4.758	5.813
Spatial presence	3.500	0.951	2.318	4.681
Involvement	3.267	0.604	2.306	4.229
Experienced realism	2.357	0.728	1.198	3.516

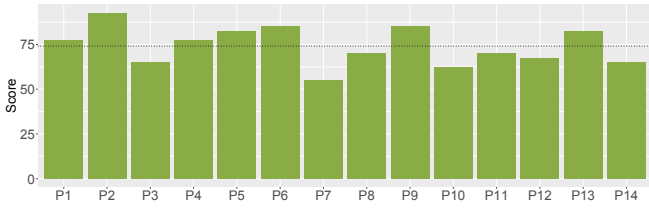


Fig. 7: System Usability Scale, participants individual score and mean combined score.

2) *System Usability Scale*: Fig. 7 presents the SUS results obtained from the 14 participants. To assess the reliability of the questionnaire, Cronbach’s alpha was computed, yielding a value of  $\alpha = 0.229$ . The highest individual score was 92.5 (best imaginable) and the lowest was 55 (good). The combined mean score was 74.10/100 (excellent). The interpretation of the SUS score was presented by Martínez in [23]. The combined mean score indicates that participants found the virtual environment as easy to use and rated the performed interaction as not complex, thereby making the participant confident during the session.

3) *Usability Metric for User Experience*: Table II shows the UMUX survey results. The survey was adapted to the context of the virtual environment (e.g., item 1: “The virtual environment capabilities meet my requirements”). The internal reliability of the scale was confirmed with a Cronbach’s alpha of  $\alpha = 0.144$ . The total UMUX score was (76.190/100). The confidence interval was 0.95. The maximum and minimum scores represent a single score for each attribute. The “Overall” attribute obtained the highest score among participants, and the “Effectiveness” attribute obtained the lowest score. Based on the results, we can infer that the proposed system might be aesthetically pleasing, engaging, or easy to use, leading to a high overall perception. However, low effectiveness indicates that participants struggled to complete their activities successfully or efficiently. Nomenclature and abbreviations for Table II: LB: lower bond, UB: upper bond, Att.: attribute, Effe.: effectiveness, Sat.: satisfaction, Ovl.: overall, and Effi.: efficiency.

TABLE II: Usability Metric for User Experience

Att.	Max	Min	Mean	SD	LB	UB
Effe.	6	3	4.500	0.759	4.061	4.938
Sat.	6	1	4.642	1.150	3.978	5.307
Ovl.	6	1	4.857	1.350	4.077	5.636
Effi.	6	2	4.285	1.540	3.396	5.175

4) *User Fatigue Survey*: Table III presents the UFS results. The maximum and minimum scores represent a single score for each symptom. At least one participant experienced the highest scale of severity (3) in all user fatigue symptoms. Clear vision was the highest rated symptom as in “too clear” vision after the experimental protocol. More than half of the participants experienced fatigue equal to or below the average symptom score. Nomenclature for Table III: A & B: average and below average.

TABLE III: User Fatigue Survey

Symptoms	Max	Min	Mean	SD	A & B
Tired eyes	3	0	1.285	0.825	64.28%
Clear vision	3	1	2.214	0.699	64.28%
Eye dryness	2	0	1.000	0.784	71.42%
Tired back	3	0	1.000	1.109	71.42%
Tired neck	3	0	0.857	1.167	57.14%
Severe headache	3	0	0.428	0.851	71.42%
Sleepy feeling	3	0	1.285	1.069	57.14%

5) *Virtual Reality System Usability Questionnaire*: Table IV presents the results of the VRSUQ questionnaire. The internal consistency of the survey data was evaluated using Cronbach’s alpha, which resulted in a coefficient of  $\alpha = 0.664$ . The confidence interval was 0.95. The “Satisfaction” attribute obtained the highest score among participants, and the “Effectiveness” dimension obtained the lowest score. We can infer that participants enjoyed the experience (satisfaction) despite the potential challenges. The VR system should have had engaging visuals (efficiency), good interaction design, or an immersive experience that contributed to positive user sentiment. However, with low effectiveness, users may have struggled with the controls, navigation, or precision, making the work equipment assembly not particularly effective. The VRSUQ single score was 69.841/100. Nomenclature and abbreviations for Table IV: LB: lower bond, UB: upper bond.

TABLE IV: Virtual Reality System Usability Questionnaire Scores

Attribute	Mean	SD	LB	UB
Effectiveness	3.380	0.329	2.561	4.200
Efficiency	3.952	0.459	2.811	5.093
Satisfaction	4.027	0.459	2.906	5.188

### C. Report of Errors

Table V presents the error reports after the experiment. There are two conditions in the current report: a) repetitions, which is the number of times that the activity was reset and repeated because of a system fault (the virtual environment crashed or freeze); and b) mistakes, which is considered a mistake when the participant dropped off an object in which it was interacting with. The virtual environment system ran 56 times (14 sessions of training and 42 sessions of assembling material), it recorded 4 repetitions after having all participants sessions; the virtual environment system accuracy was 92.86%. During the training session, 14 participants interacted with 5 pieces of assembling material, making 70 interactions, having 9 mistakes (12.85%), and the interaction accuracy was 87.15%. After each assembly task, the participants interacted with 10 pieces of assembly material, resulting in 140 interactions. In Task 1, the participants reported 6 mistakes (4.28%), resulting in a virtual assembly accuracy of 95.72%. Then, in Task 2 and Task 3, participants registered 3 mistakes respectively (2.14%), which gave a virtual assembly accuracy of 97.86%.

TABLE V: System and Users Errors Reports

Task	Repetitions	Mistakes	Interactions	Accuracy
Training	1	9	70	87.15%
Activity 1	1	6	140	95.72%
Activity 2	1	3	140	97.86%
Activity 3	1	3	140	97.86%

## V. CONCLUSIONS AND FUTURE WORK

Disrupting technologies such as telepresence provides a potential solution to train workers in VR-based environments, as shown in the following results. The intrinsic motivation inventory results suggested that the participants progressively found the assembly activities more important and enjoyable, although they felt slightly pressured and lacked full confidence in their competence. The results in terms of presence indicated that participants generally felt immersed in the virtual environment; nevertheless, lower spatial presence, involvement, and realism scores suggested that some elements reminded them that they were in a simulation. For user experience, it was perceived that the participants found the virtual environment generally satisfactory and efficient; its effectiveness in helping users complete tasks successfully could be improved. Regarding motion sickness, most participants experienced mild to moderate fatigue symptoms, issues like eye strain and visual discomfort were common, indicating potential areas for improvement in user comfort. Usability results suggested that participants initially found the tasks easier and more satisfying; however, their ease, satisfaction, and efficiency slightly decreased as the experiment progressed. The task completion time results revealed an improvement in task efficiency across activities, indicating a stable learning curve. Finally, the error report results indicated that the VR environment demonstrated high system accuracy with minimal crashes. In the future, we plan to use this VR environment to collect biomedical data from participants using wearable devices to estimate falls from height during operations in the construction sites.

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## REFERENCES

- [1] B. Teti, B. Vasconcelos, E. Lago, and T. Zlatar, "Working at Heights: An Investigation on Accidents and its Causes," *Building Information Modelling: as a Safety Management Tool for Preventing Falls from Height. Saarbrücken: LAMBERT Academic Publishing*, pp. 18–25, 2018.
- [2] L. Kissiková and I. Dluhoš, "Comprehensive evaluation of the work at height," *Acta Metallurgica Slovaca*, vol. 24, no. 1, pp. 100–106, 2018.
- [3] N. N. A. Abdul Halim, F. Abdullah, N. Amil, N. A. Khalid, K. Arifin, and M. H. Jaafar, "Risk Assessment of Falling from Height in the Construction Industry in the Northern Region of Peninsular Malaysia Using Structural Equation Modelling," *Sustainability*, vol. 14, no. 24, p. 16755, 2022.
- [4] G. Bucci, "La Prevenzione dei Rischi nei Lavori in Quota tra Necessità Normative e Modelli Applicativi, Analisi dei dati infortunistici relativi alle cadute dall'alto," tech. rep., Istituto nazionale per l'assicurazione contro gli infortuni sul lavoro, Italia, Nov. 2022.
- [5] S. Rokoei, A. Shojaei, A. Alvanchi, R. Azad, and N. Didehvar, "Virtual reality application for construction safety training," *Safety Science*, vol. 157, p. 105925, Jan. 2023.
- [6] E. Rey-Becerra, L. H. Barrero, R. Ellegast, and A. Kluge, "The effectiveness of virtual safety training in work at heights: A literature review," *Applied Ergonomics*, vol. 94, p. 103419, July 2021.
- [7] M. Cyma-Wejchenig, J. Tarnas, K. Marciniak, and R. Stemplewski, "The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height," *Sensors*, vol. 20, p. 3731, Jan. 2020.
- [8] H. Chander, A. Shojaei, S. Deb, S. N. K. Kodithuwakku Arachchige, C. Hudson, A. C. Knight, and D. W. Carruth, "Impact of Virtual Reality-Generated Construction Environments at Different Heights on Postural Stability and Fall Risk," *Workplace Health & Safety*, vol. 69, pp. 32–40, Jan. 2021.
- [9] B. M. Tehrani, J. Wang, and D. Truax, "Assessment of mental fatigue using electroencephalography (EEG) and virtual reality (VR) for construction fall hazard prevention," *Engineering, Construction and Architectural Management*, vol. 29, pp. 3593–3616, Aug. 2021.
- [10] C. Di Loreto, J.-R. Chardonnet, J. Ryard, and A. Rousseau, "WoaH: A Virtual Reality Work-at-Height Simulator," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 281–288, Mar. 2018.
- [11] M. I. Al-Khiami and M. Jaeger, "Safer Working at Heights: Exploring the Usability of Virtual Reality for Construction Safety Training among Blue-Collar Workers in Kuwait," *Safety*, vol. 9, p. 63, Sept. 2023.
- [12] J. T. Meyer, N. Tanczak, C. M. Kanzler, C. Pelletier, R. Gassert, and O. Lamercy, "Design and validation of a novel online platform to support the usability evaluation of wearable robotic devices," *Wearable Technologies*, vol. 4, p. e3, 2023.
- [13] L. Barešytė, S. Slatman, J. Austin, M. Rosema, I. van Sintemaartensdijk, S. Watson, and C. Bode, "Questionnaires for evaluating virtual reality: A systematic scoping review," *Computers in Human Behavior Reports*, vol. 16, p. 100505, Dec. 2024.
- [14] M. Tavakol and R. Dennick, "Making sense of Cronbach's alpha," *International Journal of Medical Education*, vol. 2, pp. 53–55, June 2011.
- [15] T. Schubert, F. Friedmann, and H. Regenbrecht, "The Experience of Presence," *Presence: Teleoperators and Virtual Environments*, June 2001. Publisher: MIT Press/PUB1010/Cambridge, MA, USA.
- [16] E. McAuley, T. Duncan, and V. V. Tammen, "Psychometric Properties of the Intrinsic Motivation Inventory in a Competitive Sport Setting: A Confirmatory Factor Analysis," *Research Quarterly for Exercise and Sport*, vol. 60, pp. 48–58, Mar. 1989.
- [17] J. Sauro and E. Kindlund, "Using a single usability metric (SUM) to compare the usability of competing products," in *Proceedings of the Human Computer Interaction International Conference (HCII)*, 2005.
- [18] R. A. Grier, A. Bangor, P. Kortum, and S. C. Peres, "The System Usability Scale: Beyond Standard Usability Testing," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 57, pp. 187–191, Sept. 2013.
- [19] K. Finstad, "The Usability Metric for User Experience," *Interacting with Computers*, vol. 22, pp. 323–327, Sept. 2010.
- [20] M. Hirota, K. Yada, T. Morimoto, T. Endo, T. Miyoshi, S. Miyagawa, Y. Hirohara, T. Yamaguchi, M. Saika, and T. Fujikado, "Objective evaluation of visual fatigue in patients with intermittent exotropia," *PLOS ONE*, vol. 15, p. e0230788, Mar. 2020. Publisher: Public Library of Science.
- [21] Y. M. Kim and I. Rhiu, "Development of a virtual reality system usability questionnaire (VRSUQ)," *Applied Ergonomics*, vol. 119, p. 104319, Sept. 2024.
- [22] M. Melo, G. Gonçalves, J. Vasconcelos-Raposo, and M. Bessa, "How Much Presence is Enough? Qualitative Scales for Interpreting the Igroup Presence Questionnaire Score," *IEEE Access*, vol. 11, pp. 24675–24685, 2023. Conference Name: IEEE Access.
- [23] M. Martínez Gutiérrez and J. Rafael Rojano-Cáceres, "Interpretation of the SUS questionnaire in Mexican sign language to evaluate usability an approach," in *2020 3rd International Conference of Inclusive Technology and Education (CONTIE)*, pp. 180–183, Oct. 2020.