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Drivers of the Integration of Virtual Reality into Construction Safety Training in Ghana

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Abstract: The utilization of virtual reality (VR) in safety training in the construction industry is increasingly driven by the requirement to enhance both the level of safety and the effectiveness of safety training. The research takes a quantitative approach toward the determination and exploration of the determinants for VR uptake for safety training. Standardized questionnaires were distributed to sample a cross-section of Ghanaian construction professionals to find areas of commonality regarding the drivers of VR use in construction safety training. Technological advancement and boosting the culture of safety were found to be the highest drivers based on exploratory factor analysis (EFA). Technological advancement and boosting safety culture are the two highest drivers the research recommends. Technological advancements facilitate the creation of realistic simulation and training environments, significantly enhancing the learning process. The improvement in safety culture is facilitated by VR-based training, which renders safety proactive and enables a higher level of knowledge retention through frequent safety-free simulations. This study provides industry stakeholders with valuable insights into how the advantages of VR applications should be maximized to enhance the level of safety standards and train efficiency. The findings provide a foundation for formulating new ways to effectively utilize VR in safety training construction industries of developing nations.

Keywords: virtual reality; construction industry; safety training; training effectiveness; data-driven insights; EFA

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1. Introduction

The use of virtual reality (VR) in safety training has been a groundbreaking innovation across various industries, transforming the traditional training model [1]. The relevance of VR technology lies in its ability to deliver an immersive and interactive learning experience that surpasses the limitations of traditional methods, enabling trainees to interact with real-world environments and hazardous conditions without physical risks [2]. This capability enhances engagement and ensures standardized learning outcomes for every trainee; it is a valuable factor in domains where standardized safety protocols are necessary. The development of VR platforms has increased functionality, with the technology becoming less expensive and more accessible [1]. Combining this with the ability to mimic

risky situations in a controlled environment provides better training in which employees are well-positioned to deal with real-world situations. Regulations from governments and institutions make it a requirement that safety training be conducted using VR technology, as adherence to proper procedures will prevent accidents from occurring in the workplace [3,4]. Compliance with the law is, therefore, possible through the simulation of dangerous situations in a safe environment that provides maximum training efficacy. Financial incentives, especially subsidies and tax relief, facilitate investment in VR technologies, help absorb the initial shock, and support their rise in popularity in all other sectors [5,6]. Such poor performance also incorporates low safety statistics, mainly resulting from previous training methods in all high-risk sectors such as construction and manufacturing businesses [7,8]. It is these loopholes that VR simulation addresses in order to ensure workers are adequately trained in decision-making and sensitivity to the safety environment, thus lowering the accident rate and guaranteeing workplace safety standards [9,10]. Cost-effectiveness is also an aspect that supports the application of VR in safety training. In contrast to traditional practices involving huge investments in materials and logistics, the VR module can be scaled up with the potential of reducing operation costs in the long run [9,11]. Although initially designed, the modules can be recycled in other locations and sessions without extra downtime costs, thereby maximizing training efficiency to the maximum. Stakeholder pressure, i.e., investor pressure, customer pressure, and regulatory pressure, is of central importance to compel organizations to adopt novel solutions like VR [12–14]. By displaying evidence of investment in technology and safety, businesses can enhance their reputations and competitiveness, particularly firms in which the record of safety is a determinant of success [13]. High-fidelity simulation realism and virtual worlds enhance training efficiency because they can transfer muscle memory and skills by hand in a secure learning environment [15,16]. The immediate feedback mechanisms in VR systems help with continuous improvement, enabling trainees to develop their skills rapidly and efficiently [17,18]. Moreover, through the use of information from VR training, organizations can tailor training interventions, improve performance, and continuously sustain employee competencies [19,20]. Another advantage of VR accessibility is its ability to reach distant or geographically dispersed teams, with impartial training experience [15,21]. Individualized training schedules are provided to accommodate various job positions and learning styles. This results in increased interest and retention of safety practices. The scalability of VR training programs allows organizations to expand their training programs without any corresponding increase in the logistical needs or costs incurred [22,23]. VR emergency simulations train employees to handle emergencies with ease, enhancing readiness and confidence without ever placing them at risk [24,25]. Such capability not only enhances performance at the individual level but also enhances an organization's safety culture and resilience. By bringing safety awareness into daily practice routines through immersive training, VR creates an organizational culture in which safety is embedded at all layers. One can say that the concept of employing VR in safety training is a benchmark over the others, offering unmatched benefits in terms of engagement, effectiveness, and thriftiness. For organizations with a strong emphasis on safety and operational performance, VR can be viewed as an enabling technology that not only meets regulatory requirements but also maintains organizational competitiveness and resilience in the innovation-based global market, on the basis of safety standards. Table 1 provides an overview of the literature on potential drivers (labeled as DR-1 to DR-17) of VR in construction safety training.

Table 1. Summary of the literature on drivers of VR integration in construction safety training. **S/N**.

S/N	Drivers of VR Integration for Safety Training in the Construction Industry	Authors
DR-1	Technological advancements in industry	Onyesolu & Eze, 2011 [1]
DR-2	Government/organizational regulations and policies	Dhalmahapatra et al., 2022; Torres-Guerrero et al., 2020; Shi et al., 2023; Sadeghi et al., 2022 [3–6]
DR-3	Underperformance of safety statistics (number of injuries to enforce improved training standards)	Nickel et al., 2013; Sacks et al., 2013; Avveduto et al., 2017; Huang et al., 2022 [7–10]
DR-4	Cost of safety training	Pedram et al., 2021, Avveduto et al., 2017 [9,11]
DR-5	Stakeholder pressure	Mossel et al., 2015; Lawson et al., 2015; Ghobadi & Sepasgozar, 2020 [12–14]
DR-6	Competitive advantage	Baceviciute et al., 2022; Bao et al., 2024 [26,27]
DR-7	Realistic training environments and high-quality simulations	Smith et al., 2020; Johnson & Brown, 2021; Lee et al., 2019 [15,16,28]
DR-8	A risk-free environment compared to real-world training	González-Franco & Lanier, 2017; Mikropoulos & Natsis, 2011 [2,29]
DR-9	Real-time/immediate training feedback and performance tracking for workers	Bell & Federman, 2013; Boud & Molloy, 2013 [17,18]
DR-10	Data-driven insights	Chan et al., 2010; Rosen et al., 2008 [19,20]
DR-11	Enhanced accessibility for remote or distributed teams	Smith et al., 2020; Johnson & Miller, 2021 [15,21]
DR-12	Customization and personalization of training programs	Anderson et al., 2019; Lee & Kim, 2020 [30,31]
DR-13	Engagement and retention of training content	Bailenson et al., 2018; Fernandez, 2019 [32,33]
DR-14	Scalability of training programs	Huang & Liaw, 2018; Patel et al., 2019 [22,23]
DR-15	Reduction in training time	Waller & Cannon-Bowers, 2019; Buttussi & Chittaro, 2018; Kothgassner et al., 2019; Dede, 2009 [34–37]
DR-16	Simulation of rare or high-risk scenarios	Rizzo et al., 2017; Bruder et al., 2019 [24,25]
DR-17	Improvement in safety culture	Bohle & Quinlan, 2020; Lucas et al., 2018 [38,39]

2. Materials and Methods

To accomplish the goals of this research, a questionnaire survey strategy was used. The survey tested the level of consensus among Ghanaian professionals regarding the hindrances to undertaking virtual reality (VR) safety training. Figure 1 illustrates the research process, which includes the following major steps: literature review, questionnaire design and administration, collection and analysis of questionnaire data, and reporting results.

This study initially identified drivers through an extensive literature review. It was quantitative, employing questionnaire surveys to gather numerical data for in-depth analysis [40]. From the literature, a structured questionnaire was developed based on a 5-point Likert scale, which is renowned for eliciting participant opinions [41]. Construction experts in Accra, Koforidua, and Kumasi were randomly selected based on their willingness and availability to participate in the study. Purposive sampling was employed to deliberately select participants who would be in a position to provide meaningful information regarding VR safety training in the Ghanaian construction industry. The population under study consisted of a combination of professionals, including project managers, builders, masons, electricians, plumbers, carpenters, site supervisors, contractors, health and safety officers, site inspectors, civil engineers, architects, and quantity surveyors. Electronic questionnaires were distributed by means of email invitations and Google Forms, with paper-based copies provided for those without electronic access. A total of 180 questionnaires were distributed, and 153 were returned completely filled in, providing an approximate response rate of 85%, which gives robust data for analysis [41]. The sample was biased toward younger adults, who tend to be more familiar with VR technology, potentially limiting the generalizability of the findings to older individuals with less experience. Data analysis was conducted using IBM SPSS version 27 with descriptive and inferential statistics. Reliability was determined using Cronbach's alpha, and a value of 0.70 was employed as the cut-off for good internal consistency [42]. MIS was utilized to rank the drivers in virtual reality (VR) usage in safety training, based on participant ratings from n1 to n5, denoting 'strongly disagree' to 'strongly agree'. The criteria were

ranked using MIS, with the order ranking their significance, starting from the greatest significance. For further examination of the data, a one-sample *t*-test was employed to contrast mean responses with a specified test value and to determine whether there were statistically significant differences. ANOVA was also used to assess the differences between different groups, examining whether the means of multiple groups differed significantly from each other. Factor analysis was used to identify and categorize VR safety training drivers according to their shared relationships, as this provided the chance to identify key elements that determine the training. Factor analysis, as a statistical method of condensing study variables by identifying correlated components [43,44], utilizes exploratory factor analysis (EFA). Factors with eigenvalues >1.0 were used, excluding factor loadings <0.5. SPSS 27 was used to conduct EFA, using principal axis factoring to extract data. Varimax Kaiser normalization was applied to rotate and direct oblimin Kaiser normalization for second-order factor analysis. Validity ensured that the questionnaire survey results had high levels of validity as measured by a validity test that tested measurement precision [45]. Reliability was checked to ensure the consistency of the data collection tool, with a Cronbach's alpha coefficient > 0.7 indicating reliability [46]. Non-parametric tests resolved data that did not meet parametric assumptions [43], while one-way ANOVA was used to examine mean differences between independent groups [47], with statistical significance at $p < 0.05$.

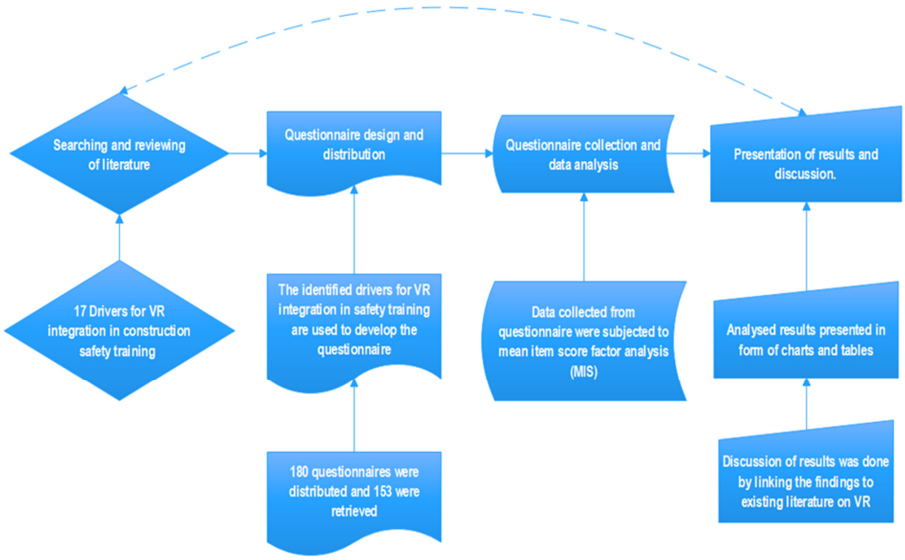


Figure 1. Research process. Source: Authors' construct.

3. Results

3.1. Characteristics of Respondents

Table 2 presents the profiles of the respondents by occupation, academic qualification level, and years of experience. The most frequent group was site supervisors (20.9% of respondents), and most of them were directly involved in the management of construction sites. The second largest group was builders, who made up 20.3% of the respondents, indicating their central role in construction work. Civil engineers made up 9.2% of respondents, highlighting their important position in structural and technical building design. Quantity surveyors and project managers each made up 7.8% of respondents, reflecting their worth in providing project delivery and cost planning, respectively. Moreover, masons made up 5.2% of the respondents, highlighting the continued presence of skilled manual labor in the construction sector. Contractors and plumbers accounted for 7.2% and 4.6% of the respondents, respectively, again showing the broad range of functions needed to facilitate

the effective completion of projects. Health and safety officers also accounted for 4.6% of the respondents, demonstrating the priority afforded to maintaining safety standards on construction sites. The remaining occupations, including electricians, carpenters, site inspectors, and architects, represented between 2.6% and 3.3% of respondents; they covered a variety of occupations across the construction industry. Regarding educational qualifications, the evidence indicates that the largest number of respondents, at 43.8%, possessed higher national diplomas, indicating a good standard of technical education. BTECH degree holders constituted 22.2% of the respondents, indicating the level of technical specialty knowledge among the respondents. Moreover, 11.1% of the respondents possessed a bachelor's degree, and 5.2% possessed a master's degree, indicating a very high level of higher education among the respondents. Those with WASSCE qualifications constituted 7.2% of respondents, while 5.2% had certificates such as CTC or EET. The diploma holders accounted for 2.6% of the respondents, and a minority, 1.3%, were PhD holders, indicating highly specialized individuals in the industry. Concerning work experience, the statistics indicate that 47.1% of the respondents had 1 to 5 years of experience, indicating a young and vibrant workforce. Those with less than a year of experience accounted for 31.4% of respondents, indicating a tremendous number of new professionals entering the field. The group with 6 to 10 years of experience accounted for 12.4% of respondents, indicating a stable group with mid-career experience. Those who had 11 to 15 years and 16 to 20 years of experience made up 3.3% of the respondents, while those who had more than 20 years of experience represented the lowest proportion (2.6% of respondents), showing a limited proportion of highly experienced professionals. This reflects a broad, young workforce with a mix of new and experienced professionals, which is an advantage for this research.

Table 2. Demographic profiles of respondents.

Demographic Information	No. of Respondents	%	Cumulative
Professional background			
Project manager	12	7.8	7.8
Builder	31	20.3	28.1
Mason	8	5.2	33.3
Electrician	5	3.3	36.6
Plumber	11	7.2	43.8
Carpenter	5	3.3	47.1
Site supervisor	32	20.9	68.0
Contractor	7	4.6	72.5
Health and safety officer	7	4.6	77.1
Site inspector	4	2.6	79.7
Civil engineer	14	9.2	88.9
Architect	5	3.3	92.2
Quantity surveyor	12	7.8	100.0
Academic qualification			
BECE	2	1.3	1.3
WASSCE	11	7.2	8.5
BSc Degree	17	11.1	19.6
BTECH	34	22.2	41.8
Certificate (CTC, EET)	8	5.2	47.0
Diploma	4	2.6	49.6
Higher national diploma	67	43.8	93.4
Master's degree	8	5.2	98.6
PhD	2	1.3	100
Years of Experience			
Less than 1 year	48	31.4	31.4
1–5 years	72	47.1	78.4
6–10 years	19	12.4	90.8
11–15 years	5	3.3	94.1
16–20 years	5	3.3	97.4
More than 20 years	4	2.6	100.0

Source: Authors' construct.

3.2. Ranking Drivers of Virtual Reality Integration in Construction Industry Safety Training

Table 3 illustrates the ranking of drivers for integrating virtual reality (VR) into construction industry safety training, based on mean scores in descending order. The analysis shows that the majority of these drivers are statistically significant ($p < 0.05$), as indicated by the one-sample t-test value of 3.5. The mean scores of drivers fall between 3.50 and 4.03, denoting different degrees of importance according to the respondents. The most highly rated driver is "Technological Advancements in the Industry" (mean = 4.03; SD = 0.98; t (152) = 6.643; $p < 0.001$), highlighting the central role played by technological innovation for VR adoption. Similarly, "Improvement in Safety Culture" (mean = 4.03; SD = 0.90; t (152) = 7.208; $p < 0.001$) ranks second, reflecting the potential of VR to facilitate a stronger safety-focused culture within the sector. "Improved Accessibility for Remote or Distributed Teams" (mean = 3.86; SD = 0.88; t (152) = 5.026; $p < 0.001$) ranks third, reflecting the flexibility enabled by VR for teamwork in remote environments. The fourth driver, "Engagement and Retention of Training Content" (mean = 3.84; SD = 0.90; t (152) = 4.695; $p < 0.001$), indicates the value of VR in driving learning outcomes. "Customization and Personalization of Training Programs" (mean = 3.81; SD = 0.94; t (152) = 4.098; $p < 0.001$) is fifth, showing the importance of creating VR training to the individualized needs of workers. The remaining high drivers are "Competitive Advantage" (mean = 3.80; SD = 0.96; t (152) = 3.851; $p < 0.001$) and "Risk-free Environment Compared to Real-World Training" (mean = 3.80; SD = 1.04; t (152) = 3.534; $p < 0.001$), both of which indicate the ability of VR to provide risk-free, cost-effective training environments that translate into a strategic advantage. "Data-Driven Insights" (mean = 3.78; SD = 0.97; t (152) = 3.640; $p < 0.001$) and "Realistic Training Environments and High-Quality Simulations" (mean = 3.76; SD = 0.94; t (152) = 3.493; $p < 0.001$) follow closely, demonstrating the value of VR's detailed feedback mechanisms and immersive simulations. The scalability of training programs (mean = 3.76; SD = 0.90; t (152) = 3.564; $p < 0.001$) and real-time performance tracking (mean = 3.75; SD = 1.00; t (152) = 3.021; $p = 0.003$) are also significant, illustrating the efficiency and adaptability of VR-based training methods. Drivers with low statistical significance include "Simulation of Rare or High-Risk Scenarios" (mean = 3.66; SD = 0.98; t (152) = 2.019; $p = 0.045$), "Cost of Safety Training" (mean = 3.63; SD = 0.93; t (152) = 1.693; $p = 0.092$), and "Reduction in Training Time" (mean = 3.62; SD = 1.09; t (152) = 1.367; $p = 0.174$), among others. Although these means suggest a generally positive perception, their higher p-values indicate considerable variation in respondent views, implying that not all participants regarded these factors as consistently influential. For instance, simulation of rare or high-risk scenarios may be seen as less immediately relevant due to infrequent occurrence on typical sites, while concerns over training costs and time savings appear to depend heavily on organizational context and existing training budgets. This variability underscores the need for further targeted qualitative follow-ups to understand the conditions under which these drivers become critical. The findings provide valuable insights into the strongest drivers of VR adoption in construction safety training, with particular emphasis on technological advancement, safety culture, and improved accessibility.

Table 3. Ranking the drivers of virtual reality integration in safety training within the construction industry.

S/N	Drivers of Virtual Reality Integration in Safety Training Within the Construction Industry	Mean	Standard Deviation (SD)	t-Value ($\mu = 3.5$)	df	Sig. (2-Tailed)	Mean Difference	Rank	Significant ($p < 0.05$)
DR-1	Technological advancements in the industry	4.03	0.980	6.643	152	0.001	0.526	1	Yes
DR-17	Improvement in safety culture	4.03	0.903	7.208	152	0.001	0.526	2	Yes

Table 3. *Cont.*

S/N	Drivers of Virtual Reality Integration in Safety Training Within the Construction Industry	Mean	Standard Deviation (SD)	t-Value ($\mu = 3.5$)	df	Sig. (2-Tailed)	Mean Difference	Rank	Significant ($p < 0.05$)
DR-11	Enhanced accessibility for remote or distributed teams	3.86	0.877	5.026	152	0.001	0.356	3	Yes
DR-13	Engagement and retention of training content	3.84	0.904	4.695	152	0.001	0.343	4	Yes
DR-12	Customization and personalization of training programs	3.81	0.937	4.098	152	0.001	0.310	5	Yes
DR-6	Competitive advantage	3.80	0.955	3.851	152	0.001	0.297	6	Yes
DR-8	A risk-free environment compared to real-world training	3.80	1.041	3.534	152	0.001	0.297	7	Yes
DR-10	Data-driven Insights	3.78	0.966	3.640	152	0.001	0.284	8	Yes
DR-7	Realistic training environments and high-quality simulations	3.76	0.937	3.493	152	0.001	0.265	9	Yes
DR-14	Scalability of training programs	3.76	0.896	3.564	152	0.001	0.258	10	Yes
DR-9	Real-time/immediate training feedback and performance tracking for workers	3.75	1.003	3.021	152	0.003	0.245	11	Yes
DR-16	Simulation of rare or high-risk scenarios	3.66	0.981	2.019	152	0.045	0.160	12	No
DR-4	Cost of safety training	3.63	0.931	1.693	152	0.092	0.127	13	No
DR-15	Reduction in training time	3.62	1.094	1.367	152	0.174	0.121	14	No
DR-3	Underperformance of safety statistics (number of injuries to enforce improved training standards)	3.61	1.040	1.361	152	0.176	0.114	15	No
DR-2	Government/organizational regulations and policies	3.56	0.979	0.785	152	0.434	0.062	16	No
DR-5	Stakeholder pressure	3.50	1.027	−0.039	152	0.969	−0.003	17	No

3.3. Kruskal–Wallis One-Way Analysis of Variance (ANOVA) Test in Examining Differences in Respondents' Perceptions of Drivers of VR Integration in Safety Training

A Kruskal–Wallis one-way analysis of variance (ANOVA) test was employed to examine the variations in perceptions of respondents from various professional backgrounds regarding the drivers of virtual reality (VR) adoption in construction industry safety training. The test hypothesis was that there were no variations in perceptions between professions. The significance level of the analysis was 0.05, and Table 4 presents the results. The data were not normally distributed, as determined by the Kolmogorov–Smirnov test. Nevertheless, the Kruskal–Wallis test was used because it is suitable for use with non-parametric data. Table 4 indicates that there were statistically significant differences in perceptions among drivers based on various professional backgrounds ($p < 0.05$), whereas in others, there were no statistical differences, depicting divergence in the evaluation of the significance of these drivers by professionals with various roles in the construction industry. Health and safety officers ranked "Technological Advancements in the Industry" (mean = 108.57) and "Improvement in Safety Culture" (mean = 98.36) as the key drivers facilitating the use of virtual reality in a systematic way, thus emphasizing the significance of technological development and robust safety culture from their professional viewpoint. Conversely, project managers ranked "Real-time/Immediate Training Feedback and Performance Tracking" (mean = 97.50) and "Technological Advancements in the Industry" (mean = 92.38) as top priorities due to their focus on leveraging virtual reality to optimize the performance of employees and monitor progress more effectively in real-time. Quantity surveyors placed high emphasis on "Technological Advancements within the Industry" (mean = 92.46), reflecting the views of project managers and health and safety officers. However, they placed less emphasis on "Competitive Advantage" (mean = 80.79), indicating a more conservative

approach to the strategic advantages associated with virtual reality implementation. On the other hand, contractors ranked "Technological Advancements" (mean = 86.68) at a moderate level of priority, and they gave higher priority to "Customization and Personalization of Training Programs" (mean = 83.29), which is consistent with their training solution emphasis on very customized solutions that address the unique needs of on-site settings. Masons and electricians also had different priorities, with masons ranking "Real-time/Immediate Training Feedback" the lowest (mean = 79.56) among the groups, possibly reflecting lower use of feedback mechanisms in their work. Electricians, however, marked "Cost of Safety Training" the highest (mean = 95.60), suggesting that financial motivations may be a blanket motivator for using VR in safety training. Electricians also marked "Technological Advancements" the highest (mean = 90.30), suggesting an interest in staying updated with the current technologies in their field of work. Interestingly, carpenters rated "Cost of Safety Training" (mean = 104.70) and "Competitive Advantage" (mean = 104.70) as the most important drivers, indicating that they view virtual reality as both cost-effective and a means to gain a competitive advantage. This finding concurs with the financial issues expressed by other industries; however, their assessment of the other drivers, like "Technological Advancements" (mean = 62.60), was quite conservative, echoing the preference for the cost factors over technological innovations. Site supervisors were more balanced in their perspective, showing moderate judgments across various influencing factors. The participants ranked "Technological Advancements" (mean = 82.27) and "Real-time/Immediate Training Feedback" (mean = 73.64) with high importance, but their rankings were more toward the middle range, suggesting a balanced strategy toward the adoption of virtual reality (VR). Contractors also demonstrated intermediate ratings, with the highest ratings awarded to "Technological Advancements" (mean = 91.21) and "Real-time Feedback" (mean = 84.21), reflecting an overall perception of the advantages of VR. Architects and civil engineers displayed some variation in priorities. Architects placed "Customization and Personalization of Training Programs" (mean = 103.80) and "Technological Advancements" (mean = 93.60) as leading drivers, indicating strong interest in customized solutions and staying abreast of industry innovations. Conversely, civil engineers placed "Technological Advancements" much lower (mean = 48.04), indicating relatively less focus on this factor. Civil engineers, on the other hand, showed a moderate level of concern toward "Real-time/Immediate Feedback" (mean = 60.96) and "Risk-free Training Environments" (mean = 48.04), reflecting perhaps their focus on practicality and safety issues in training environments. Site inspectors rated "Technological Advancements" lower (mean = 66.38) than health and safety officers and project managers, but rated "Customization and Personalization of Training Programs" (mean = 95.63) highly, indicating concern for flexible training programs to meet specific safety issues on-site. The findings from the Kruskal–Wallis test indicate that, although there are some variations in the perceptions of respondents from various professional groups regarding the determinants underlying the integration of VR, there is a general agreement on the relevance of major factors such as technological innovation, individualization of training programs, and providing feedback in real-time. Yet, economic factors, including the costs of training and the pursuit of competitive advantage, are far more prominent in some professions, such as carpenters and electricians. The general differences in perception based on job roles validate the importance of individually tailored strategies when promoting VR adoption in safety training in the construction industry.

Table 4. One-way analysis of variance (ANOVA) to examine any differences in the perceptions of the respondents' professional backgrounds.

	Drivers	DR-1	DR-2	DR-3	DR-4	DR-5	DR-6	DR-7	DR-8	DR-9	DR-10	DR-11	DR-12	DR-13	DR-14	DR-15	DR-16	DR-17
Project manager	**Rank**	4	9	2	5	5	8	3	3	2	2	6	3	5	6	2	4	4
	Mean	86.92	67.92	93.29	86.58	86.79	79.88	92.38	90.50	97.50	88.67	80.13	91.92	81.63	81.17	91.46	95.88	82.00
Builder	**Rank**	5	3	6	6	8	6	8	8	8	8	10	4	6	8	7	10	9
	Mean	86.68	88.60	80.27	79.76	79.32	81.68	72.61	73.55	68.31	74.23	74.60	83.29	78.97	75.74	74.82	67.47	70.87
Mason	**Rank**	7	13	13	13	13	13	10	2	12	5	8	10	9	7	10	7	10
	Mean	76.50	42.69	45.25	51.31	40.75	52.56	63.06	98.38	79.56	68.56	75.00	58.13	74.75	77.06	70.19	74.31	69.56
Electrician	**Rank**	3	12	10	1	1	10	4	7	6	10	4	8	11	11	6	13	12
	Mean	90.30	56.50	64.60	95.60	105.80	67.00	90.70	77.10	67.50	78.20	87.80	67.00	65.80	70.50	82.10	62.20	67.60
Plumber	**Rank**	2	5	7	10	10	4	5	6	7	3	5	2	4	2	1	8	6
	Mean	95.55	86.09	75.82	67.91	74.32	92.86	84.82	80.91	93.45	75.09	81.95	92.82	81.64	91.45	98.50	71.73	75.27
Carpenter	**Rank**	11	7	12	3	2	1	11	1	3	12	12	12	12	5	8	6	8
	Mean	64.20	75.30	62.20	93.30	103.90	104.70	62.60	103.20	63.10	84.40	71.00	51.80	48.20	81.30	70.90	80.70	73.70
Site Supervisor	**Rank**	1	6	9	8	7	9	6	12	5	7	9	6	7	4	9	11	7
	Mean	69.44	79.19	69.80	78.39	80.64	70.53	82.27	68.59	73.64	78.95	74.66	79.41	77.41	82.53	70.64	67.17	74.38
Contractor	**Rank**	10	4	3	9	3	5	7	10	1	4	11	9	13	9	13	12	2
	Mean	68.50	88.07	91.86	77.50	91.21	82.71	77.00	70.43	84.21	99.00	74.00	60.71	47.21	75.57	56.64	65.07	86.07
Health and Safety Officer	**Rank**	8	1	1	12	9	2	1	4	4	1	2	1	2	10	4	1	3
	Mean	74.79	94.50	112.21	62.64	77.79	98.36	108.57	88.64	119.17	84.36	97.50	105.71	97.50	70.57	89.93	104.71	86.07
Site Inspector	**Rank**	9	8	8	2	7	11	9	13	11	11	3	13	3	3	3	2	11
	Mean	112.13	73.88	73.00	95.50	87.25	64.50	66.38	67.38	65.88	71.50	95.63	51.50	95.50	87.50	90.50	103.00	68.50
Civil Engineer	**Rank**	13	11	5	11	12	12	12	9	10	13	13	11	10	13	11	5	5
	Mean	56.71	64.82	82.57	65.07	54.14	55.00	48.04	70.82	60.96	73.71	56.57	54.64	69.46	58.75	69.29	80.96	80.07
Architect	**Rank**	6	2	4	4	6	3	13	5	13	9	1	7	1	1	12	9	13
	Mean	81.80	89.70	91.60	87.80	81.20	93.60	47.70	87.20	68.00	42.80	103.80	72.60	103.90	92.70	66.00	70.40	67.60
Quantity Surveyor	**Rank**	12	10	11	7	11	7	2	11	9	6	7	5	8	12	5	3	1
	Mean	61.58	67.38	64.58	78.83	67.67	80.79	92.46	69.25	75.42	73.88	77.38	81.33	76.96	65.79	83.79	100.46	99.25

Source: Authors' construct.

3.4. Exploratory Factor Analysis on the Drivers of Virtual Reality Integration in Safety Training Within the Construction Industry

The responses were also analyzed through exploratory factor analysis (EFA). Data appropriateness was checked by finding the correlation matrix, wherein values of 0.3 and above fell within the factor analysis requirement limit. Table 5 shows that the Kaiser–Meyer–Olkin (KMO) measure was 0.872, well above the threshold of 0.6. In addition, Bartlett's test of sphericity also confirmed statistical significance on all the variables with a *p*-value of 0.001, which is far less than 0.050, confirming factorability. The correlation matrix also confirmed data suitability for factor analysis as it displayed correlation coefficients higher than 0.3, confirming the findings of KMO and Bartlett's tests. Table 6 indicates the total variance explained by all the variables, with eigenvalues determined using Kaiser's criterion. As evident from the table, the first four components—with eigenvalues greater than 1.0 in the initial eigenvalue column—are considered meaningful because their eigenvalues are considerably above 1.0, and together, they explain 56.780% of the total variance. The first component explains 35.654% of the variance, followed by the second (7.529%), the third (7.041%), and the fourth (6.555%) components. The total percentage reveals that these components explain a large percentage of variability in the data and, hence, are of tremendous significance in determining the structure of the data.

Table 5. KMO and Bartlett's test.

Kaiser–Meyer–Olkin Measure of Sampling Adequacy.		0.872
Bartlett's Test of Sphericity	Approx. Chi-Square	891.894
	df	136
	Sig.	<0.001

Table 6. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.061	35.654	35.654	6.061	35.654	35.654	2.808	16.520	16.520
2	1.280	7.529	43.183	1.280	7.529	43.183	2.583	15.196	31.716
3	1.197	7.041	50.224	1.197	7.041	50.224	2.462	14.481	46.198
4	1.114	6.555	56.780	1.114	6.555	56.780	1.799	10.582	56.780
5	0.985	5.795	62.575						
6	0.945	5.559	68.134						
7	0.884	5.199	73.333						
8	0.663	3.900	77.233						
9	0.617	3.630	80.863						
10	0.570	3.353	84.216						
11	0.490	2.884	87.100						
12	0.453	2.666	89.766						
13	0.436	2.566	92.332						
14	0.393	2.310	94.642						
15	0.333	1.958	96.600						
16	0.314	1.845	98.444						
17	0.264	1.556	100.000						

Extraction method: principal component analysis.

Factor Cluster Report

Table 7 presents the pattern matrix derived from principal component analysis (PCA) with Varimax rotation, which extracted four factors with eigenvalues greater than 1. These

factors represent clusters of variables that explain a great percentage of the data variance. Based on the variable relationships, the interpretations were as follows:

Table 7. Pattern matrix.

		Component				Cronbach's Alpha Coefficient
		1	2	3	4	
Technological and Safety Enhancements (6)	Technological advancements in the industry	0.520				0.792
	Competitive advantage	0.446				
	Realistic training environments and high-quality simulations	0.732				
	A risk-free environment compared to real-world training	0.654				
	Real-time/immediate training feedback and performance tracking for workers	0.608				
	Improvement in safety culture	0.613				
Regulatory and Financial Drivers (5)	Government/organizational regulations and policies		0.611			0.719
	Underperformance of safety statistics (number of injuries to enforce improved training standards)		0.506			
	Cost of safety training		0.731			
	Stakeholder pressure		0.791			
	Data-driven insights		0.447			
Customization and Accessibility (4)	Enhanced accessibility for remote or distributed teams			0.532		0.758
	Customization and personalization of training programs			0.659		
	Engagement and retention of training content			0.734		
	Scalability of training programs			0.759		
Operational Efficiency and Risk Management (2)	Reduction in training time				0.850	0.715
	Simulation of rare or high-risk scenarios				0.758	

The first factor, "Technological and Safety Enhancements", includes the following six variables: 'Technological Advancements in the Industry' (loading = 0.520), 'Competitive Advantage' (loading = 0.446), 'Realistic Training Environments and High-Quality Simulations' (loading = 0.732), 'Risk-Free Environment Compared to Real-World Training' (loading = 0.654), 'Real-Time/Immediate Training Feedback and Performance Tracking for Workers' (loading = 0.608), and 'Improvement in Safety Culture' (loading = 0.613). This explains the highest proportion of the variance, citing technological advancement and safety improvement as the most important factors enabling VR adoption in safety training.

The second factor, "Regulatory and Financial Drivers", includes the following five variables: 'Government/Organizational Regulations and Policies' (loading = 0.611), 'Underperformance of Safety Statistics' (loading = 0.506), 'Cost of Safety Training' (loading = 0.731), 'Stakeholder Pressure' (loading = 0.791), and 'Data-Driven Insights' (loading = 0.447). This factor highlights the impact of regulatory climates, fiscal pressures, and external pressures on the implementation of VR in safety training.

The third factor, "Customization and Accessibility," includes the following four variables: 'Enhanced Accessibility for Remote or Distributed Teams' (loading = 0.532), 'Customization and Personalization of Training Programs' (loading = 0.659), 'Engagement and Retention of Training Content' (loading = 0.734), and 'Scalability of Training Programs' (loading = 0.759). This factor captures the focus on creating flexible, engaging, and scalable training solutions that can meet different team requirements.

The fourth dimension, labeled "Operational Efficiency and Risk Management", includes the following two indicators: 'Reduction in Training Time' (loading = 0.850) and 'Simulation of Rare or High-Risk Scenarios' (loading = 0.758). This dimension emphasizes the effectiveness of VR training in reducing the training time as well as its use in subjecting workers to rare or high-risk situations.

The Cronbach's Alpha coefficients also determine the reliability of clusters created (see Table 7). "Technological and Safety Features" yields the highest consistency, with a Cronbach's Alpha = 0.792, which implies very high internal consistency between variables within this factor. "Customization and Accessibility" follows, with Alpha = 0.758, indicating reasonable reliability between variables under customization and accessibility. For "Regulatory and Financial Drivers", Cronbach's Alpha = 0.719, which is far above the acceptable limit, supporting internal consistency among regulatory and financial drivers. "Operational Efficiency and Risk Management" has an Alpha of 0.715, which indicates high internal consistency among variables that deal with efficiency and risk management. These reliability coefficients ensure that the clusters obtained are consistent in terms of measuring the constructs under them, and one can be sure of the result of the analysis.

4. Discussion

To ascertain the drivers of virtual reality (VR) integration for construction industry safety training, an exploratory factor analysis was employed to generate four clusters. Every cluster is a combination of similar drivers, providing a comprehensive overview of the drivers for VR adoption. The clusters are described extensively to elicit the distinguishing features in each cluster and their implications for VR integration in the construction industry.

4.1. Cluster One—Technological and Safety Enhancements

This cluster, accounting for 35.654% of the explained variance, has the following six underlying variables: 'Technological Advances in Industry' (0.520), 'Competitive Advantage' (0.446), 'High-Quality Simulations and Realistic Training Environments' (0.732), 'Risk-Free Environment in Comparison to Real-World Training' (0.654), 'Real-Time/Immediate Training Performance Monitoring and Feedback for Workers' (0.608), and 'Enhanced Improvement in Safety Culture' (0.613). The high variance accounted for by this cluster indicates the key role played by technological advancements in safety training in driving VR adoption among construction companies. The 'Technological Advancements in Industry' dimension refers to the growing concern by the industry to adopt advanced technologies in order to remain competitive and improve safety protocols. VR's capability of 'Realistic Training Environments and High-Quality Simulations' is especially valued, as it provides employees with immersive, realistic training sessions that replicate actual work activities without incurring risks present on actual worksites. This supports [2,15] assertions that highlight the importance of VR as an insurer of safe, immersive training. Moreover, 'Risk-Free Environment Compared to Real-World Training' and 'Real-Time/Immediate Training Feedback and Performance Tracking for Workers' underscore VR's ability to reduce the risk involved with training while giving immediate, actionable feedback—a key consideration in the development of reinforcement learning, allowing workers to make mistakes in a risk-free environment before practicing in the real world. Lastly, 'Improvement in Safety Culture' resonates with a movement within the industry to prioritize safety, positioning VR as a key tool for building a robust safety culture. The application of VR not only introduces new technology but also a shift in how safety is thought about and implemented within the industry, as endorsed by [1,43], which identified that advances in safety technology are responsible for enhancing the safety culture of the construction industry.

4.2. Cluster Two—Regulatory and Financial Drivers

This cluster, accounting for 16.520% of the variance, comprises the following variables: 'Government/Organizational Regulations and Policies' (0.611), 'Underperformance of Safety Statistics' (0.506), 'Cost of Safety Training' (0.731), 'Stakeholder Pressure' (0.791), and 'Data-Driven Insights' (0.447). This cluster's influence shows the firm influence on regulatory mechanisms, cost implications, and pressure from external actors to use VR for safety training. Interventions such as 'Government/Organizational Regulations and Policies' and 'Stakeholder Pressure' suggest that compliance with regulatory requirements and stakeholder demands are primary drivers toward VR adoption. Since construction companies operate under stringent safety legislation, VR can meet such requirements and avoid legal or financial sanctions. Refs. [3,12] also highlight how external forces, particularly in safety-critical industries, can accelerate the adoption of technology. The addition of 'Cost of Safety Training' embodies the cost consideration of deploying VR. While VR can come with significant initial expenses, the future dividends that it generates through improved safety performance and decreased accidents make it an economic choice for organizations. Ref. [11] aligns with this viewpoint by stressing the cost-effectiveness of VR as a vital aspect of its implementation in safety training. In conclusion, the addition of 'Data-Driven Insights' in this category reflects increasing reliance on data to enhance and optimize training initiatives. By using data analytics, companies can continuously refine their training programs to make them both effective and pertinent. This trend toward data-driven practice aligns with the broader industry trend toward using analytics to improve operational performance, as Chan et al. [19] and Rosen et al. [20] documented. The difference in perception of the relevance of data-driven insights among industry segments, as evident from the Kruskal–Wallis test, suggests that while some segments of the industry are embracing data analytics in training, others may need further advice and support in adopting this practice completely.

4.3. Cluster Three—Customization and Accessibility

This component, which explains 14.481% of the variance, includes the following four variables: 'Augmented Accessibility for Remote or Distributed Teams' (loading = 0.532), 'Personalization and Customization of Training Programs' (loading = 0.659), 'Training Content Engagement and Retention' (loading = 0.734), and 'Training Program Scalability' (loading = 0.759). The focus of this cluster is on the flexibility, extent, and effectiveness of VR training, particularly in the context of a globalized and more heterogeneous workforce. Reference to 'Improved Accessibility for Remote or Distributed Teams' highlights the need to make training available to all, especially in the construction industry, where teams are typically spread across multiple sites. The ability of VR to provide uniform and quality training to remote workers ensures that each worker, far or near, is exposed to consistent learning. This concurs with studies conducted by [15,22], who establish that VR can bridge disparities between remote groups. 'Customization and Personalization of Training Programs' is a reflection of the growing demand for adaptive training solutions that respond to the specific requirements of different individuals and groups. The adaptability of VR as a modality allows it to develop tailored training modules addressing the specific issues of various workers, thus improving the effectiveness of the overall training. Refs. [36,37] also highlighted the growing need for workplace individualization; this is an area in which VR is designed to excel. 'Engagement and Retention of Training Content' and 'Scalability of Training Programs' highlight VR's value in providing highly engaging training that not only captures workers' attention but also improves the retention of critical safety information. The scalability of VR training solutions also allows organizations to deploy these solutions uniformly to groups of employees by the thousands, providing a high-quality, consistent

learning experience. Refs. [23,32] underscore the engagement and retention function of training, highlighting that the immersion capabilities of VR significantly enhance these functions compared to traditional solutions.

4.4. Cluster Four—Operational Efficiency and Risk Management

The final cluster, accounting for 10.582% of the variance, comprises the two most significant variables, that is, 'Reduction in Training Time' (loading = 0.850) and 'Simulation of Rare or High-Risk Scenarios' (loading = 0.758). The cluster here deals with the operational benefits of VR training, particularly concerning efficiency and risk management. 'Reduction in Training Time' indicates one of the largest strengths of VR—its ability to cut the training process. VR allows workers to undergo targeted, intense training sessions, enabling workers to learn more content in less time compared to traditional methods. This increased productivity is particularly beneficial in the construction industry, where downtime must be kept to a minimum. Refs. [34,35] supported this observation, noting that VR cuts employee training time by a significant amount. The 'Simulation of Rare or High-Risk Situations' factor emphasizes VR's unique ability to simulate dangerous situations that would be difficult or impossible to recreate in real life. Through this capability, employees can practice responding to emergencies and other high-risk scenarios without endangering themselves, thus becoming better prepared and confident. Refs. [24,25] highlighted the imperative role of VR in risk management, particularly in training for improbable but potentially catastrophic events.

4.5. Substantial Contributions and Implications

This study makes significant contributions by identifying and organizing the most compelling drivers of VR adoption in construction safety training. It is the first contribution where technological innovation and safety improvement are the primary drivers of VR adoption. These findings offer a structured view of VR driver adoption, with an emphasis on the application of immersive and accessible training in the construction sector. Moreover, this research adds to the literature on the application of VR in the construction sector, particularly in developing economies such as Ghana, where such technologies are emerging. This study provides a brief distinction of the key drivers with positive implications for industry stakeholders wanting to improve safety training through VR.

4.6. Practical Implications

This study offers a few practical implications from the findings, especially for industry actors who have an interest in implementing VR in their safety training programs. We break them down as follows:

- *Investment in technology*: The leading position of technological advances means that construction firms need to prioritize investments in cutting-edge VR technologies. This includes the purchase of VR hardware and software, allowing for the creation of realistic, high-quality simulations that can be used to support immersive and safe training exercises. Organizations that continue to be technologically up-to-date will experience improved training outcomes and more effective safety cultures.
- *Enhancing safety culture*: This study highlights the necessity of VR in developing a stronger safety culture within the construction industry. The integration of VR allows companies to promote better safety behaviors by providing immersive training that effectively simulates actual hazards in real-life settings, without putting workers in actual danger. Industry captains need to stress the promotion of VR as a means of inculcating a safety-first culture across all levels of employees.

- *Scalable and customizable training solutions*: The ability of VR to provide personalized training experiences based on specific learning needs is of utmost importance. Construction companies should design VR modules that address the distinctive challenges of different tasks and roles in the industry so that training is current and engaging. In addition, the scalability of VR allows it to be implemented among huge, geographically dispersed teams, making it an ideal solution for companies with dispersed or remote operations.
- *Focus on engagement and retention*: The greatest advantages of VR include its potential to increase engagement and retention of learning content. Businesses must emphasize the experiential capacity of VR as a means of enhancing employee participation, which can lead to enhanced retention and a better workforce. Integrating VR into safety training can result in enhanced training systems that are more enjoyable, yet simultaneously bring about lasting transformations in labor performance and workplace safety.
- *Collaboration of industry players*: Industry players such as construction companies, training providers, and technology firms need to collaborate to create quality VR training programs. This can lead to pooled resources, better content creation, and more affordable access to VR equipment for small businesses. Standardization of VR training programs and ensuring alignment with industry requirements through collaboration will make them more effective.

4.7. Recommendations

Based on the findings, the following recommendations are made for industry operators to promote the use of VR in construction safety training:

- *Enhancing technological infrastructure*: Construction companies must invest heavily in VR technology to create and enhance their training facilities. These involve buying VR headsets, designing in-house training modules, and entering into collaborations with vendors of VR software to create training programs specific to the industry's needs.
- *Creating a strong safety culture through VR*: In order to improve safety measures, businesses must integrate VR into their safety procedures and make it a part of the training process. Simulating real-world dangers in a secure environment, VR enables employees to learn more about safety procedures.
- *Tailoring training for different roles*: VR's flexibility facilitates the development of customized training to suit the singular needs of varying construction roles. Companies need to develop VR modules tailored to various tasks and skill levels, ensuring that training remains effective and relevant throughout the workforce.
- *Collaboration of industry players*: In order to make VR adoption more convenient, industry players like large building firms, small contractors, and technology providers should collaborate. Mutual sharing of knowledge and resources enables companies to lower the costs associated with integrating VR and develop communal training programs for the benefit of the entire sector.
- *Remote team accessibility enhanced*: Construction companies can leverage the ability of VR to train remote or distributed teams. This will give employees, wherever they may be located, access to the same top-quality training, will improve consistency, and raise safety levels across the industry.

Implementing these steps will enable the construction industry to implement VR technology effectively in safety training programs, enhancing training outcomes and creating a safer, more productive workforce.

5. Conclusions and Future Directions

This study presents the findings of a survey that identifies the most crucial drivers of the adoption of virtual reality (VR) safety training in the Ghanaian construction industry. The most notable drivers, in descending order, are technological innovation in the sector, enhancing safety culture, easier access for physically scattered or remote personnel, training content maintenance and retention, and customizing and tailoring training modules. These drivers point to the role of modern technology, flexible and scalable training methods, and the need for improved safety protocols. The following four primary factors influencing the adoption of VR are revealed through factor analysis: technological and safety enhancements, regulative and financial drivers, customization and accessibility, and operational efficiency and risk mitigation. These factors determine the drivers of VR adoption in construction safety training, providing insights into how the industry can benefit from VR to enhance training efficacy and safety levels. Future research should increase the sample size to improve generalizability and address variability, extend the study through cross-industry and cross-regional comparisons, evaluate additional VR platforms, and integrate objective performance metrics to further validate and refine the key drivers identified. In addition, targeted qualitative methods, such as interviews and case studies, should be employed to examine the organizational and contextual factors that determine when these drivers become critical, thereby clarifying the conditions under which each driver most significantly influences VR adoption in construction safety training.

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