Virtual Reality Simulations to Evaluate Readiness and Responsiveness for Fire Emergencies

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ABSTRACT

This study evaluated the potential of a three-dimensional gas power plant (GPP) simulation in an immersive virtual reality (IVR) environment for fire emergency preparedness and response (EPR).To this end, the study evaluated the feasibility of safety situational awareness, evacuation drills, and hazard mitigation exercises during a fire emergency simulation scenario. Additionally, the study assessed the environment's safety and ergonomics while addressing this goal. The virtual reality accident causation model (VR-ACM) was utilized for the assessment with 54 participants individually in IVR. Participants were divided into two groups based on whether or not they had prior engineering work experience. The results revealed that IVR can be realistic and safe.

Keywords:

Three-dimensional simulation; fire evacuation drills; ergonomics; simulation-based; immersive virtual reality; emergency preparedness and response

CHAPTER - 1

INTRODUCTION

Several compelling findings suggest that there has been a significant reduction in accident rates and an increase in safety awareness and litigation avoidance due to active and robust occupational safety practices. Such emergency practices play important roles by ensuring workers and employers are well-equipped and prepared for hazards. For this reason, industries and safety standards regard emergency preparedness and response (EPR) as key to safety countermeasures. Evidence also implies that the absence of safety training (ST), inadequate ST or a lack of relevant EPR contributes to increasing industrial injuries and fatalities during emergencies. This notwithstanding, exposing workers to hazardous situations in live sections can be dangerous and too costly. Consequently, the status quo of EPR logically, but rarely, involves practice by doing. However, immersive virtual reality (IVR) technology can present three-dimensional (3D) computer simulations of objects, processes, and events realistically for experiential and engaging encounters. IVR thus serves as a suitable option in situations that are either too expensive or impractical for direct hazard assessments necessary for EPR.

Grounded in methodologies, IVR thrives on the interest, realism, and enthusiasm that subjects experience during an immersive encounter. Furthermore, IVR provides real-time experience of computer-generated environments needed in simulation-based (SB) assessments. Coupled with this, the technology presents information retention capabilities and benefits of experiential learning that exceed traditional methods. Besides, evidence suggests that IVR is the best currently known method for assessments regarding hazard identifications and accident reconstructions. Accordingly, Dale's theory of the learning pyramid specifies between 75 and 90% absorption and retention as subjects 'practice by doing'. For this reason, research related to employee development places IVR assessments in the category of practice by doing. Thus, IVR serves as a useful alternative with captivating tasks towards enhancing EPR. For this reason, IVR is currently gaining popularity in education and industry for risk assessments, design reviews, and training Despite these growing potentials, applications of EPR are confined mainly to specific high-risk industries such as construction, mining, aviation, and healthcare.

Traditional EPR methods are limited to classroom learning, and this has disadvantages in realism and without response to interactions. Such traditional methods are rather common for risk assessments in gas power plants (GPPs), where the gas system has been noted as a high fire risk. Therefore, activities of EPR in conditions with no accidental exposure renders the practice minimally effective. This study therefore targeted investigating the prospects of EPR in a 3D simulation of a GPP in IVR.

CHAPTER – 2

LITERATURE REVIEW

The literature review delves into the realm of "Transforming industrial safety with AI" by exploring the historical context and limitations of traditional risk management methods. It extensively investigates recent technological advancements in AI and automation and their applications across various industries. The integration of AI in industrial safety, emphasizing risk assessment tools and predictive maintenance, is thoroughly examined. The role of automation in enhancing human-machine interaction for safer operations is explored, revealing existing gaps in the literature. The methodology section justifies the research approach, emphasizing data collection techniques. Industrial risk factors are identified and analyzed, supported by case studies illustrating real-world examples. The overview of AI and automation technologies relevant to risk reduction includes discussions on their advantages and limitations. The case studies section presents in-depth analyses of successful risk reduction through AI and automation. Proposed implementation strategies address factors like cost and adaptability. Ethical considerations regarding AI and automation in safety-critical environments are discussed. The conclusion summarizes key findings, identifies current challenges, and offers recommendations for future research, highlighting the imperative for industries to adopt AI and automation for comprehensive industrial risk management strategically.

CHAPTER – 3

METHODOLOGY

1.1. Research framework, hypotheses, and assessment model

This section explains our EPR assessment model, hypotheses, and research methodology, The model is built on a modified version of Bhide's virtual 3D emergency fire evacuation training design and is also based on Dhal Mahapatra et al.'s VR-ACM com- prizing SB modeling, recognition of impending hazards and, finally, assessments. Although the ACM was originally designed for accident investigations, the VR-ACM is as suitable for assessing awareness and preparedness for fire emergencies. consists of the following three parts and elaborates on our study methodology:

- identification (i.e., recognition of the problem, RQs, and hypotheses formulation);
- virtual environment, explaining the experiment procedure characterized by a maintenance task in IVR, accident causation, awareness of the situation, evacuation, and hazard mitigation in the GPP simulation;

➢ evaluation of the experience, where participants answer the 15-item questionnaire regarding the exercise.

The evaluation, firstly, assesses participants' levels of SA that answer RQ1 as stated in H_1 (see Section 3.5 for details of H_1–H_4). We adapted related questions from the SUSQ that are extensively utilized in analyzing SA. Next was the evaluation of H_2 in answer to RQ2, which assesses the effectiveness of FED and the hazard mitigation exercises in IVR. In this way, H_2 also evaluates the success or otherwise of the immersive exposure. The questionnaire for assessing H_2 was derived from Kirk-Patrick's three-stage model for evaluations. Thirdly, RQ3 seeks to discover the safety and ergonomics (SE) of the simulation environment as stated in H_3, and relies on the SSQ for measuring VR-induced symptoms and effects (VRISE). VRISE occurs if one exposed to a virtual simulation generates symptoms like motion sickness. The SSQ was designed by Kennedy et al. and measures three distinct factors: nausea, oculomotor disturbance, and disorientation. Notably, whereas the main hypotheses of this study (i.e., H_1, H_2, and H_3) focus essentially on SA, and FED with mitigation and ergonomics, and are related to the ACM in the immersive environment, the moderator hypothesis (H_4) relies on the independent variable work experience in engineering. Therefore, H_4 evaluates the differences in answers to RQ1, RQ2, and RQ3 between participants with engineering work experience and participants without any engineering work experience. Although literature served as the main source of information for this model, we were privileged to interview two experts in EPR about GPPs, on preparedness for emergencies and FED. Key issues obtained in the interviews highlighted gas leakage and the location of the main gas valve outside the plant.

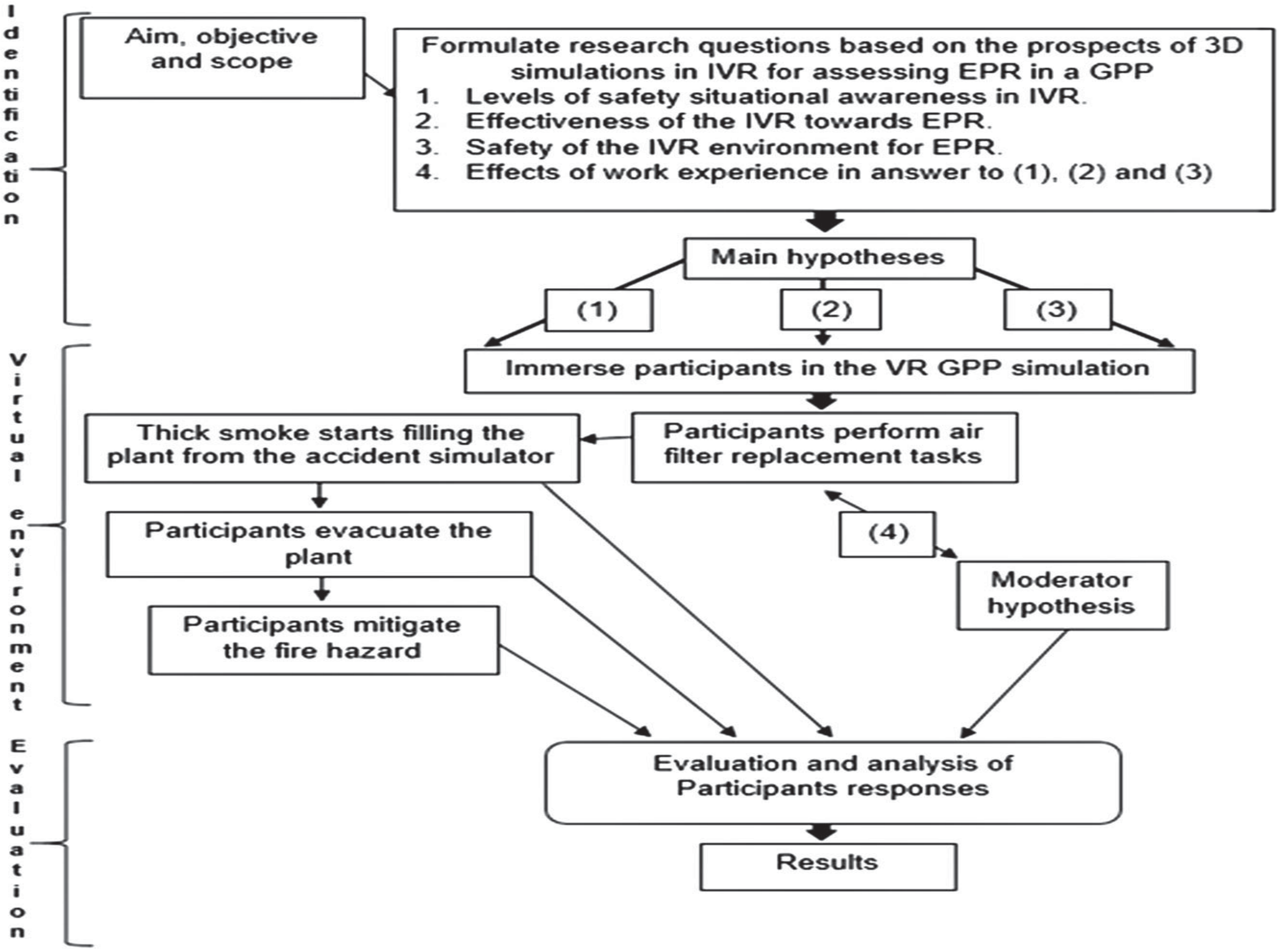

Figure 1. Conceptual model of the study.

NOTE:

3D = three-dimensional

EPR = emergency preparedness and response

GPP = gas power plant

IVR = immersive virtual reality

VR = virtual reality.

1.2. The 3D immersive environment

We developed our model for the plant with the aid of Fusion 360 version 2.0.9305 3D designing software and Unreal real-time game engine version 4.2 (UE4) that enabled creating simulations for the assessment. A Win- dows 10 Enterprise, 64-bit computer (ASUS, Taiwan) with an Intel Core i7-7700 Quad-Core processor at 3.6 GHz processing speed, having a GTX 1070 graphics card, pow- ered the simulation. Two base stations (HTC Vive, China) relayed the plant simulation for participants to experience full immersion through an HMD and hand-held controllers (HTC Vive, China) with gesture sensors. The 3D simu- lation environment constituted a conceptual power plant, powered by three gas-fired engines.

1.3. Assessment procedure

The exercise began by first explaining the IVR envi- ronment, the tasks for the assessment and the personal emergency evacuation plan (PEEP) individually to all participants and allowed questions. The explanation also covered the IVR techniques regarding the HMD, con- trollers and drills as well as the questionnaire based on the EPR. Participation was voluntary, and confidentiality of the participants' identity was guaranteed. Upon agreement, both researchers and participants signed the informed con- sent form. Consequently, we collected participants' demo- graphic information (Table 1) based on the anonymity and non-traceability criteria. Participants then wore the HMD head set, which allows 3D views of the simulated plant depending on the angle of sight. One of the participants had to discontinue the exercise after commencement since she could not see clearly through the HMD headset with- out her eyeglasses. The participants were then divided into the two groups according to their work experience in the field of engineering. This was because those who work in the engineering field are usually perceived to have some

Table 1. Demographic characteristics of study participants.

Demographic factor	Value
Age	18–28 years = 37 (68.52%),
	29–39 years = 13 (24.07%),
	39 years and older = 4 (7.41%)
	Females = 13 (24.07%),

Gender	males = 41 (75.93%)
Study level	First degree = 22, master's degree = 24,
Work experience	Participants without engineering work experience = 21 (38.89%), participants with engineering work experience = 33(61.11%)

1.4. Fire evacuation and mitigation assessments

The exercise in VR proceeded as follows:

- Both groups of participants were initially tasked with replacing the air filter of the third engine in the plant.
- During the filter replacement, the accident simula- tor triggered dense smoke because of fire eruption, which quickly populated the plant. This smoke was
- caused by gas leakage from the second engine in the plant.
- Upon sensing the emergency, participants were to evacuate the plant through the nearest door exit.
- After safely exiting the plant, participants were then tasked to isolate the power source by shutting the emergency valve.

These procedures were to be implemented through the premeditated PEEP, which incorporated identification of key escape routes with specific evacuation procedures and, finally, mitigation of the impending hazard. Detec- tion of fire was purely by the awareness of participants and the model purposefully omitted gas detectors, alarms and sirens. The reason for this was to test levels of SA at the onset of the fire hazard. The simulated smoke hazard was relevant to the awareness and preparedness for fire emer- gencies since smoke inhalation is attributed as the leading cause of death during fire outbreaks [11]. Secondly, early detection of gas leakage with subsequent mitigation is nec- essary in GPP EPR to avert the possibility of explosion. Evacuation from the plant (Figure 2) was possible with the aid of handheld controllers that enabled participants in the operating equipment to manoeuvre, walk and open doors in the plant. The second part of the assessment involved miti- gation of the fire outbreak. The mitigation process involved moving outside the plant and closing the gas valve as seen in Figure 3 to stop fuelling the ignited fire.

1.5. Data collection and analysis

The 54 students who took part in the assessment were from four universities in Vaasa, Finland (Table 1). We targeted four universities to obtain a wide diversity of participants. Table 1 also presents the demographics of the partici- pants who comprise the two groups: students without any engineering work experience; and students with some engi- neering work experience. The exercise took place between November 2018 and February 2020 at the Technoboth nia Virtual Reality Research and Development Laboratory, which is equipped with state-of-the-art equipment needed for the exercise. After performing the task outlined in Section 3.4, participants finally evaluated the prospects of the exercise as well as the SE of the IVR environment. Assessment was obtained on a 5-point Likert scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*.

1.6. Analysis of safety SA

SA in the context of occupational safety refers to the awareness of individuals to the surrounding conditions due to their ability in identifying potential risks and hazardous situations ahead of possible dangers [9]. Notably, SA is relevant in situations where quick information process- ing is vital with serious consequences for inaction or poor decisions [15]. The three levels of SA considered for this assessment, according to the SUSQ guidelines [24], consti- tute: level 1, perception potentials of hazardous conditions in the environment; level 2, comprehension of the condi- tion; level 3, links to future projections in the event of the perceived condition occurring. We posit the following in answer to the levels of SA that are attainable in the plant simulation as stated in RQ1:

➢ H_1: substantial levels of SA necessary for fire hazard recognition are attainable in an IVR GPP simulation environment.

➢ Measures: we measured participants' level of SA (Q1–Q5) by portions of the SUSQ that, as afore- mentioned, measures and ascertains the depth of presence and exposure in virtual environments [24]. Table 3 presents the data obtained for the SA. We obtained Cronbach's $\alpha = 0.725$.

1.7. Assessment of the evacuation exercises

The evacuation exercise consisted of three parts; recogni- tion, response and evacuation [7]. Participants rated their experience by their ability to evacuate from the plant from the time the fire broke out, by their ability to sense the danger and find the nearest exit for evacuation within the maximum evacuation time limit of 2.5 min as stipulated in the fire safety guides for factories and warehouses [39]. Closing the main gas valve (Figure 4) that pumps natu- ral gas to the engine successfully halts the fire hazard and concludes the assessment. In answer to RQ2 linked to the effectiveness of the evacuation and mitigation exercises, we hypothesize the following.

Figure 4. Completion of the EPR assessment.

Note: EPR = emergency preparedness and response.

- H_2: compelling fire evacuation and mitigation exer- cises are feasible in IVR GPP simulations.
- Measures: to measure the effectiveness of the evac- uation and mitigation drills in our questionnaire,

we derived Q6–Q10 (Table 4) pursuant to Kirk- patrick's three steps for evaluating successes or oth- erwise of exercises. The steps are reaction (level 1), learning (level 2) and behaviour and results (level 3) [40,41]. These steps have been employed for measuring experiential learning effectively in virtual emergency evacuation exercises. We obtained Cronbach's $\alpha = 0.705$.

1.8. SE of the assessment environment

We combined questions of possible SS and user friend- liness according to the SSQ to answer Q11–Q15. These questions, as explained earlier, consider disorientation and the oculomotor impact of VRISE as well as the ergonomics of the set-up. Oculomotor impact refers to fatigue, headache, concentration and the difficulty one encounters in focusing [23]. Besides, our simulation exper- iment was set up according to the health and safety instruc- tions of the HMD safety regulatory guide in compliance with protecting the safety and well-being of participants during immersive exercises. Adhering to these regulations is essential, considering that a technology employed for assessing and promoting safety needs to ensure substan- tial safety levels during the assessments. For example, improper adjustment of the VR headset to a 'bad fit' on participants can lead to blurred images and poor optical presentation, which increases VRISE [15]. Secondly, it was necessary to provide supervision and adequate guid- ance to participants during the exercise to prevent the immediate danger posed to participants. The immersed participants are blinded to the natural environments during

Variable	*N*	*M*	*SD*	Minimum	Maximum
Engineering work experience	54	0.611	0.492	0	1.000
Situational awareness	54	4.226	0.485	2.200	5.000
FED/hazard mitigation	54	4.293	0.449	3.200	5.000
Safety and ergonomics	54	4.226	0.396	3.000	5.000
Overall perception	54	4.248	0.354	3.200	4.867

Note: FED = fire evacuation drills.

fully immersive exercises and this can lead to crashes or falls [42]. Thirdly, the total assessment tasks were sched- uled to last less than 25 min per participant. This initiative was a measure we instituted in view of the positive cor- relation that exists between exposure time and VRISE [41]. The evaluation of SSQ and the ergonomics of the experiment answer RQ3, and we therefore posit:

- H_3: an IVR environment can be safe and ergonomi- cally viable for assessing fire EPR.
- Measures: we measured any possibility of VRISE and the simulation environment ergonomics with portions

of the SSQ [38]. Table 2 presents the descriptive statistics of measurements while Table 5 presents the results in answer to RQ3, which satisfies H3. We obtained Cronbach's $\alpha = 0.713$.

1.9. The moderating factor 'engineering work experience'

Whether a participant had some engineering work experi- ence or not was the key factor employed in moderating H_1, H_2 and H_3, which correspond, respectively, to SA, FED and mitigation, and SE of the simulation environment. The difference in the responses between the two groups answers H_4. It was necessary to analyse H_4 given the general notion that work experience influences the safety response [43].

1.10. Effects of engineering work experience on prospects of SB fire EPR

It is commonly believed that engineering work experience correlates positively to safety culture and safety behaviour

[4]. However, as previously noted, studies into the relation- ship between engineering experience and perception and the prospects of IVR towards EPR are silent. In unravelling this perception, we thus posit:

- H_4: participants with engineering work experience perceive IVR to be more beneficial for EPR than those without any engineering work experience.
- Measures: we measured the differences between the two groups by testing the independent-sample *t* test between the *M* of both groups for the three factors under consideration. This involves comparing the *M* results of H_1, H_2 and H_3, which represent SA, FED and mitigations, and SE, respectively, for both sam- ple groups. The obtained results answers H_4. Table 6 presents the outcome.

1.11. Assessment evaluation

We evaluated our model by analysing the responses to the 15 items presented in Tables 3–6. These tables answer H_1–H_4 according to RQ1–RQ4, respectively. Furthermore, we computed interaction effects of the independent variable 'engineering work experience' to test the simultaneous effects on the dependent variables SA, FED and mitiga- tions, and SE. This was for the purpose of evaluating the impact of the dependent variables on the indepen- dent variables [44]. We further computed the independent variables in two successive steps to control possible con- fusing effects. During evaluation, answers to Q14 and Q15 in Table 5 were reverse coded due to the nega- tive connotation present in the question format. SAS EG version .

Table 3. Results of SA for both participating groups

		Without WEE	(*n* = 21)		With WEE	(*n* = 33)
Safety	situational awareness	*M*	*SD*		*M*	*SD*
Q1	Presence levels in the simulation	4.095	0.625		4.061	0.747
Q2	Awareness levels while working	4.286	0.644		4.364	0.859
Q3	Awareness of the plant situation	4.524	0.602		4.333	0.854
Q4	Recognition of the fire hazard	4.238	0.539		4.061	0.789
Q5	Action upon recognition of hazard	4.191	0.602		4.182	0.528
Total		4.267	0.390		4.200	0.538

Note: SA = situational awareness; WEE = work experience in engineering.

Table 4. FED and mitigation results for both groups of participants.

	Without WEE	(*n* = 21)		With WEE	(*n* = 33)
Evacuation drills and mitigations	*M*	*SD*		*M*	*SD*
Q6 Personal emergency evacuation plan	4.286	0.717		4.212	0.740
Q7 Evacuation routes and signs during fire	4.333	0.483		4.182	0.846
Q8 Mitigation action to arrest the hazard	4.429	0.508		4.182	0.635
Q9 Applicability of skills to life situations	4.286	0.717		4.515	0.566
Q10 Interesting and engaging experience	4.286	0.644		4.273	0.626
Total	4.324	0.440		4.273	0.460

Table 5. Results of SE for the two groups.

Response to H_3: safety/ergonomics of the immersive exercises and environment

Safety and ergonomics		Without WEE (n = 21) *M*	*SD*	With WEE (n = 33) *M*	*SD*
Q11	Safety of VR technology/environment	4.143	0.478	4.152	0.619
Q12	Ease of the controls/navigation in the VR	4.476	0.680	4.364	0.549
Q13	Favourable learning conditions in the VR	3.952	0.669	4.152	0.566
Q14	Feeling uncomfortable during exposure	4.238	0.539	4.303	0.637
Q15	Feeling uncomfortable after exposure	4.143	0.655	4.273	0.452
Total		4.190	0.435	4.248	0.374

Note: SE = safety and ergonomics; VR = virtual reality; WEE = work experience in engineering.

CHAPTER – 4

RESULTS

This section presents the results of the three assessments as provided by the participants, which answer RQ1–RQ3 as hypothesized by H_1–H_3, respectively, and are moderated by RQ4 for H_4. These results are presented in Tables 2–5, which present the measured average values of responses for identifying the central position within each group of answers. Next, four independent-sample *t* tests were con- ducted to determine the similarities between the results of participants with some work experience and partici- pants without any work experience, which answers RQ4, as presented in Table 6.

Table 6. Results of independent-sample *t* tests between variables.

Variable	*M* of WEE	*M* of no WEE	Mdn	95%confidence interval	*t*	*df*	*p*
SA	4.200	4.267	0.067	[−0.207, 0.340]	0.489	52	0.627
FED	4.273	4.324	0.051	[−0.203, 0.308]	0.404	52	0.688
SE	4.248	4.190	0.058	[−0.281, 0.166]	−0.521	52	0.605
MOP	4.240	4.26	0.02	[−0.180, 0.220]	0.199	52	0.84

Note: FED = fire evacuation drills; Mdn = median; MOP = mean overall perception; SA = situational awareness; SE = safety and ergonomics; WEE = work experience in engineering.

1.12. Descriptive statistics

Table 2 presents the combined results for both groups regarding the *M* and *SD* of the empirical ranges for the key study variables of all 54 participants. The table also presents the results of the general impression of all respon- dents to the entire assessment at the overall *M* percep- tion row. We achieved a measure of reliability in internal consistency of 0.706.

1.13. Responses to the levels of SA

Table 3 presents the levels of SA in the immersive envi- ronment according to the SUSQ, which also elaborates the individual questions for SA and answers H_1. We also computed participants' preferences according to the Likert- scale items in percentages due to the low number of par- ticipants. Overall, 90.74% of responses from both groups combined scored 'strongly agree' or 'agree' to the ques- tions according to Table 3. Only 1.85% of the responses registered 'strongly disagree' or 'disagree', and 7.41% were undecided regarding the question which answers H_1.

1.14. Results of FED and mitigations

The results of the questions pursuant to the effectiveness of FED and mitigation drills for both groups of partici- pants are presented in Table 4. These questions concerned participants' interest, skill and knowledge acquired, which synchronizes to Kirkpatrick's three steps for evaluations and answers RQ2. The total responses of both groups to the questions presented in Table 3 and Table 4 represent the overall success or otherwise of the assessment regard- ing the effectiveness of IVR for EPR. The analysis of the results from Table 4 according to the independent-sample *t* test produced results of 0.404 with $p = 0.688$ (Table 6) for answering RQ4.

1.15. Results of SE in IVR

The results obtained from the questions related to SE according to H_3 answers RQ3, and Table 5 elaborates the SE of the entire IVR exercise. In this case, the results present findings on whether the simulation environment was safe for EPR. Specifically, Table 5 presents partic- ipants' perception of SS because of VRISE. This per- ception, as explained earlier in Section 3, assessed the three general categories of VRISE from the SSQ with the ergonomics of IVR.

Chapter- 5

Work experience in engineering on prospects of SB fire ST

Regarding H_4, which purports that participants' work experience in engineering affects their perception of the prospects of IVR for EPR, we conducted an independent- sample *t* test on all three dependent variables – i.e., SA, FED and mitigation, and SE – based on the independent variable 'work experience in engineering'. This analysis measures *M* of both groups for the three dependent vari- ables to determine whether evidence exists to suggest any significant differences between the perceptions of partic- ipating groups. We obtained the individual values of the three factors as presented in Table 6, with an overall $p = 0.843$ at a significant α level of 0.05.

2. Discussion

2.1. Examination of the obtained results

This section explains the results presented in Section 4 regarding the effectiveness of the IVR simulation environment for SA, preparedness and response for fire emergen- cies, and the possible effect of engineering work experience on the examined factors. These were investigated as SA, FED and mitigation, and SE during the assessment. The obtained results individually indicated that the main ingredients of a fire EPR plan – safety awareness, safety knowledge and safety mitigation skills – can be mimicked in a real-time IVR simulation environment for improving plant safety.

2.1.1. SA analysis in IVR

Referring to the results presented in Table 3 that answer RQ1 about feasible levels of SA necessary for fire detection, the overall *M* of 4.267 (from 1 = *poor* to 5 = *excellent*) implies that a high level of SA was experienced during the immersive encounter by both partici-

pating groups. These values do not also vary greatly from *M* according to the obtained total *SD* of 0.390 and 0.538, respectively, for both groups. This implies an appreciable level of agreement amongst participants, and also reflects significant comprehension between time and space for par- ticipants during the immersive experience, which affirms H_1, in answer to RQ1, that substantial levels of SA neces- sary for fire detection can be attained through a 3D simulation of a GPP in an IVR environment. SA was assessed based on the underlining factors of perception, comprehension and projection. These three factors are the main ingredient that the SUSQ assesses. The results also suggest that the plant simulation set-up provides an enabling envi- ronment for assessing risks and for recognizing hazards in the intended plant design. Besides, these results conform to previous findings in the field by, e.g., Slater et al. who employed the SUSQ to analyse the relationship that exists between physiological responses and breaks in the presence of 20 participants and found a significant difference between the experimental phase and the actual training. Similarly, Giglioli et al. compared the sense of pres- ence and performance with the SUSQ for subjects in an ecological task, while Lee Chang et al likewise anal- ysed the impact of simulation against lectures for training by employing the presence tool. This suggests that IVR

is feasible for SA and therefore applicable for EPR in a plant simulation. Such assessments are critical for ensur- ing safety in high-risk fire-prone facilities. The exercise has also enabled participants to understand the impor- tance of emergency preparedness, for maintaining high safety awareness of one's working environment. Implica- tions are that IVR can present 3D simulations realistically for experiencing hazardous situations necessary for EPR. Such situations make it possible to act accordingly and receive real-time response for learning, which hitherto was not possible with traditional classroom methods for comprehending SA during risk assessments.

2.1.2. Analysis of FED and the mitigation exercises

The results for H_2 with respect to RQ2 concerning the effectiveness of FED and the mitigation drills also indicate a positive trend. Primarily, the combined high *M* of 4.293 realized in Table 2 for both groups as well as the total *M* values of 4.324 and 4.273 presented in Table 4, according to the Likert scale from 1 to 5 based on Kirkpatrick's evaluation model, significantly indicate a positive trend. This suggests that the immersive environment can be effective for FED and mitigation, which thus confidently accepts and affirms H_2. The results also revealed that participants received full experience of close to real scenarios in a safe and controlled environment without any distractions while immersed. Besides, the exercise has demonstrated that sim- ulating a real plant fire hazard with immediate feedback for realizing the consequences of following or not follow- ing safety procedures provides the platform necessary for experiential learning. This implies that specific hazardous scenarios can be simulated for more critical IVR safety assessments before definitive construction of the intended facility. Moreover, the combined responses register that the immersive experience offers participants the privilege to prove their knowledge at the onset of a fire emergency and receive instant feedback. Furthermore, the immersive encounter has exposed participants to the need of preparedness for decisive actions during a fire emergency. These results are also consistent with research that employs IVR towards FED and mitigation, e.g., Smith and Ericson ,Tian et al., Torda ,Patel and Dennick ,and Lee Chang et al.

2.1.3. SE assessment of the IVR environment

This section explains the results obtained while assess- ing the SE of the IVR environment for EPR. Regarding the possibilities of VRISE, which answers RQ3, the *M* values of 4.190 and 4.248 obtained for both participating groups according to the SSQ results presented in Table 5 suggest appreciable levels of safety and ergonomic via- bility experienced by participants during the immersive exercise. These values were likewise obtained with the 5- point Likert scale as was employed in assessing responses

to RQ1 and RQ2. The values advocate participants' per- ception, which affirms H_3 that the immersive environment provided safe conditions with negligible effects of SS, usu- ally present in VRISE, and therefore is suitable for fire EPR. It is also necessary to explain that the high values obtained from participants presented in Table 5, regarding the safety of the VR environment, were partly due to the safety measures employed in the experiment.
The following explains the measures in accordance with the safety and regulatory guidance (HTC Vive, China) for the HMD headset. Firstly, we adhered to the minimum age of 18 years during our inclusion criteria, purposefully to prevented possibilities of seizures, which according to the manual are a factor common in children . Secondly, a virtual translucent wall in the immersion served as a guide to participants despite the physical guid- ance researchers provided for each participant throughout the exercise. This inherent feature in the HMD set-up is a safety guide for informing users of the safe area, in the actual world, to prevent the possibility of falling or crash- ing into an object. Thirdly, we ensured that the HMD was secured comfortably on each participant before running the simulation. This was to prevent poor optical presentation and blurred images since both factors increase SS. Simi- larly, we prevented hearing discomfort or loss by keeping the volume of the earpiece moderate, considering that lis- tening to loud sounds for a long time can damage the ear. We also limited the total exposure time to 25 min accord- ing to the HTC factory-recommended exposure time of less than 30 min per immersion with a 10-min break if needed. Additionally, we ensured that the headset was cleaned by sanitizing after every immersion, consid- ering that the HMD is usually worn tightly on the user's scalp. Adhering to these safety measures contributed to increasing the safety and eliminating the health and risks potentials of the IVR environment. It was interesting to note that, apart from one participant who had to pull out of the assessment due to an eyeglasses issue, the remain- ing 54 participants completed the assessment successfully. This, coupled with their tabulated responses, indicates that there were no substantive symptoms such as fatigue, nau- sea, drowsiness, increased salivation, visual abnormalities like eye strain and double vision or any symptoms similar to motion sickness.

Chapter - 6
Effects of engineering work experience

This section explains the results obtained for RQ4, which sought to compare the results between the two participating groups. To achieve this, we compared the *M* of SA, FED and mitigation, and SE representing H_1, H_2 and H_3, respectively, for both groups to determine any significant differences between their perceptions. For the SA, since $p = 0.6272$ (Table 6) is greater than $\alpha = 0.05$, we can con- clude that no differences exist between the perceptions of both groups regarding SA. Secondly, the results obtained for FED and mitigation provided $p = 0.688$, which is equally greater than $\alpha = 0.05$. This contrast also signifies no compelling differences between the two groups regarding answers to RQ2. Considering the results of SE, which answer RQ3, the obtained $p = 0.605$ in Table 6 is also greater than the significance $\alpha = 0.05$. This also indicates that no statistical differences exist between the perception of both groups to the levels of SE. Likewise, the over- all M perception of the combined responses of all three RQs, which answers RQ4, according to H_4, shows p = 0.843 which is much greater than the significance α = 0.05. We can therefore conclude that there are no significant differences in the perception between the two groups for all three factors under consideration. In this vein, H_4, which purports that work experience in engineering affects the perception of the prospects of IVR for EPR, lacks substance and we can therefore confidently reject that notion. However, these similarities signify that the application of 3D simulation in IVR for EPR is not only suitable for those who have prior safety engineering exposure, but is equally suitable for novices.

2.2. Results validity

We employed a purification process to check the construct validity of our results. Secondly, our data have undergone other purification processes comprising three stages:

- A check on the convergent validity; this was met since p values for all items presented in Table 6 were always high and significant. Besides, the standard errors of these items were relatively low.
- A check on discriminant validity based on the examined 95% confidence interval for each pair of constructs did not include 1.00 at any instant, as Anderson and Gerbing explain.
- We verified the construct reliability, which was sat- isfactory as all constructs evaluated exhibited Cronbach's α greater than 0.70. Collectively, the com- bined results demonstrate that common method bias was unlikely to be a cause for concern in the current study.

Furthermore, the results for H_1, H_2 and H_3 are consis- tent with IVR simulation in related research works, e.g., Bilotta et al. Bhide and Nedel et al. all of whom discovered that participants perceive SB fire evac- uations in immersive environments positively. Likewise, Rzez´niczek et al. and Borrego et al. produced appreciable values when evaluating the effects of VRISE during assessments by administering the SSQ.

2.3. Limitations of the study

This study has some limitations worth noting. As a latitu- dinal study, the research did not test participants' retention of lessons over any period. Several studies, e.g., Berg and Vance ,Bilotta et al. Lee Chang et al. and Cha et al. however, have conducted such longitudinal studies and there is therefore ample literature to support the superiority of participants' retention in the IVR envi- ronment over conventional classroom methods. Another limitation was that the detection of the fire hazard in the form of gas leakage that caused smoke in the simulation was possible only by sight and not by smell, and there- fore has the potential to limit SA in the IVR environment. Besides, the plant simulation eliminated some dynamic automated processes in an actual GPP that were not rel- evant to this assessment but could affect the overall plant EPR. Next, participants were able to move superficially in the plant simulation during evacuations by hurdling over objects and stairs as well as jumping from the first floor to the ground floor in seconds. This is a practice that is not feasible in reality. Despite these limitations, the study nonetheless offers valuable contributions for enhancing applications of IVR towards industrial fire EPR practices.

Contributions and implications

The study contributes practically and theoretically towards EPR in several ways:

- The study has demonstrated that participants in an IVR encounter of a 3D simulation environment can experience real-time emergency scenarios for safety preparedness and response at the factory concep- tual stages.

This is possible anywhere away from the location of the intended facility.

- By providing proactive emergency and realistic sce- narios, with engaging and interesting fire encounter, the study adds to research findings regarding IVR environments for enabling adequate preparedness and planning, which helps promote factory safety measures.
- Specifically, the study demonstrates the importance of safety SA for survival during plant fire emer- gencies. This underpins the essence of awareness of immediate threats even when engaged in factory demanding tasks.
- To the evolving scientific literature concerning the utilization of IVR for fire emergency awareness and response, the study demonstrates that realis- tic situations and environments are possible, and can therefore influence safety designs at the factory conceptual stages.
- Likewise, the study contributes to the prospects of SB risk assessments as well as plant hazard iden- tifications that are both key to EPR. According to Standard No. ISO 9001:2015 ,and Standard No. ISO 45001:2018,EPR ought to continuously improve for the purposes of promoting plant safety countermeasures .We are therefore confident that the findings presented in the experiment will spur detailed research in this direction.

Despite these potentials, and in view of the numer- ous limitations, however, the study does not propose that the application of IVR for fire EPR should be a complete alternative to the status quo of fire safety assessments. Rather, it should serve as a complement to traditional EPR assessments.

Chapter- 7
Conclusion

A VR-based fire emergency simulator has been developed and utilized in assessing the prospects of IVR for fire EPR. The model presents real-time 3D images, processes and interactivity necessary for experimentations during fire emergencies. The assessment constituted the following:

safety SA, which studied the capacity of the immer- sive environment in presenting realistic hazards regarding the perception, comprehension and inter-
pretation of a fire emergency;

- FED and mitigations, which assessed the viability of the immersive environment for EPR;
- SE of the IVR plant simulation environment.

The main purpose of the study was to examine the suit- ability of IVR for EPR. Two groups participated in the assessment: student participants with no engineering work experience; and student participants with some work experience in engineering. The reason for these groups was to analyse any differences in opinion for the three factors necessary for EPR. Results of the assessment revealed that, indeed, substantial levels of SA necessary for fire haz- ard identifications were feasible in IVR. This was because participants experienced appreciable levels of presence, interactivity and fire hazard mitigation during the assess- ment while immersed. Thus, our results conclude that the IVR technology is capable and suitable for revealing details of a plant design with the necessary dynamisms for fire EPR. Our experiment, notwithstanding, revealed no significant differences between perceptions of the two participating groups, which implies that the immersive technology is suitable for both groups equally for assessing EPR. The study also confirmed that a simulation envi- ronment can be safe and ergonomically suitable for fire emergency assessment provided the VR equipment, safety instructions, protocols and safety procedures are adhered to.

Suggestions for future research

In the future, we hope to extend a fully immersive VR- ACM for risk assessments and hazard mitigations in areas where the t echnology is lacking. We also hope to train two groups of participants in a prospective cohort study – one group in an actual factory and the other group in an immer- sive virtual environment of the same factory simulation – and verify the differences in safety culture immediately after training and over a period. The results will enable us to verify the applicability of the technology for more safety-related practices.

Disclosure statement

No potential conflict of interest was reported by the authors.

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