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Understanding VR-Based Construction Safety Training Effectiveness: The Role of Telepresence, Risk Perception, and Training Satisfaction

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Abstract: The use of virtual reality as a safety training technology is gaining attention in the construction industry. While current studies focus mainly on the development of VR-based safety training programs, studies focusing on improving its effectiveness is still lacking. Thus, this study aims to understand the psychological process of training transfer and determine the factors that affect VR safety training effectiveness. The study analysed survey data from 248 construction workers who finished construction safety training using VR using PLS-SEM. The results show that the telepresence experienced through the VR and the risk perception of the trainees regarding occupational accidents significantly affect their satisfaction with VR safety training, which affected its effectiveness. Considering that the use of VR in the construction safety training context is still in its early stages, the results of our study, which comprehensively analyses both the technological and psychological aspects of VR safety training, could provide meaningful implications to VR training content developers. Furthermore, the theoretical approach of our study could be implemented in future studies focusing on the topic of training effectiveness.

Keywords: virtual reality; telepresence; training transfer; training satisfaction; safety training

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1. Introduction

The construction industry often requires several workers to perform hands-on tasks to produce a final product. This makes construction workers especially vulnerable to occupational accidents, such as falling or electrocution [1]. According to a report from the Korean Ministry of Employment and Labor (MoEL), the construction industry recorded 9.41 accidents per 1000 workers in 2018, while the average rate for all industries was only 5.36 [2]. Furthermore, according to Zhao and Lucas [3], 80% of the occupational accidents in the construction industry are caused by human error, with at least 49% being due to unawareness or misjudgment, meaning that they are preventable.

Over the years, various efforts to improve the safety of construction workers have been made, one of them being the implementation of mandatory safety training. Since 2012, construction workers in South Korea have been obligated to complete a four-hour basic safety and health training. The training focuses mainly on introducing various hazards in a construction site and ways to prevent accidents from happening therein. The workers must also complete additional training every time they change workplaces or when they operate special equipment, such as excavators.

However, despite these training sessions and their content, the current safety training has not resulted in an improvement in accident rates in the construction industry. According to the Korean MoEL, the construction industry exhibited an increase in the number of accidents per 1000 workers from 7.48 in 2015 to 9.41 in 2018, in contrast with the downward trend of accident rates in other industries [2]. The increase in accident rate implies that the knowledge and skills garnered from the safety training are not being transferred to the workplace.

To enhance the effectiveness of safety training and promote safe working practices of construction workers, different training methods and technologies are being employed and tested with the current safety training. For example, advances in the IT sector have promoted the use of e-learning as a tool for safety training. Compared with the traditional training method, the use of e-learning has reduced training costs dramatically while the quality of the training has improved [4].

Recently, the e-learning trend has further advanced with the adoption of virtual reality (VR) technology. VR safety training allows construction workers to interact in a virtual environment using a head-mounted display and a controller [3,5]. This allows them to experience various workplace hazards and practice safe working procedures in a safe, controlled environment [6,7]. In addition, a systematic review of literature on VR/AR use in the educational context found that the use of VR/AR technology enhances interactivity, encourages collaborative learning, and increases learner satisfaction [8]. Furthermore, owing to the COVID-19 pandemic, the use of VR as a training tool is gaining attention because it can be conducted with minimal human contact [9].

Although the adoption of VR safety training in the construction industry is rapidly increasing, studies on understanding the factors that increase VR safety training effectiveness are still lacking. Some studies have focused on developing a VR training system and comparing its effectiveness to that of other training methods using ANOVA or a paired sample *t*-test as analysis methods; nevertheless, simply demonstrating that the VR method is more effective fails to explain the reason for its effectiveness. For example, Sacks et al. [10] found that trainees who completed VR safety training showed higher test scores for certain construction tasks compared with those who received traditional classroom training; however, the researchers failed to explain the reason for the effectiveness of the VR-trained group in selective tasks. This type of methodological approach to understanding effectiveness has led researchers to assert that research on training effectiveness lacks a theoretical basis [11].

Therefore, this study aims to employ a more theoretical approach to explain VR construction safety training effectiveness. Specifically, we utilize the technology acceptance model (TAM) to determine the specific features of VR safety training and risk perception toward occupational accidents that affect the workers' perception toward VR safety training and finally, training transfer. Consequently, we aim to provide timely implications for improving the effectiveness of construction safety training using VR.

2. Theoretical Background

2.1. Training Transfer

Training transfer is defined as the implementation of knowledge or skill obtained from the training to the actual workplace and is one of the primary criteria for evaluating its effectiveness [12]. Because the training of human resources requires investing a significant amount of both time and money, improving the transfer of training has been a persistent issue for both researchers and practitioners. More specifically, according to Baldwin and Ford [13], only 10% of the total investment in human resource training and development leads to the successful transfer of the training content. Increasing the overall transfer is particularly important, because the accident and fatality rate of construction workers remains high despite the government-mandated training.

According to prior studies, factors affecting training transfer can be broadly divided into two categories: individual factors and organizational factors. Individual factors are related to the trainees' characteristics or the characteristics of the training content. For example, job function, job position, or training satisfaction are some widely used individual factors that affect training transfer [14]. In contrast, organizational factors, such as transfer climate or organizational support, are related to the characteristics of the organization to which the trainee belongs [14,15].

However, because this study focuses mainly on identifying the characteristics of VR training that affect effectiveness, organizational factors are not of interest. Therefore, this

study develops a research model that focuses on identifying the individual factors and technological characteristics of the VR construction safety training that affect its effectiveness.

2.2. Modified Technology Acceptance Model

The TAM was developed by Davis in order to explain the effect of a user's beliefs on their attitude and behaviour regarding a new technology [16]. Specifically, the TAM explains that a user's perceived usefulness and ease of use of a new technology affects their attitude toward its use, which then affects their behavioural intention and actual usage behaviour.

TAM is one of the most powerful and commonly used theoretical models for explaining the adoption of new technologies. It has been utilized to explain and predict the adoption behaviour of e-commerce, ride-sharing services, and mobile-learning [17–19]. It has also been revised and extended in follow-up studies, leading to the development of modified models such as TAM2 and TAM3, which are intended to explain technology acceptance more effectively by adding factors such as subjective norm and self-efficacy [20,21]. Despite these moderations, perceived usefulness, perceived ease of use, behavioural intention, and acceptance/use behaviour remain the key constructs.

TAM itself, however, fails to consider the distinctive features of specific technologies and contexts. To overcome this shortcoming, researchers have extended the TAM by adding technological or usage-specific factors that affect the user's belief. For example, to study the acceptance of VR in aeronautical assembly tasks, Sagnier et al. [22] analysed the effect of technology-specific factors, such as pragmatic quality and hedonic quality stimulation. Similarly, to explain the use of ICT among senior citizens, Guner and Acarturk [23] utilized social influence, anxiety, and self-satisfaction as external variables affecting the user's perceived usefulness and perceived ease of use. Therefore, in the current study, we consider both technology-specific and usage-specific external variables that reflect the distinctive features of VR construction safety training.

Another shortcoming of the TAM is that in cases where technology usage is mandatory, such as a system mandated by company policy, predicting acceptance through usage intention is rather inadequate. In such cases where users were mandated to adopt a certain system, satisfaction was found to be an effective predictor of user acceptance or performance [24]. Therefore, because the adoption VR construction safety training is mandatory, we adopted training satisfaction as a predictor of user acceptance.

2.3. VR and Telepresence

Telepresence, defined as the feeling of being present in an environment constructed through certain communication media, is one of the key features that characterize VR [25,26]. In fact, Steuer [25] defined VR as "a real or simulated environment where the user experiences telepresence."

Furthermore, Steuer [25] introduced two dimensions that influence telepresence within the VR environment: vividness and interactivity. Vividness, also known as realness, is defined as the richness of the mediated virtual environment. The higher the number of senses the medium stimulates and the better the medium replicates the human sensory experience, the higher the vividness of the VR [27]. Interactivity is defined as the degree to which users of the medium can manipulate the mediated environment in real time. The faster the medium responds to the user's commands, the wider the range of manipulation. The more similar the response of the virtual environment is to that expected in the real world, the higher the interactivity [26]. That is, if users feel that they have control over their actions in the virtual environment, they experience a higher level of interactivity.

A number of studies have employed telepresence, vividness, and interactivity as key concepts for studying VR adoption. For example, Kim and Ko [28] studied the influence of the use of VR on flow experience and satisfaction. Their study found that users of VR showed a significantly higher level of vividness and interactivity compared with those of traditional 2D media, which led to a higher level of telepresence. They also found that

telepresence significantly impacted the users' flow experience, which affected their overall satisfaction. Other studies such as Jang and Park [29] and Wu et al. [30] found that display quality and interactivity positively affected the presence felt by the user, which affected their continued intention to use VR games and credibility of VR news.

In the construction safety training context, studies have not yet focused specifically on telepresence. Instead, most studies have focused on comparing the effectiveness of VR safety training and traditional training. For example, Sacks et al. [10] tested the effectiveness of a VR safety training system compared with that of the traditional training method. The results showed that while VR safety training showed higher test results for some tasks, such as stone cladding work, it had no observable advantages in overall safety training. Other studies, such as that by Zhao and Lucas [3], focused on developing and testing a VR training program for construction workers.

Because telepresence is a crucial factor that distinguishes VR training from the traditional classroom training method, understanding how it affects training effectiveness provides a key implication for our study. Hence, the two dimensions of telepresence are utilized as external variables of the TAM that affect the trainee's beliefs regarding VR safety training.

3. Research Model and Hypotheses

Prior studies on VR safety training have focused mainly on comparing the effectiveness of the VR training method with that of traditional methods. However, simply comparing the performance between different training groups fails to explain the reason for the effectiveness of one training method over another. This has been a major issue in studies related to measuring training effectiveness. Clark et al. [31] specifically mentioned that "without a theoretical basis for studying the techniques . . . researchers are often at a loss either to explain why they are effective or to predict their effectiveness in other settings".

Therefore, this study aims to provide an explanation for the effectiveness of the use of VR as a safety training tool. Specifically, by applying the TAM, we explain the effect of the characteristics of VR construction safety training on trainees' beliefs regarding VR safety training, which affect the trainee's satisfaction and the training effectiveness. Our research model is presented in Figure 1.

3.1. Modified TAM

The TAM posits that an individual's belief, specifically their perceived usefulness and perceived ease of use concerning a certain technology, affects their attitude, usage intention, and acceptance of the technology. The two cognitive beliefs presented in TAM are perceived usefulness and perceived ease of use, which are each defined, respectively, as "the degree to which a user believes that the use of a certain system would enhance their performance" and "the degree to which a user believes that using a certain system would be free of effort [16]".

Prior studies have confirmed the effectiveness of TAM when explaining and predicting acceptance of a newly emerging technology [32,33]. In a training or education context, TAM has been utilized to study an individual's intention to use e-learning or other newly introduced training tools. For example, Chang et al. [34] adopted the TAM to study the factors affecting students' intention to use e-learning. They found that although perceived ease of use had no significant effect on perceived usefulness, both perceived usefulness and perceived ease of use positively affected students' intention to use e-learning. Additionally, Wu and Vu [35] confirmed the positive effect of perceived usefulness and perceived ease of use on an aviation student's intention to use an augmented reality maintenance training system.

Additionally, in cases where technology adoption is mandatory, satisfaction was found to be an effective indicator of user acceptance. For example, to study the acceptance of web-based training among construction professionals, Park et al. [24] utilized user satisfaction as a variable replacing usage intention in the TAM model. Similarly, Nah et al. [36] applied

'symbolic adoption' as an alternative to usage intention regarding the acceptance of an enterprise system, and measured the construct through items such as 'I am excited about using the SAP system in my workplace'.

Therefore, based on prior studies, we defined perceived usefulness as the degree to which a trainee believed that the VR safety training would enhance their performance, and perceived ease of use as the degree to which a trainee believed that the VR safety training would be free of effort. Furthermore, based on studies employing the TAM as a theoretical basis for studying the acceptance of technologies in a mandatory setting, we present the following hypotheses:

H1. *Perceived usefulness has a positive effect on training satisfaction.*

H2. *Perceived ease of use has a positive effect on training satisfaction.*

H3. *Perceived ease of use has a positive effect on perceived usefulness.*

3.2. External Variables of TAM

3.2.1. Telepresence in VR

Telepresence is a multi-dimensional concept consisting of vividness and interactivity [25]. While vividness is determined by the sensory breadth and depth perceived by the user, interactivity is determined by the response speed, range, and mapping of the VR technology. In summary, higher levels of telepresence could indicate that the users perceived the virtual environment as reflecting the real world. Prior studies have utilized these two dimensions of telepresence to analyze its effect on flow experience or satisfaction [28].

Furthermore, recent studies focusing on the acceptance of VR or AR have utilized TAM, and they have observed the effect of telepresence on user belief. For example, a study on the acceptance of AR interactive technology, in which consumers were allowed to try on clothing products using AR, confirmed the significant effect of presence on the perceived usefulness and ease of use for both consumers with high and low cognitive innovation [37]. Similarly, Oh and Yoon [38] confirmed the effect of presence on perceived usefulness and perceived ease of use when adopting haptic enabling technology (HET), which allowed users to control a virtual environment using touch.

Therefore, to study the effect of telepresence on user beliefs in the VR construction safety training context, we present the following hypotheses:

H4(a). *Vividness has a positive effect on perceived usefulness.*

H4(b). *Vividness has a positive effect on perceived ease of use.*

H5(a). *Interactivity has a positive effect on perceived usefulness.*

H5(b). *Interactivity has a positive effect on perceived ease of use.*

3.2.2. Risk Perception: Perceived Vulnerability and Severity

Perceived vulnerability and perceived severity are each defined as an individual's perceived probability of a threatening event happening to them and the severity of the damage the event will cause to their life or health, respectively. In this study, these two constructs are defined as the probability of an accident occurring to the construction worker at their workplace, and the damage the accident would do to their health.

Perceived vulnerability and perceived severity are often used in research to study an individual's protective behaviour toward a certain threat. They are also often integrated with TAM as external variables affecting an individual's perceived usefulness toward a health-related technology. For example, Ahadzadeh et al. [39] found that perceived health risk, which is a multi-dimensional construct composed of perceived severity and perceived susceptibility, has a positive effect on perceived usefulness in the context of health-related internet use. Furthermore, Hansen et al. [40] found that perceived risk significantly affected perceived usefulness when studying consumers' intention to use

social media for transactions. Dou et al. [41] also confirmed the effect of perceived health threat on perceived usefulness in a study identifying the factors affecting the acceptance of M-health technologies.

Because construction workers are especially vulnerable to life-threatening accidents in the workplace, the level of risk perceived by the worker could have a significant effect on their perceived usefulness of VR safety training. If they consider themselves to be at risk of accidents, there is a higher chance they will think that the training content would be useful in keeping them safe. Therefore, the following hypotheses are presented:

H6. *Perceived vulnerability has a positive effect on perceived usefulness.*

H7. *Perceived severity has a positive effect on perceived usefulness.*

3.3. Training Effectiveness

Training transfer is one of the most widely used criterion for measuring training effectiveness. In several studies, training satisfaction was confirmed to be a significant predictor of training transfer [42,43]. Therefore, by integrating the TAM with the concept of training transfer, the following hypothesis is presented:

H8. *Training satisfaction has a positive effect on training transfer.*

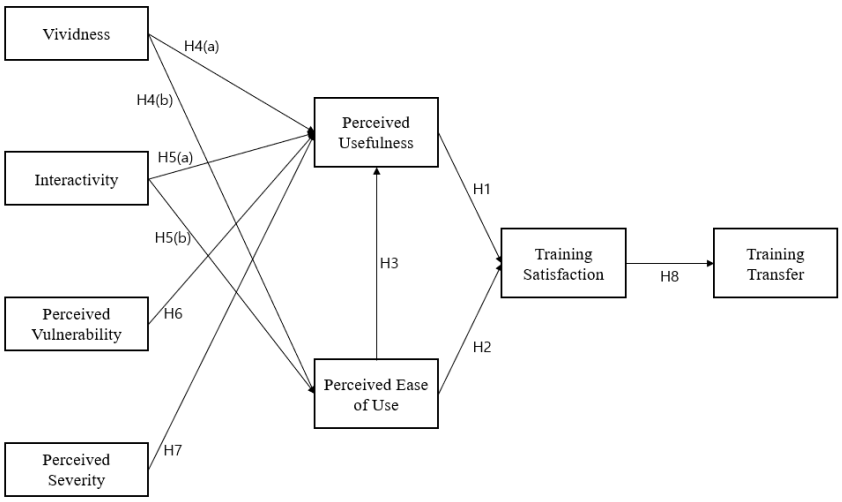


Figure 1. Proposed Research Model.

4. Materials and Methods

4.1. Survey Items

We adopted survey items from prior studies and modified them to fit our research context. The use of existing survey items assures its validity and accuracy since it has been vigorously tested after its development [44]. The items related to the TAM were adopted from Yoon and Kim [45]; Sun et al. [46]; Latif [47]; and Sun et al. [48]. Items for measuring interactivity and vividness were adapted from Kelley et al. [49]; and Yim et al. [50]. Perceived vulnerability and severity were measured using the items adopted from Yoon and Kim [45]; Sun et al. [46]; and Ahadzadeh et al. [39]. Finally, training transfer was measured using items from Gegenfurtner [42]. In addition, the items were revised through a pilot test to ensure content validity. The pilot test was conducted with 10 participants who completed the VR training. Items that did not meet the validity criteria were deleted in the final survey. All items were measured based on a 5-point Likert scale, ranging from 1 for 'strongly disagree' to 5 for 'strongly agree.' The survey items are presented in Table 1.

Table 1. Survey Items.

Variable	Measurement Item
Vividness	VI1. The contents of the VR safety training were very well-defined VI2. The contents of the VR safety training were very clear VI3. The contents of the VR safety training were very detailed VI4. The contents of the VR safety training were very vivid
Interactivity	IN1. I was in control of my navigation through the VR safety training IN2. I was in control of seeing the contents of the VR safety training IN3. I was in control over the pace of the VR safety training IN4. The VR safety training environment responded to my commands quickly and efficiently
Perceived Vulnerability	PV1. I am at risk of suffering from workplace accidents at the construction site PV2. It is likely that I will suffer from workplace accidents at the construction site PV3. It is possible for me to suffer from workplace accidents at the construction site PV4. There is a chance that I will suffer from workplace accidents at the construction site
Perceived Severity	PS1. If I were to suffer from workplace accidents at the construction site, the damage would be severe PS2. If I were to suffer from workplace accidents at the construction site, the damage would be critical PS3. If I were to suffer from workplace accidents at the construction site, the damage would be significant PS4. If I were to suffer from workplace accidents at the construction site, I will have difficulty with my work
Perceived Usefulness	PU1. The VR safety training will be helpful for staying safe at the construction site PU2. The VR safety training is effective for staying safe at the construction site PU3. Upon applying the knowledge and skills obtained from the VR safety training, I will be less likely to be injured at the construction site
Perceived Ease of Use	PEOU1. It is easy for me to complete the VR safety training and apply it to my work PEOU2. I have the ability to complete the VR safety training and fully apply it to my work PEOU3. I am able to complete the VR safety training and apply it to my work without much difficulty
Training Satisfaction	TS1. The VR safety training contents were relevant to the job I perform TS2. The VR safety training increased my understanding of the subject TS3. If I had an opportunity to undergo another safety training using VR, I would gladly do so TS4. Overall, I was very satisfied with the VR safety training
Training Transfer	TT1. I will try to transfer the knowledge and skills obtained from the VR safety training to the construction site TT2. I feel that I am able to use the knowledge and skills gained from the VR safety training at the construction site TT3. The VR safety training prepared me well for applying the related knowledge and skills at the construction site TT4. I will continuously use the knowledge and skills obtained from the safety training at the construction site

4.2. Sample

We conducted a survey in April and March 2021 on workers currently working at construction sites in South Korea. The survey was conducted in-person and prior to the survey, all respondents completed a VR safety training wherein they experienced common workplace accidents and were instructed in safe working procedures to prevent such accidents. The VR training was conducted using an Oculus VR HMD and the contents of the training were developed by the Korea Occupational Safety & Health Agency (KOSHA) [51]. An example of the VR screenshot is presented in Figure 2.



Figure 2. Example VR screenshot of the scaffolding task safety training (Source ref [51], 2019, Korea Occupational Safety & Health Agency).

After eliminating 22 samples with insincere or incomplete responses, a total of 248 samples were used for the final analysis, resulting in a 92% response rate, which is higher than the required rate of 80% [52]. Furthermore, according to Hair et al. [53], for our study to have a statistical power of 80% and a significance level of 5% with a minimum R^2 value of 0.25, it is recommended that we have at least 70 samples. Thus, sample size was not an issue in our study. The demographic characteristics of the respondents are shown in Table 2.

Table 2. Demographic Characteristics.

Classification		Frequency (N = 248)	Percentage (%)
Gender	Male	218	87.9
	Female	30	12.1
Age	20s	15	6.0
	30s	67	27.1
	40s	92	37.1
	50s	61	24.6
	60 and over	13	5.2
Experience in the construction industry	<1 year	18	7.3
	1–5 years	40	16.1
	6–10 years	45	18.1
	11–15 years	63	25.4
	16–20 years	54	21.8
	>20 years	28	11.3
Avg. working hours per day	<3 h	2	0.8
	4–8 h	145	58.5
	9–12 h	96	38.7
	>12 h	5	2.0

5. Results

We conducted partial least squares structural equation modelling (PLS-SEM) using the SmartPLS 3.0 program. PLS-SEM has advantages over traditional analysis methods because it allows for the assessment of measurement error and can predict latent variables using observed variables. In addition, it effectively analyses the causal relationship between several complex variables. Furthermore, compared to CB-SEM, PLS-SEM shows greater statistical power and is applicable when the structural model is complex [54]. Finally, the PLS-SEM method can analyse ordinal data, such as survey data, based on a Likert scale; this was also performed in our study [55].

5.1. Measurement Model Testing

Prior to hypotheses testing, we verified the measurement items by confirming their convergent and discriminant validity. Convergent validity is confirmed when (1) the factor loadings of the survey items exceed 0.7, (2) the average variance extracted (AVE) of the

constructs exceeds 0.5, and (3) the composite reliability (CR) and Cronbach's alpha exceed 0.7 [54]. Furthermore, discriminant validity is confirmed if the heterotrait–monotrait ratio of correlations (HTMT) for each construct is lower than 0.9 [54]. As shown in Tables 3 and 4, all the criteria for convergent and discriminant validity were met, confirming the validity of our measurement model.

Table 3. Convergent Validity.

Variable	Factor Loadings	AVE	CR	Cronbach's α
Vividness	0.784, 0.871, 0.888, 0.902	0.744	0.921	0.885
Interactivity	0.881, 0.902, 0.832, 0.790	0.726	0.914	0.875
Perceived Vulnerability	0.903, 0.942, 0.951, 0.954	0.879	0.967	0.954
Perceived Severity	0.967, 0.962, 0.962, 0.948	0.921	0.979	0.971
Perceived Usefulness	0.934, 0.942, 0.907	0.861	0.949	0.919
Perceived Ease of Use	0.936, 0.947, 0.940	0.886	0.959	0.936
Training Satisfaction	0.867, 0.878, 0.888, 0.875	0.769	0.930	0.900
Training Transfer	0.921, 0.925, 0.914, 0.882	0.829	0.951	0.931

Table 4. Discriminant Validity (HTMT).

	VI	IN	PV	PS	PU	PEOU	TS	TT
VI								
IN	0.744							
PV	0.097	0.131						
PS	0.180	0.179	0.556					
PU	0.521	0.443	0.069	0.260				
PEOU	0.487	0.487	0.094	0.185	0.775			
TS	0.701	0.677	0.155	0.171	0.642	0.585		
TT	0.638	0.533	0.069	0.165	0.588	0.588	0.757	

Furthermore, we tested for possible collinearity issues regarding our structural model. As shown in Table 5, all VIF values were less than 3, confirming that collinearity is not an issue [54].

Table 5. Collinearity Test (VIF).

	PU	PEOU	TS	TT
VI	1.903	1.772		
IN	1.867	1.772		
PV	1.408			
PS	1.449			
PEOU	1.362		2.074	
PU			2.074	
TS				1.000

Note: VI: Vividness, IN: Interactivity, PV: Perceived Vulnerability, PS: Perceived Severity, PU: Perceived Usefulness, PEOU: Perceived Ease of Use, TS: Training Satisfaction, TT: Training Transfer.

5.2. Hypotheses Testing

We tested our hypotheses using the PLS-SEM method. A bootstrap resampling procedure was performed to test the significance of the paths. The results, including the path coefficients and the overall explanatory power, are shown in Table 6.

Table 6. Results of the Hypotheses Testing.

Path	Hypotheses	Beta	Results	f^2
PU → TS	H1	0.403 **	Supported	0.125
PEOU → TS	H2	0.254 **	Supported	0.050
PEOU → PU	H3	0.621 **	Supported	0.642
VI → PU	H4(a)	0.160 *	Supported	0.031
VI → PEOU	H4(b)	0.303 **	Supported	0.070
IN → PU	H5(a)	0.008	Not supported	-
IN → PEOU	H5(b)	0.255 **	Supported	0.049
PV → PU	H6	−0.088	Not Supported	-
PS → PU	H7	0.155 *	Supported	0.038
TS → TT	H8	0.698 **	Supported	0.951

Note: * $p < 0.05$, ** $p < 0.001$. Note: VI: Vividness, IN: Interactivity, PV: Perceived Vulnerability, PS: Perceived Severity, PU: Perceived Usefulness, PEOU: Perceived Ease of Use, TS: Training Satisfaction, TT: Training Transfer.

The results of the hypotheses test showed that the effects of interactivity and perceived vulnerability on perceived usefulness were statistically insignificant at $p < 0.05$. Thus, H5(a) and H6 were rejected. However, all the other hypotheses were statistically significant and thus supported. Vividness (β = 0.160), perceived severity (β = 0.155), and perceived ease of use (β = 0.621) had a significant effect on perceived usefulness, whereas vividness (β = 0.303) and interactivity (β = 0.255) significantly affected the perceived ease of use. Moreover, both perceived usefulness (β = 0.403) and perceived ease of use (β = 0.254) significantly affected training satisfaction, which led to training transfer (β = 0.698).

Additionally, while H1, H2, H4(a), H4(b), H5(b), and H7 showed weak effect size (f^2 ≥ 0.02), H3 and H8 showed strong effect size (f^2 ≥ 0.35) [56]. The specific f^2 value of each hypothesis along with its significance is presented in Table 6.

Finally, the explanatory power (R^2) of perceived usefulness (R^2 = 0.559), perceived ease of use (R^2 = 0.258), training satisfaction (R^2 = 0.374), and training transfer (R^2 = 0.487) all exceeded the required threshold of 0.10, proposed by Falk and Miller [57].

6. Discussion and Implications

6.1. Discussion

By empirically testing our research model, this study aimed to identify the specific factors of the VR safety training that affected training transfer in the construction industry, thereby providing guidance for improving the effectiveness of the training. The following are some important findings based on the hypotheses testing results.

First, the constructs of the TAM, which are perceived usefulness, perceived ease of use, and training satisfaction, directly and indirectly act as significant predictors of training transfer. This confirms the usefulness and effectiveness of the TAM in predicting training transfer behaviour when implementing a new technology; moreover, this is consistent with the findings of Park et al. [24] and Granić and Marangunić [58]. Furthermore, the high explanatory power of the TAM constructs also supports the TAM's usefulness in our research.

Second, the two dimensions of telepresence, which are vividness and interactivity, significantly affected the trainees' perceived usefulness and perceived ease of use concerning the VR safety training. Specifically, while vividness influenced both perceived usefulness and perceived ease of use, interactivity directly affected only the perceived ease of use and indirectly affected the perceived usefulness. This result is somewhat consistent with the research of Oh and Yoon [38] and Grabowski et al. [59], which concluded that telepresence experienced while using HET significantly affects the perceived usefulness of HET. Thus, it could be concluded that the telepresence felt during the VR safety training had a significant impact on the trainee's belief regarding the training, which plays a critical role in increasing the effectiveness of the training.

Lastly, of the two external factors regarding the trainee's attitude toward accidents in the workplace, only perceived severity had a significant effect on perceived usefulness.

This is consistent with the result of Ahadzadeh et al. [39], who concluded that perceived health risk, which is a multidimensional construct composed of perceived severity and perceived susceptibility, has an effect on perceived usefulness in the case of health-related internet use. Therefore, instilling a sense of alarm, related to occupational accidents, to the trainees could increase the overall effectiveness of the VR safety training.

6.2. Implications

6.2.1. Theoretical Implications

This study provides an important theoretical contribution in that it analysed the impact of the use of VR technology on the effectiveness of safety training using the TAM as a theoretical basis. By developing a theoretical research model, we were able to overcome the lack of a theory-based approach to the topic of training transfer, which was pointed out by Kontoghiorghes [11]. Our TAM-based research model could be extended to other training/education contexts wherein a new technology is emerging as a training tool.

By analysing the survey data using a SEM-based approach, we were able to understand how the use of VR helps improve the effectiveness of VR safety training. Prior studies that simply compared the results of different training methods failed to explain or provide implications on how to improve effectiveness of a newly introduced method. However, the results of our study could be used for developing and further improving VR safety training content to increase the training effectiveness.

Finally, we utilize the concept of telepresence, which is the key characteristic that distinguishes VR technology from other media. By analysing the effect of the two main dimensions of telepresence, vividness, and interactivity, we were able to understand how each dimension affects the trainee's perception toward the training. The results of our study showed that although both vividness and interactivity are important, the vividness of the VR directly affects both the perceived usefulness and ease of use for the trainee, and these are critical factors that affect the effectiveness of the training.

6.2.2. Managerial Implications

Our study also has meaningful practical implications for VR safety training content developers and training instructors, particularly because the pandemic has caused a dramatic increase in the demand for training methods requiring less face-to-face contact.

The results of our study showed that a trainee's belief and attitude toward VR safety training plays a critical role in enhancing the training effectiveness. These factors are affected by the vividness and interactivity of the VR, along with the trainee's perception of occupational accidents and their own safety.

Therefore, first, content developers should focus on increasing the vividness and interactivity perceived by a trainee to increase the training effectiveness. Because vividness is determined by the sensory breadth and depth perceived by the VR user, developers could use high-definition images captured from a real construction site instead of the currently used animation-based content. Furthermore, newly emerging VR hardware, such as haptic suits that provide a feeling of pressure or vibration based on actions in the virtual environment, could be utilized to provide a richer sensory experience, further increasing vividness.

To increase the interactivity perceived by the trainee, a higher degree of freedom during the VR safety training should be provided to allow users to manipulate the virtual environment in real time. Although response time is not an issue for most VR systems, the current VR training system fails to provide users with a sense of control over the pace, navigation, and content while proceeding through the training. According to a study by Bailenson et al. [60], users who learned physical tasks on a VR training system reported a higher sense of interactivity when they were provided multiple viewing angles of themselves, such as a first-person view and a third-person view, in the virtual environment. Owing to the multiple viewing angles, users easily gained information and real-time feedback regarding their own movements, which gave them a sense of control over the

pace and navigation of their own body. Therefore, safety training content developers should provide features that allow users to switch between multiple viewing angles to increase their perceived interactivity, and thus increase training effectiveness.

Furthermore, allowing multiple trainees to interact with each other within the virtual environment could also provide a higher level of freedom and interactivity. The results of Vidal-Balea et al. [61] emphasizes the importance of shared experience among trainees on the effectiveness of an AR-based training. Because the construction industry often requires workers to work cooperatively on a single task, we believe that the development of a social VR training system could significantly improve the effectiveness of the VR safety training. However, to create a realistic social VR environment, advances in related technologies, such as VR cloud and 5G, must be preceded [62].

Both content developers and instructors should focus on increasing a trainee's perceived severity toward accidents at the workplace. This could be achieved by introducing not only accident cases and prevention methods, but also the aftermath of these incidents. Furthermore, the use of VR is likely to increase the severity perceived by the trainees because it provides a more realistic sensation compared with that experienced when simply viewing a training video.

Finally, because training satisfaction positively affects training transfer, instructors should keep track of the trainee's satisfaction level after the training. A survey that obtains trainees' opinion and improves the training based on the obtained feedback could help increase the overall satisfaction level of future trainees. Furthermore, a continuous survey may help eliminate the possibility of the Hawthorne effect, also known as the "novelty effect". The Hawthorne effect, occurs when a user is not experienced or familiar with a new technology, thus resulting in elevated levels of motivation and usability [63]. Since the effect is temporary, a series of surveys would allow instructors to gain a more accurate understanding of the VR training.

7. Conclusions

This study aimed to elucidate how the use of VR helps increase the effectiveness of safety training in the construction industry. We proposed a research model, based on the TAM, to examine the impact of technology- and usage-specific factors of VR safety training on the effectiveness of training. A PLS-SEM analysis of 248 construction workers in Korea was conducted. The results supported most of our hypotheses. Vividness, interactivity, and perceived severity had a significant effect on trainees' beliefs and attitudes concerning the VR safety training. Furthermore, the trainees' satisfaction regarding the training was crucial in increasing the transfer of the skills and knowledge obtained via safety training.

Our findings provide several meaningful implications for improving the effectiveness of a VR-based construction safety training. First, creating an immersive virtual environment that creates a feeling of telepresence is critical for enhancing training effectiveness. This could be achieved by providing various sensory stimulations through the use of haptic suits and other related technologies. Also, an interactive virtual environment with a high degree of freedom must be created. Finally, an effort to keep trainees interested and satisfied must be made by providing updates based on trainee feedback.

Although our study provided meaningful implications, it is not without its limitations. First, our survey was only conducted in Korea. Different countries have different training contents, work practices, and safety regulations. Thus, comparing different cultures may provide a more generalized result and new implications. Another shortcoming of our study is that we analysed a limited number of samples only consisting of construction workers. Future studies could conduct a multi-group analysis between workers and managers, or between construction tasks. Finally, our study fails to consider the possible bias caused by the novelty effect. To mitigate the novelty effect, future studies may need to provide tutorial courses so that the trainee is familiar with the VR before the training begins [64]. Also, a time-series analysis on training effectiveness may provide new implications while eliminating possible bias caused by the novelty effect.

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