

Research Article

Industry 4.0 in Nigeria: Key Drivers for Adopting Virtual Reality in Construction Workers' Safety Training

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Abstract

The Nigeria construction sites faces extremely high accident rates, which point to low safety performance, mainly resulting from training methods. However, the industry 4.0 technologies progression gave rise to the use of Virtual Reality (VR) for improved safety training on construction sites. Virtual Reality (VR) uses virtual information on a real-life scenario. The technology allows the use of three-dimensional (3D) models on real-time videos in a 3D visualization environment for effective safety performance on construction sites. Thus, provides a risk-free environment with worthy potential in ensuring construction workers are made more aware of their hazard identification capability on a construction site. Accordingly, this studies echoed the drivers for espousal of VR for workers' safety training in Nigeria construction sites. A sample of 200 experienced construction professionals, out of which 150 feedbacks from Quantity Surveyors, Engineers, Architects, and Project managers were retrieved. Subsequently, the responses from the construction professionals shows the dispersal of a data set. However, the significant values of Kolmogorov-Smirnov and Shapiro-Wilk exhibit $p > 0.05$, thus the data was assessed to be normally distributed, and acceptable for statistical analysis. Besides, the RII results shows that on average, six drivers for adopting virtual reality for workers' safety training in construction sites were identified. The EFA results shows that the drivers can be grouped into four; modernized safety features, regulatory and fiscal tools, user preferences inclusion, and performance optimization. Overall, the results indicates that to drive VR technology, workers should be adequately trained in safety awareness and critical decision making. Hence, it was recommended that the construction organization should espouse VR technology, and after-action review should be adopted in order to achieve effective safety training in construction sites.

Keywords

Construction Sites, Safety, Technologies, Three-Dimensional (3D) Model, Training, Virtual Reality, Workers

1. Introduction

The Nigerian construction sites is ranked one among the most hazardous industry [5]. This is due to the fact that its construction activities to a large extent is labour intensive,

which make the industry susceptible to accidents and injuries [12]. However, construction workers who play a key role in

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the construction activities are the major victims of these accidents. For instance, findings of [1] and [17] pointed out that not less than hundreds of construction workers died each year and many more rendered permanently disabled. This points to low safety performance, mainly resulting from training methods [4, 6]. Accordingly, studies have reiterated the need for safety training to enhance construction safety and lessen the occurrence of workplace hazards [27]. [25] claimed that safety training aims to minimize safety risks in construction sites through learning of identification of job hazards and safety risk assessment. However, the efforts of construction firms and other relevant stakeholders do not show any improvement in the workers' safety [3]. Though, contemporary studies have shown that using technologies to ensure safety on construction sites has become imperative to reduce fatalities [23, 24, 27, 28]. Similarly, [26] echoed that technology can create dynamic environments for safety training that cannot be realized through traditional methods alone.

Consequently, the industry 4.0 technologies engender the use of technologies, specifically laser scanners, sensor-based technologies, drones, wearable devices, Building Information Modelling (BIM), Virtual Reality (VR), and robots for improved safety performance on construction sites [3, 7]. Nevertheless, out of the safety technologies, Virtual Reality (VR) uses virtual information on a real-life scenario. The technology allows the use of three-dimensional (3D) models on real-time videos in a 3D visualization environment for effective safety performance on construction job site [2]. VR tool provides a feasible and risk-free environment for safety training with worthwhile potential in ensuring construction workers are made more aware of their hazard identification capability on a construction site. According to [18, 38], VR is effective in personalized safety training, translating to better safety site performance. [32] used 3D-immersive Virtual Reality (VR) to train students on in-situ concrete works, and found that employing VR in the training helps to maintain the trainee's awareness and thoughtfulness. This exhilarated the adoption of VR for safety training programs. Also, [10] focused on using VR technology in safety training for construction workers. The study developed a VR-based safety training system that simulated different hazardous scenarios on construction sites. The results showed that workers who received VR training had significantly better safety knowledge and skills than those who received traditional classroom training.

The important ingredient is that the construction worker is assessed to ascertain his strengths and weaknesses in a bid to communicate the requisite information and feedback. In addition, VR has proven to be efficient in identifying potential hazard spots and safety monitoring prior to the commencement of construction projects [39]. [23] stated that VR technologies suggest quality benefits in safety risk assessment, safety education and training, visualization, and communication for the reduction of accidents and hazards on construction sites. It is in this light that this studies seek to pin down the drivers for

adopting VR for workers' safety training in Nigeria construction sites,

2. Literature Review

Many researchers have reported drivers in adoption of VR for workers' safety training. For instance, [22] stressed that the development of VR platforms has improved practical usefulness of safety awareness, and with the technology becoming affordable, inclusive, or a low-end solution. This facilitated risky situations in the sites to be mimic, and positioned workers to deal with real-world situations [38]. Thus, adherence to procedures will prevent accidents from occurring in the construction sites. However, regulations from governments and institutions make it a requirement for safety training [11, 37]. Hence, upholding regulatory requirements will, therefore, provides maximum training efficiency [35]. Though, [13] emphasized on the stakeholder and regulatory pressure as essential to oblige organizations to adopt VR. Moreover, financial spurs, specifically subsidies and tax relief, expedite investment in VR technologies. This helps to absorb the initial shock, and support VR status in all other sectors [33]. Besides, the cost-effectiveness of VR is an aspect that supports its application in safety training. In contrast, the traditional practices involve vast investments in supply chain management, while, the VR component can be scaled up with the potential of ultimately reducing operating expenses [30]. Although, the VR component can be salvaged in other locations and sessions without idle time expenses, thereby exploiting training efficiency.

Similarly, organizations whose record of safety is a basis of success can heighten their image and competitiveness, by revealing evidence of investment in VR safety training [36]. Likewise, virtual realism heighten training efficiency because they can transfer procedural memory and manual abilities in a secure learning environment [19]. Also, the real-time feedback in VR systems help with incessant improvement, supporting trainees to develop their skills swiftly and efficiently [34]. Moreover, VR training information can aid organizations gain training interventions, improve performance, and unceasingly sustain worker's competencies [20]. Hence, personalized training programs are provided to showcase various trades and learning styles. This results in increasing VR attention and sustaining of safety training. Besides, the flexibility of VR training programs allows organizations to expand their skills development programs without any increase in the operational requirements or incur costs [16, 29]. VR emergency simulations train workers to handle crises with easiness, readiness and self-confidence [8, 9, 31]. Such ability does not only enhances worker's performance, but also heightens an organization's safety culture.

Based on the literature reviewed, thirteen (13) drivers of VR for workers' safety training were identified. These involve customization and personalization of training programs, government/organizational regulations and policies, realistic

training environments and high quality simulations, unveiling the cost effectiveness of VR, engage key stakeholders, industry collaboration, real-time/immediate training feedback and performance tracking for workers, showcase success stories of using VR, improvement in safety culture, focus on enhanced engagement and knowledge retention, enhanced accessibility for remote or distributed teams, demonstrate the positive impact on compliance, and scalability of training programs.

Accordingly, these drivers indicate that VR can transform safety from a responsive into a practical one. This aid organizations to create a culture in which safety is embedded in all trades. For organizations with a heavy focus on safety and operational performance, VR can be regarded as an enabling technology that meets regulatory requirements, maintains organizational affordability, and flexibility in the innovation-based global market.

3. Research Methodology

3.1. Research Strategy

Based on the studied literatures on the drivers of VR for safety training, five point Likert scale structured questionnaire was prepared. Moreover, content validity of the questionnaire

was weighed before its final approval for pilot study. Consequently, a pilot study of thirty (30) construction professionals was conducted, and Cronbach's Alpha coefficient test was employed for evaluating the reliability of the questionnaire. In this study, the values of Cronbach's Alpha coefficient for the construct as well as the variables confirmed good reliability (more than 0.70 threshold). This also affirmed that the dataset can be measured on the same latent trait and scale. Subsequently, 200 practicing construction professionals involved in designated projects within F.C.T, Abuja were directly targeted in the questionnaire administration, encompassing 50 each of Quantity Surveyors, Structural Engineers, Architects and Project Managers, out of which 150 (75%) responses were retrieved.

However, the responses from the construction professionals shows the dispersion of a data set. Therefore, normality tests was performed to check the distribution of the data set [28]. Kolmogorov-Smirnov and Shapiro-Wilk was employed to assess the normality of the distribution of scores. A non-significant result ($p > 0.05$) indicates normality. Similarly, skewed value '0' of a normal distribution is often not commonly obtained in social research like this study. A limit of ± 1 is considered acceptable for both the skewness and kurtosis [14]. The summary of Kolmogorov-Smirnov, Shapiro-Wilk, skewness, and kurtosis of the responses for the variables are contained in Table 1.

Table 1. Summary of statistical results from normality test.

Sample groups	Kolmogorov- Smirnov		Shapiro- Wilk		Skewness	Kurtosis
	Statistics	df	Statistics	df		
QS	0.36	40	0.85	40	-0.35	-0.57
Engrs	0.37	41	0.87	41	-0.38	-0.66
Arc	0.35	35	0.84	35	-0.31	-0.54
PM	0.33	34	0.82	34	-0.29	-0.53

*Kolmogorov- Smirnov/Shapiro- Wilk > 0.05 .

From Table 1, the summary of significant values of Kolmogorov-Smirnov and Shapiro-Wilk is above 0.05 level of significance ($p > 0.05$). Besides, skewness and kurtosis fall within the acceptable limit of ± 1 . The data were thus assessed to be normally distributed, and acceptable for statistical analysis.

3.2. Relative Importance Index (RII)

This section resonances the RII results of the drivers for integrating virtual reality for workers' safety training in construction sites. The performance of each variable was evaluated based on the RII of each variable.

From Table 2, the RII results was arranged from the utmost

to the lowermost. Unveil the cost effectiveness of VR was ranked 1st, followed by realistic training environments and high quality simulations. Customization and personalization of training programs was ranked 3rd, while real-time/immediate training feedback and performance tracking for workers was ranked 4th. The 5th ranked was engage key stakeholders. Industry collaboration was ranked 6th. Moreover, government/organizational regulations and policies, and improvement in safety culture were ranked 7th. Focus on enhanced engagement and retention was ranked 9th, enhanced accessibility for remote or distributed teams was ranked 10th, and conduct pilot programs was ranked 11th. Whereas, showcase success

stories of using VR was ranked 12th, and demonstrate the positive impact on compliance was ranked 13th.

Table 2. *RII of drivers for integrating virtual reality into workers' safety training in construction sites.*

Drivers	RII	Ranking
Unveil the cost effectiveness of VR	0.875	1 st
Realistic training environments and high quality simulations	0.850	2 nd
Customization and personalization of training programs	0.825	3 rd
Real-time/immediate training feedback and performance tracking for workers	0.813	4 th
Engage key stakeholders	0.788	5 th
Industry collaboration	0.775	6 th
Government/organizational regulations and policies	0.763	7 th
Improvement in safety culture	0.763	7 th
Focus on enhanced engagement and knowledge retention	0.713	9 th
Enhanced accessibility for remote or distributed teams	0.710	10 th
Scalability of training programs	0.706	11 th
Showcase success stories of using VR	0.703	12 th
Demonstrate the positive impact on compliance	0.695	13 th
Total	9.979	
Average RII	0.768	

Consequently, in order to have a general agreement in the ranking of all the drivers, average mean was calculated and was used to quantitatively measure the agreement in the importance ranking among the construction professionals. In relation to the average mean, [21] marks the cut-off levels for interpretation as follows; “Unimportant” (points falling beneath the average mean) and “highly important” (points falling above the average mean). This interpretation implies that the result which fall under “unimportant level” should be dismissed, as it does not represent the perceptions of the respondents. While, the results in “highly important level” indicates how much more a variable is important to the respondents.

Based on the outcome, 6 drivers; unveil the cost effectiveness of VR, realistic training environments and high quality simulations, customization and personalization of training programs, real-time/immediate training feedback and performance tracking for workers, engage key stakeholders, and industry collaboration.

The results shows unveil the cost effectiveness of VR as the topmost driver for adopting virtual reality into workers' safety training in construction sites. This agrees with the contention of [33] who stressed that VR platforms should be made cost affordable, accessible, and with increased functionality. Realistic training environments and high quality simulations was

also revealed as the driver, which is in line with the opinion of [15] who focused on the use of VR-based immersive simulations for safety training programs, where workers can easily practice their trades in a safe environment, thereby improving their awareness when replicating such activities in the tangible reality.

The result also show customization and personalization of training programs. This was corroborated by [29] who asserted that comprehensive safety training programs equip workers with the necessary knowledge and skills to identify potential hazards. Real-time/immediate training feedback and performance tracking for workers was also revealed as one of the drivers. [19] acknowledged that real-time/immediate training feedback and performance tracking can facilitate workers to share hazard insights, which enables bottom-up input of ideas and lessons learned.

Engage key stakeholders was also ranked as one of the drivers for adopting virtual reality for workers' safety training in construction sites. This finding agrees with the contention of [13] who affirmed that stakeholder involvement is of principal importance to oblige organizations to adopt VR. Besides, the result shows industry collaboration as an important driver. [13] recognized that industry collaboration is significant for devel-

oping practical, evidence-based practices, which foster continuous improvement, and establishing a strong, shared safety culture across organizations.

3.3. Exploratory Factor Analysis (EFA)

EFA was employed to reveal the major structure and principal correlations present within the set of variables. The suitability of the construction professionals' responses was examined using Kaiser-Meyer-Olkin (KMO) estimate of sampling adequacy. The data revealed suitability for conducting factor analysis, while, Bartlett's test of sphericity is remarkably significant for determining the degree of correlation between the variables. The findings show that 82.4% of the gathered data are suitable for factor analysis (KMO = 0.824). Additionally,

the p -value is below 0.05, indicating that the data are acceptable for factor analysis. Furthermore, Bartlett's test shows the correlation matrix (p -value = 0.000), and revealed that exploratory component analysis is suitable as all the listed items have a significant correlation at the 5% level. Table 3 revealed the rotated component matrix of the drivers for adopting virtual reality for workers' safety training in construction sites. In Table 3, the highest factor loading is selected from the rows, which automatically falls under a group. Besides, the variables are strewn into four groups of factor components. According to the factor grouping, each variable only has a significant effect on one of the groups. The identification of the groups is subjective since it relies on the common relationship of the variables.

Table 3. Rotated components matrix for the drivers.

Drivers	F1	F2	F3	F4
Unveil the cost effectiveness of VR		0.875		
Realistic training environments and high quality simulations				0.850
Customization and personalization of training programs			0.825	
Real-time/immediate training feedback and performance tracking for workers	0.813			
Engage key stakeholders				0.788
Industry collaboration				0.775
Government/organizational regulations and policies		0.763		
Improvement in safety culture				0.763
Focus on enhanced engagement and knowledge retention	0.713			
Enhanced accessibility for remote or distributed teams			0.710	
Scalability of training programs	0.706			
Showcase success stories of using VR	0.703			
Demonstrate the positive impact on compliance		0.695		

According to the EFA results, the drivers for integrating virtual reality for workers' safety training in construction sites are clustered into four major groups based on the respondents responses; modernized safety features (F1), regulatory and fiscal tools (F2), user preferences inclusion (F3), performance optimization (F4).

The first group (modernized safety features) accounts for 29.46% of the total variance with four drivers that is, real-time/immediate training feedback and performance tracking for workers, focus on enhanced engagement and knowledge retention, scalability of training programs, and showcase success stories of using VR. All the variables received higher factor. This echoes with a drive to position VR as a key tool for building a robust safety culture. The application of VR is a

shift in how safety is thought about and implemented within the industry, as validated by [11], which acknowledged that progresses in safety technology are accountable for improving the construction organization's safety culture.

The second group is regulatory and fiscal tools. This group make up 23.38% of the total variance with three drivers; unveil the cost effectiveness of VR, government/organizational regulations and policies, and demonstrate the positive impact on compliance. All the variables received higher factor. This finding agrees with the contention of [13] who affirmed that while some sectors have already embraced VR in training, construction organizations may need further support in adopting this practice completely.

The third group is user preferences inclusion. This group

constitutes 15.38% of the total variance with two drivers namely, customization and personalization of training programs, and enhanced accessibility for remote or distributed teams. This concurs with studies conducted by [29] who established that VR can bridge differences between distant groups. Customization and personalization of training programs reflects the growing demand for competency-based training solution that respond to the specific needs of different trades and groups. The adaptability of VR allows it to advance training programs addressing the specific concerns of various workers, thus improving the effectiveness of the overall training.

The fourth group is performance optimization. This group form 31.83% of the total variance with four drivers namely, realistic training environments and high quality simulations, engage key stakeholders, Enhance construction scheduling, industry collaboration, and improvement in safety culture. All the variables received higher loading. [15] emphasized that VR allows workers to undergo targeted training sessions, which enable workers to learn more content in limited time compared to traditional methods. This is beneficial in the construction industry, where downtime must be kept to a minimum.

4. Conclusion

From the results obtained; unveil the cost effectiveness of VR, realistic training environments and high quality simulations, customization and personalization of training programs, real-time/immediate training feedback and performance tracking for workers, engage key stakeholders, and industry collaboration are identified as the drivers for adopting virtual reality for workers' safety training in construction sites in Abuja. This results shows that better training in VR positioned workers well to deal with real-world situations. Moreover, the EFA results shows that the drivers are gathered into four major groups based on the respondents' responses; modernized safety features (F1), regulatory and fiscal tools (F2), user preferences inclusion (F3), performance optimization (F4). This results is due to the fact that to drive VR simulation, workers should be adequately trained in sensitivity to the safety environment, thus lowering the accident rate and guaranteeing workplace safety standards.

5. Recommendation

Based on the above findings, the following recommendations were made;

- 1) The construction organization should espouse VR technology in improving safety training in construction sites.
- 2) Appropriate VR approaches be adopted for evaluating and getting feedback for the purpose of achieving effective safety training in construction sites.

- 3) Safety training is a concerted effort of both the government, associated construction professionals and the contractors. Hence, there is need for mindset shifts in the safety training in construction sites.

Largely, this study can be adopted by the construction industry as a guide in handling workers' safety training, which will go a long way to affect productivity, work quality, projects duration, sites accidents and overall construction project delivery. This will thus help enhance workers commitment in the construction industry.

Abbreviations

BIM	Building Information Modelling
EFA	Exploratory Factor Analysis
KMO	Kaiser Meyer Olkim
RII	Relative Importance Index
3D	Three Dimensional
VR	Virtual Reality

Author Contributions

Mohammed Isah Leje: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing

Aminu Mubarak Sadis: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation

Aisha Onyiahinoyi Abubakar: Conceptualization, Data curation, Formal Analysis, Project administration, Resources, Software

Conflicts of Interest

The authors declare no conflicts of interest.

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