sustainability

MDPI

Article

Potential of Virtual Design Construction Technologies to Improve Job-Site Safety in Gulf Corporation Council

Muhammad Tariq Shafiq * and Muneeb Afzal

Department of Architectural Engineering, College of Engineering, United Arab Emirates University, Al-Ain 155551, Abu Dhabi, UAE; muneeb.afzal@uaeu.ac.ae

* Correspondence: muhammad.tariq@uaeu.ac.ae; Tel.: +971-52-535-7606

Received: 30 January 2020; Accepted: 27 February 2020; Published: 8 May 2020

Abstract: With the advancement of digital design practices in the global construction industry, different aspects related to the project lifecycle are extracting their benefits, including making improvements in safety. The objective of this paper is to ascertain the awareness of these technologies, their potential, and any barriers related to the use of different virtual design construction (VDC) tools, such as building information modeling, virtual reality, augmented reality, and geographic information systems, to improve job-site safety in Gulf Cooperation Council (GCC) countries. The paper presents an overview of the GCC construction industry and highlights current safety management practices and problems in the region. The potential of VDC tools for improving job-site safety is discussed and presented. The study has used a questionnaire survey to identify the drivers and barriers of using VDC tools in improving job-site safety management in the GCC region. The results indicated that "designing emergency and evacuation plans" and "fall-hazard prevention strategies" are the two best safety applications of these tools if used proactively. Similarly, "lack of knowledge about return on investment for VDC tools" was considered as the predominant barrier, preventing stakeholders from using these technologies to improve construction safety. These results will help the GCC construction industry to build a strategy for the digitalization of proactive constructability analysis techniques for improving job-site safety. Overall, due to the multilingual dynamics of this region, it is recommended that VDC tools should become more prevalent so that the transfer of safety information and hazard prevention becomes easier, mitigating safety risks.

Keywords: Gulf Corporation Council (GCC); barriers; building information modeling (BIM); virtual design construction (VDC); job-site safety; virtual reality (VR)

1. Introduction

The construction industry is considered to be one of the oldest industries. However, the number of safety lapses that happen on construction sites is much higher than in other industries [1]. These injurious incidents are mostly due to human error and an individual's lack of hazard-identification skills [2]. Other suggested reasons for these errors include the particular nature of construction, difficult workplace conditions, and a lack of safety-management practices [3]. The unpredictable and complex nature of the construction industry forces it to embrace new technologies to reduce these incidents as much as possible. Research has shown that building information modeling (BIM) and other visualization tools can help with the identification, assessment, and treatment of hazards during the design phase [4].

According to Fischer et al. [5], virtual design and construction are defined as "the use of … multi-disciplinary performance models of design-construction projects, including the product (i.e., facilities), organization of the design-construction-operation team, and work processes, to support explicit and public business objectives". Different digital design tools and technologies, such as BIM, virtual reality (VR), augmented reality (AR), geographic information systems (GIS), the Global Positioning System (GPS), wireless sensor networks (WSNs), drone technology, 3D visualizations, "serious games", cloud technology, and other information-technology-based (IT-based) systems, have been of increasing interest as means to improve health and safety (H&S) practices. These technologies are also increasingly being used to improve job-site safety.

According to Azhar [6], traditional safety planning includes making observations and considering the past experiences of safety personnel. Along with personal expertise, 2D drawings are used for reference, but this can result in misleading information and judgments, potentially increasing risk. Rajendran and Clarke [7] suggest that incorporating digital technologies into traditional safety methods can lead to the following benefits: (1) design for safety; (2) safety planning; (3) training workers for safety; (4) accident investigation; and (5) facility management. Among these technologies, BIM has been predominant in improving different aspects of the construction lifecycle. The overall benefits of VDC tools have resulted in the rapid digitalization of the global construction industry, in particular the Gulf Cooperation Council (GCC).

The GCC consists of six countries, the United Arab Emirates (UAE), Saudi Arabia, Qatar, Kuwait, Oman, and Bahrain. Overall, the UAE undertakes projects with the highest contract value, worth a total of USD 44.5 billion in 2017, whereas, in the same period, Saudi Arabia undertook a total of just under USD 5 billion. For Qatar, this value was USD 10 billion, while in Kuwait and Oman, the totals were USD 5.6 and 5.1 billion, respectively [8]. In the same report, the GCC looked forward to various national reform plans and strategies, such as Saudi Vision 2030, Abu Dhabi Economic Vision 2030, Dubai Plan 2021, and Qatar National Vision 2030. This has resulted in these countries boosting their construction industries and therefore increasing their inclination toward technological adaptation and exploration. These technologies can have a profound impact on improving the safety of construction during the megaprojects currently underway in the region.

The objective of this study is to analyze the current levels of awareness among construction stakeholders, to establish their potential, and to strategize against the barriers impeding the successful implementation of VDC tools to help improve job-site safety conditions in the GCC. The findings of this study will be the starting point for the stakeholders of the region to design tools and introduce legal bindings to help improve job-site safety conditions using VDC technology.

2. Literature Review

2.1. Current Scenario for Safety in the GCC

The construction industry in the GCC has always generated much attention globally, and even with the current unstable global economic conditions, it is thriving. The valuation of GCC construction projects was USD 308.3 billion in June 2019, and for projects that were in the concept, design, or tender stages, this value was up to USD 256.1 billion [9]. This high valuation also raises the complexity of projects, which leads to an increased number of safety threats on site. There is no accurate data available on the number of construction-related deaths in the GCC region, but the reports published by international autonomous organizations reveal that the causality rate has been staggeringly high. For example, in the construction of the FIFA World Cup 2022 (Qatar) stadiums, the number of accidents has already reached 1200 [10]. According to a Human Rights Watch report [11], 520 workers from India, Nepal, and Bangladesh encountered site accidents in Qatar as a result of a number of safety lapses. Similarly, in Bahrain, 216 worksite incidents were noted within the first seven months of 2018 [12]. For Oman, according to data from ten reputable construction organizations, in 2014 alone, 3500 construction workers required medical treatment [10]. A report by the General Organization for Social Insurance indicated that by the third quarter of 2018, 47% of the occupational injuries in Saudi Arabia pertained to the construction sector [13]. The situation in Kuwait is also similar to the rest of the GCC. With such alarming statistics, there is an evident need for technological intervention and improved construction policies to mitigate these threats as much as possible.

2.2. Digital Tools for Managing Safety in Construction

Different VDC tools are being developed to improve on-site safety, and the popularity of BIM, in particular, is increasing because of its benefits across the lifecycle of a project. The integration of these technologies with BIM is simple and repeatable, which means that stakeholders can usefully incorporate them into their traditional workflows.

According to Paulson's curve [14], as a project extends further, incorporating variations becomes more difficult. Because of this, proactive measures and suitable mitigation strategies taken at the design and planning stages can provide a safe execution environment for workers. Digital tools such as BIM, VR, AR, radio-frequency identification (RFID), real-time location systems (RTLS), GIS, GPS, serious games, drones, and 3D visualization are being used for site hazard prevention and safety-management purposes. This section presents a critical appraisal of previous research regarding improving safety using these technologies. Although a lot of research has been carried out pertaining to these tools, they are not prevalent in terms of their on-site implementation. This section reviews the major technologies and their potential so that they can be implemented for construction safety.

2.2.1. Building Information Modeling

BIM is one of the most prevalent VDC technologies, and it has not only proactively improved safety but has also enhanced constructability review techniques. According to Azhar et al. [15], the technological aspect of BIM helps stakeholders to visualize what is yet to be constructed in a simulated environment to foresee any potential design, construction, or operational issues. The very process has enhanced communication, collaboration, and decision-making power during the design phase, which is the underlying principle of constructability analysis. Many construction incidents could have been avoided if appropriate measures were taken during the design phase. Designers, who have limited knowledge of construction safety and are unable to foresee safety concerns in the processes of construction and facility management [16,17], can now approach this problem using a BIM-based "design for safety" system. There is a need for a digital rectifying tool that can work alongside analysis and modeling software to produce an efficient safety model.

Zhang et al. [18] developed a BIM-based automatic safety checking framework, testing it with a case study. This approach led to automatic hazard identification and correction measures during planning and design. BIM, along with a rule-based site layout, also ensures on-site safety [19]. According to Zhang et al. [20], job hazard analysis (JHA) is a process of automatically detecting potential safety incidents and then recommending measures to negate them. Their research developed a JHA framework with the help of BIM plugins. The framework was not only compared with traditional JHA, but this BIM–JHA approach was conclusively found to be useful in safety planning.

Building information management is increasingly changing on-site safety, providing the chance for safety professionals to introduce proactive measures to minimize threats to safety.

2.2.2. Virtual Reality

The need for VR to improve construction safety has emerged because traditional capacity-building methods do not meet the objective of inculcating students and workers with effective, practical, and hands-on hazard-identification safety knowledge. VR prepares people for unforeseen problems that may occur due to various kinds of mismanagement on-site [21]. It tends to increase engagement [22], and the headsets can provide users with lifelike immersion [23]. In VR, BIM-based models are imported into a gaming engine, e.g., the Unreal Engine, and the final immersion is achieved via head-mounted devices [24]. The user can immerse in a virtual environment either with a head-mounted VR device, in which the screens are close to the eyes or by using two or three large, projected screens. This second type of setup is called a cave automatic virtual environment (CAVE) [25]. Sacks et al. [26] focused on improving collaboration between the design and execution teams using CAVE, resulting in safety improvements. A CAVE system provides a VR-based experience to teams so they can detect safety hazards proactively. VR is now being used extensively for the capacity building of workers. Teizer et al. [27] integrated location tracking and VR for training iron workers. The distinguishing benefit of this technology is that the training can be provided repeatedly without using physical resources each time. Pedro et al. [28] compared the effectiveness of traditional methods of training with the Virtual Safety Education Framework (VSES), a system whose modules focus on safety capacity building. The VSES consists of various safety scenarios that are projected in VR and are based on safety documents. The results of paper- and virtual-reality-based training were compared, and VSES was clearly much stronger in the aspects of students' understanding, knowledge, and grasp of safety concepts.

2.2.3. Augmented Reality

Like VR, AR is also an immersive interactive technology that helps users to interact with real-world-like environments. However, this technology manifests a digital image onto the real world. There is an interaction between the real and digital realms, with the imagery produced digitally and projected onto the real world. AR has the ability to intermix the real world with virtual world simulations [29]. Many researchers have studied AR, developing systems and prototypes to evaluate its potential for safety improvement. One such system is the System for Augmented Virtuality Environmental Safety, which was presented to address the ineffectiveness of existing training modules [30]. It enhances safety training by providing educational and performance-based tasks. According to Chen et al. [31], the traditional training methods, lectures and videos, tend to have a retention rate of under 20%, whereas the involvement of 3D-based exercises could increase that rate to 75%. Park et al. [32] approached safety improvement using an amalgam of technologies: BIM, location tracking, AR, and game technologies. They introduced a safety management and visualization system, which is a framework aimed at capacity building of workers to mitigate safety risks and eventually increase communication among stakeholders.

2.2.4. Wireless Sensor Networks and Cloud Technology

A wireless sensor network is a technology that is part of the "internet of things," which senses objects and communicates environmental conditions [33]. Riaz et al. [34] integrated BIM and WSN to evaluate real-time thermal conditions in congested workspaces. Their application of the Confined Space Monitoring System (CoSMoS) integrated BIM add-ins and sensor data to solve construction safety problems. Similarly, Cheung et al. [33] integrated BIM and WSN to monitor on-site hazardous gas conditions. Furthermore, BIM can be integrated with other technologies, such as cloud technology, and GIS to help improve construction safety.

Bennett and Mahdjoubi [35] looked into the potential of BIM and cloud technology for construction H&S. They concluded that such integration can not only lead to time and cost savings but can also provide improved worker health and better working conditions. Similarly, the MapSafe system by Zou et al. [2] functions to maintain safety databases, such as meeting records, requests and approvals, safety analysis, and incident reporting. This system is based on the integration of cloud computing, GIS, and mobile technology. The data captured through this system is processed in the cloud, and the refined information can be subsequently visualized and analyzed for rational safety decision making.

2.2.5. Game Technologies

Games have the potential to provide a real-life learning experience by both field training and imparting theoretical knowledge using case scenarios. The use of game engines for skill development has become a growing area of interest for the construction research community, and such engines are increasingly being used for capacity-building purposes in different industries, such as defense, medicine, architecture, and education [36]. Serious games can give a chance for users to interact with a construction site and develop skills accordingly [37]. Traditional training methodologies are not effective for improving the hazard-identification capabilities of workers. According to Dzeng et al. [38], their hazard identification game was significantly better than traditional methods of learning ($p < 0.001$). Their statistical analysis also showed that the interest generated among students was higher than with traditional methods of learning. Serious games have the potential to drastically improve the hazard identification and recognition abilities of users, without having them to be on-site.

2.2.6. RTLS and RFID

Real-time location systems can be used to track the actual locations of workers and construction equipment to give safety warnings [39]. RFID is a data collection technology that receives identification data via radio waves [40]. This technology consists of three components: an RFID tag, an RFID reader, and a corresponding computer application. An active RFID tag contains a battery and transmits signals within the range of the reader, whereas a passive tag does not have a battery and is only active when within range of a reader. A reader receives radio signals from a site and the information is stored in a database [41].

Li et al. [42] integrated BIM and RFID to allow the location and identification of potential hazards on a site and enable the use of proactive strategies. Similarly, Sattineni and Azhar [41] used RFID along with BIM for worker and equipment tracking, ensuring safety monitoring. Costin et al. [43] also integrated BIM and RFID for real-time resource tracking and recording data about safety violations. Zhang et al. [44] developed a spatial network with the integration of BIM and RFID as a safety-management system. Different spaces were marked in BIM models according to their risk levels. In this way, when a worker enters a risky space, an alarm can inform them of the situation.

2.3. Research Needs

To the best of the authors' knowledge, although studies pertaining to BIM have been conducted within the region [45,46], there has been no empirical study covering the whole GCC region that analyzed the potential and scope of VDC tools to help improve construction safety. This paper aims to address this gap in the body of knowledge. This exploratory research aims to improve construction safety in GCC countries by evaluating the current safety levels of VDC tools, analyzing their potential, and examining any barriers preventing them from being implemented on-site. Bridging this gap in the body of knowledge, the findings will provide the necessary information for construction safety practitioners and policymakers to highlight the advantages of VDC technology within the GCC construction industry.

3. Methodology

3.1. Population and Sample Size

The population targeted for this research comprised professional experts from the architecture, engineering, and construction (AEC) industries. To understand and analyze the potential of VDC at the core level, this research used six categories of stakeholders: client, consultant, project management consultant (PMC), prime contractor, sub-contractor, and academic. The respondents from these groups were selected using convenience sampling. This is a type of nonprobability sampling in which respondents are approached on the basis of them being convenient sources of data [47]. According to Israel [48], when no established sampling information (frame or list) of the population exists, the sample size from a similar study can be used. Since the nature of this study was descriptive, the research aimed to evaluate respondents' awareness of the use of VDC for construction safety in GCC countries and sought to obtain their opinions about its potential and any perceived barriers that might prevent its use. In this case, a suitable technique for data collection was to conduct an analytical survey [49] in the form of a research questionnaire. Similar studies conducted in the field [50–52] also used descriptive statistics for analysis of the results. Sample groups were chosen because of their relevance and their adoption of VDC tools and the latest construction safety trends, meaning they would be likely to provide valuable and accurate feedback.

The questionnaires were prepared using a web-based service, and a link to the survey was provided to the respondents through professional networking websites and by email. A total of 150 people were contacted, of which 126 completed the questionnaire, 14 did not answer, and ten questionnaires were incomplete and were hence ineffectual. A response rate of 84% was therefore achieved, and Table 1 shows a breakdown of the questionnaires that were used for the study.

Table 1. Breakdown of successful questionnaires as part of the study.

Organization Role	No. of Distributed Questionnaires	No. of Returned Questionnaires	Returned Questionnaires (%)	No. of Rejected Questionnaires	No. of Accepted Questionnaires	Accepted Percentage (%)
Client	25	22	88	4	21	84
Consultant	25	24	96	5	20	80
Project Management Consultant	25	22	88	3	22	88
Prime Contractor	25	23	92	3	22	88
Sub-contractor	25	22	88	5	20	80
Academic	25	23	92	4	21	84
Total	150	136	91	24	126	84

3.2. Questionnaire Design

Studies [51,53] conducted of similar nature also finalized the questionnaire by passing through rigorous protocol. The design of the questionnaire for this study was carried out in the following five stages:

Stage 1: In the first step, a comprehensive literature review was conducted to understand the dynamics of the construction industry in the GCC. Research works pertaining to digital design technologies and construction safety conditions were analyzed and trends were deconstructed so that a questionnaire could be devised that would obtain the maximum amount of data and knowledge from the respondents.

Stage 2: A preliminary questionnaire examining the potential of VDC for improving construction safety was designed. The questions were formulated in a way that would yield the required response rate, and the simple nature of the questionnaire facilitated data collection.

Stage 3: This questionnaire was distributed to a small number of experts from both industry and academia to understand any discrepancies. During this pilot study, different ideas regarding content, sequencing, and data collection were brainstormed. These valuable suggestions were later used in the preparation of the final questionnaire.

Stage 4: With all the suggestions incorporated, the final questionnaire was devised after some modifications. Overall, the content and layout of the questionnaire were simple and easy to understand, which promoted the retention of the respondent. The questions were established in a coherent manner, starting from answering basic demographic questions and gradually progressing toward digital design technologies and construction safety concepts.

Stage 5: The final prepared questionnaire was distributed to the study sample. Once the required response rate was achieved, the data were analyzed statistically to draw conclusions.

3.3. Questionnaire Specifics

The survey was divided into five sections:

- Part 1: Characteristics of the respondents and organizations.
- Part 2: Current safety conditions in GCC countries.
- Part 3: Understanding the awareness and utility of VDC for construction safety.

- Part 4: Ranking aspects of safety that have the potential to be improved using VDC.
- Part 5: Ranking barriers in implementing VDC to improve construction safety.

Part 1 was further divided into two sub-parts, a and b. Part a collected data regarding the respondent's background, and part b evaluated the capacity of the organization they were associated with. The questions were formulated to obtain an overview of the respondent's educational capability, professional experience, and current designation. Questions relating to the organization's type, role, and sector were also asked.

To obtain information about the problem under consideration, in Part 2, the respondents were asked about their current satisfaction levels regarding safety practices in their respective GCC construction industry. To help retain the respondents, they were asked simple "yes or no" questions in this part. The questions asked were intended not only to obtain a clear picture of current safety practices in the GCC but also to highlight the language barriers in the multicultural and multilingual industry of the region, if any. Part 3 focuses on understanding the current role and future potential that VDC could have in improving safety practices. Within this part, a skip logic was applied, which made sure that respondents with a lack of knowledge on how VDC could improve construction safety would be able to skip to the last part of the questionnaire, which relates to determining the barriers impeding the successful implementation of VDC to improve construction safety. Part 4 is a continuation of the data collection process along the lines of Part 3. If the respondent had some awareness pertaining to digital design technologies, this part allowed them to evaluate the importance of certain factors regarding safety that have the potential for improvement by the incorporation of VDC tools during safety management and planning. The respondents expressed their opinion on a five-point Likert scale of importance. Likert scale ranking may comprise three, five, or even more points, such as Fischhoff et al. [54] using a seven-point scale to determine risk capabilities. Part 5, as mentioned above, aims to rank the barriers that might inhibit the process of technological implementation so that construction safety practices in the GCC could be improved.

3.4. Characteristics of Respondents and Organizations

Table 2 illustrates the highest degree held by the respondents, their professional experience in years, the type of organization, and their organizational role. The convenience sampling approach made sure that the survey reached construction personnel with adequate academic qualifications and industrial experience to obtain high-value information about digital construction trends and job-site safety. The majority of the respondents had a bachelor's degree (52%), and the sample also included those with a diploma and holders of doctorate degrees. A total of 33% of the respondents had a master's qualification in subjects related to AEC.

With respect to professional experience, 36% of the respondents had less than five years' experience, and 33% of the respondents had between six and ten years of experience. More than 32% of the respondents had worked in the industry for more than a decade. More than 80% of the respondents were engaged in the private sector, and 12% were engaged in government entities.

Table 2 shows the demographic details of the respondents according to their geography. The UAE, Saudi Arabia, and Qatar were the countries from which the greatest number of responses were collected: 37%, 23%, and 22%, respectively. This large number of responses as compared with other countries, specifically Kuwait (5%), Bahrain (6%), and Oman (7%), is evidence for these countries embracing the digital wave of construction alongside improving construction practices.

Similarly, Table 3 shows the classification of the respondents by sector. Around 56% of the respondents were connected to the construction industry. This provides evidence for BIM and other related technologies already being a part of workflows in the construction industries of these countries. Other predominant sectors included management (15%), education (8%), and transportation (9%). Since the aim of the study is to analyze the digital mechanisms, the majority of the respondents recognized themselves as BIM professionals (22%). This pool of respondents contained civil engineers

(5%), mechanical engineers (5%), design engineers (6%), planning engineers (10%), project managers (15%), and HSE engineers (3%). A complete breakdown by profession is shown in Table 4.

Table 2. Demographic information of the respondents.

Characteristics of Respondents	Percentage
Highest academic qualification	
Diploma	11
Bachelors	52
Masters	33
Doctorate	4
Demographic information	
United Arab Emirates	37
Saudi Arabia	23
Qatar	22
Oman	7
Bahrain	6
Kuwait	5
Professional experience (years)	
0–5	36
6–10	33
11–15	21
16–20	3
21 and above	7
Organization type	
Government	12
Semi-government	6
Private	82

Table 3. Breakdown by sector.

Sector	Percentage	Frequency
Construction	56	70
Education	8	10
Energy	6	7
Manufacturing	3	4
Transportation	9	11
Administration	3	4
Management	15	20

Table 4. Breakdown by profession.

Profession	Frequency	Percentage
BIM professional	28	22
Mechanical engineer	6	5
Design engineer	8	6
Civil site engineer	6	5
Architect	8	6
Draftsman/CAD operator	5	4
QA/QC engineer	6	5
Materials engineer	3	2
Planning engineer	13	10
HSE engineer	4	3
Academic faculty member	8	6
Project manager	19	16
Researcher	6	5
Sustainability engineer	3	2
Facility maintenance supervisor	1	1
Administrator	2	2

4. Data Analysis

4.1. Analysis of Data

The last parts of the questionnaire, Parts 4 and 5, adopted five- and four-point Likert scale questions measuring the potential of and barriers to VDC technologies being used to improve construction safety. The relative importance index (RII) was used in this regard for tabulation and ranking. The relative importance index can be calculated through the following formula [51]:

$$\mathrm{RII} = \frac{\sum w}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N} \quad (1)$$

where w is the weighting given by each respondent, which ranges from 1 to 5 for Part 4 and from 1 to 4 for Part 5, as shown in Table 5; n_w represents the number of responses at a given weighting w; A is the highest weight that can be given, which, as noted, is 5 for Part 4 and 4 for Part 5; and N is the total number of responses.

Table 5. Likert scale values.

w	Part 4	Part 5
1	Not at all important	Not a barrier
2	Not so important	Somewhat of a barrier
3	Somewhat important	Moderate barrier
4	Very important	Extreme barrier
5	Extremely important	

4.2. Reliability of the Data

To examine whether the responses provided were reliable and had internal consistency, Cronbach's alpha was used, which is a common marker for the reliability of a questionnaire [55]. The value of this coefficient should be greater than 0.7 for data to be considered reliable. The calculated values for Cronbach's alpha, as shown in Table 6, were 0.947 for the construction safety factors that could be improved using BIM and 0.816 for the barriers to implementing BIM for safety. The general reliability of the questionnaire was 0.882, which is greater than 0.7, and hence the reliability of the survey was good.

Table 6. Cronbach's alpha values for Parts 4 and 5.

Part Description	No. of Variables	Cronbach's Alpha
Safety factors that could be improved using BIM	17	0.947
Barriers in BIM to improve safety	11	0.816
Total	28	0.8815

4.3. Normality of the Data

A Kolmogorov–Smirnov (K–S) test was performed to find out whether the data from the questionnaire followed a normal distribution. The mentioned test compares the scores of the sample to normally distributed scores with the same mean and standard deviation, considering the null hypothesis being a normally distributed sample [56]. The significance values for both Parts 4 and 5 were 0.000, which is less than 0.05. It can thus be concluded that the data is not normally distributed, and non-parametric tests were therefore conducted for further analysis. Tables 7 and 8 show the K–S test results for Parts 4 and 5.

4.4. Non-Parametric Analysis

Since it was established that the nature of the data was non-parametric, construction stakeholders were grouped by their organization roles, and significance values for the variables in Parts 4 and 5 were quantified with a Kruskal–Wallis test, as shown in Tables 9 and 10. The significance values were found to be greater than 0.05, and it can, therefore, be said that respondents across all stakeholders and organizational roles shared similar perceptions regarding the questions asked through all parts of the questionnaire.

Table 7. Kolmogorov–Smirnov test for safety factors.

Construction Safety Factors that Can Be Improved Using VDC	Statistic	df	Sig.
Hazard identification and recognition	0.273	79	0.000
Site layout	0.268	79	0.000
Analyzing confined and congested spaces	0.244	79	0.000
Safety training and capacity building of workers	0.236	79	0.000
Safety induction of workers	0.310	79	0.000
Safety reports, internal and external audits	0.275	79	0.000
Toolbox talk meetings	0.200	79	0.000
Safety inspections	0.239	79	0.000
Compliance with OSHA rules and regulations	0.234	79	0.000
Safety designing and planning of temporary structures (scaffolds, stairs, and frameworks)	0.255	79	0.000
Fall-hazard prevention strategies	0.254	79	0.000
Active site safety monitoring for critical activities	0.272	79	0.000
Risk assessment and mitigation	0.247	79	0.000
Better communication between stakeholders	0.244	79	0.000
Designing of emergency and evacuation plans	0.263	79	0.000
Emergency drills	0.278	79	0.000
Inspection of heavy equipment and machinery	0.252	79	0.000

Table 8. Kolmogorov–Smirnov test for barriers.

Barriers to Implementation of VDC Tools	Statistic	df	Sig.
Lack of knowledge about VDC technologies	0.216	126	0.000
High setup, implementation, and maintenance costs	0.218	126	0.000
Lack of effective training	0.250	126	0.000
Lack of knowledge about return on investment for VDC technologies	0.238	126	0.000
Temporary nature of construction projects	0.218	126	0.000
Lack of guidance and SOP for proper implementation of VDC technology for safety	0.227	126	0.000
Not demanded by clients	0.233	126	0.000
Resistance to technological adaptation	0.204	126	0.000
Overall poor safety culture in the construction industry	0.214	126	0.000
Lack of standard practices in the construction industry	0.219	126	0.000
Contractual limitations	0.202	126	0.000

Table 9. Test statistics [a,b] for safety factors that may improve using VDC.

Safety Applications with Potential for Improvement Using VDC	Chi-Squared	df	Asymp. Sig.
Hazard identification and recognition	4.644	5	0.461
Site layout	7.233	5	0.204
Analyzing confined and congested spaces	7.07	5	0.215
Safety training and capacity building of workers	1.758	5	0.882
Safety induction of workers	1.549	5	0.907
Safety reports, internal and external audits	3.477	5	0.627
Toolbox talk meetings	7.56	5	0.182
Safety inspections	7.36	5	0.195
Compliance with OSHA rules and regulations	3.185	5	0.672
Safety designing and planning of temporary structures (scaffolds, stairs, and frameworks)	4.734	5	0.449
Fall-hazard prevention strategies	4.895	5	0.429
Active site safety monitoring for critical activities	2.345	5	0.8
Risk assessment and mitigation	2.674	5	0.75
Better communication between stakeholders	9.449	5	0.092
Designing of emergency and evacuation plans	8.532	5	0.129
Emergency drills	3.294	5	0.655
Inspection of heavy equipment and machinery	4.171	5	0.525

[a] Kruskal–Wallis test. [b] Grouping variable: organization role.

Table 10. Test statistics [a,b] for barriers to implementing VDC.

Barriers Impeding VDC Intervention	Chi-Square	df	Asymp. Sig.
Lack of knowledge about VDC technologies	2.68	5	0.749
High setup, implementation, and maintenance costs	4.142	5	0.529
Lack of effective training	3.859	5	0.57
Lack of knowledge about return on investment for VDC technologies	3.054	5	0.692
Temporary nature of construction projects	5.021	5	0.413
Lack of guidance and SOP for proper implementation of VDC technology for safety	2.369	5	0.796
Not demanded by clients	2.91	5	0.714
Resistance to technological adaptation	10.102	5	0.072
Overall poor safety culture in construction industry	2.216	5	0.818
Lack of standard practices in construction industry	3.531	5	0.619
Contractual limitations	6.484	5	0.262

[a] Kruskal–Wallis Test. [b] Grouping variable: organization role.

5. Results and Discussion

5.1. Current Safety Conditions in the GCC

5.1.1. Safety Perceptions in the GCC

Figure 1 shows that more than 50% of respondents were satisfied with the overall conditions for job-site safety, and 22% of the respondents were neither satisfied nor dissatisfied by the current conditions. A considerable 13% of the respondents believed that job-site conditions are unsatisfactory. The safety conditions of this region have improved with different countries (client and authority bodies), making preventive measures mandatory for local contractors and sub-contractors. Aligning with these results is the regional study [57] conducted for Saudi Arabia, which maintains that although improvements are being made in health and safety standards, there is room for improvement and appropriate proactive measures need to be taken to further mitigate job-site hazards.

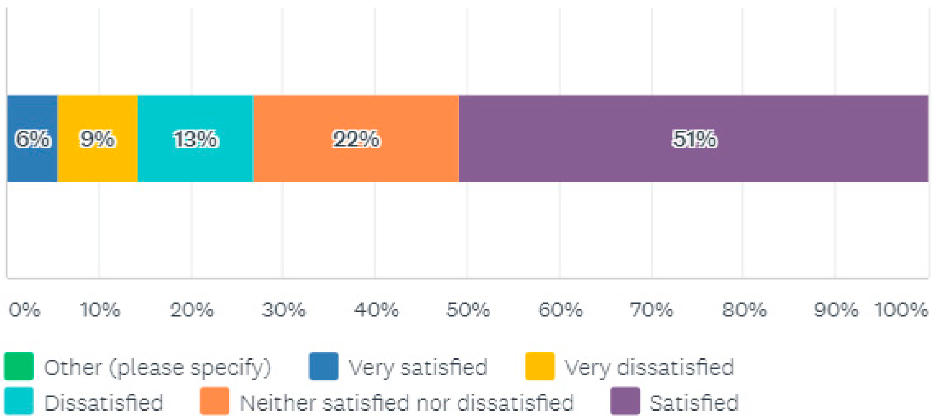

Figure 1. Satisfaction level of on-site safety practices.

5.1.2. Mode of Communication for Safety Instructions in the GCC

With the improving conditions in the GCC's construction industry, digital means are also increasingly being used by stakeholders. A total of 47% of the respondents claimed that safety-related information is communicated verbally, whereas 20% responded that traditional 2D-drawing-based methodology is used for transferring safety-related information. Digital design technologies (computers, tablets, or other IT tools) are being used by 33% of the respondents to communicate or understand safety-related information.

The construction industry of the GCC is influenced by a multicultural, multilingual environment, where employees from different countries of the world (Europe, America, Australia, India, Pakistan, Nepal, Egypt, and Bangladesh) work together to contribute to building infrastructure. As a result, different colloquial means are considered in different situations to communicate instructions, which is a reason for confusion among the workers. Figure 2 shows that the English language is predominantly chosen (71%) to impart safety-related information, while Arabic (8%) and Urdu/Hindi (16%) are also used. Other languages such as Chinese, Malayalam, Nepali, and Bengali are also used. More than 55% of the respondents confirmed that the language spoken and understood by the on-site workers and the language in which safety-related information and training were provided were different. Because of the multicultural nature of the construction industry, different languages are spoken at different levels of the hierarchy. The languages used for communication on-site (Urdu/Hindi) might not be shared by the engineering staff or executive-level staff (English). This difference in language is the main cause of the communication gap and leads to misinterpretation of information, causing injuries. Different safety perceptions among Latino construction workers in United States of America were analyzed by Puerto et al., [58] and it was concluded that mismatch in language causes incorrect assumpptions, miscommunication and possible fatalaties.

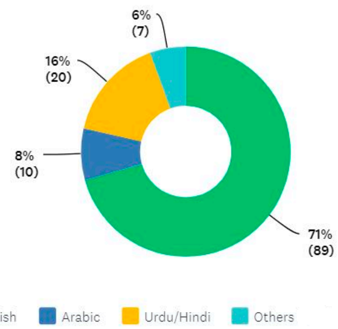

Figure 2. Percentage of languages spoken by respondents.

5.2. VDC Perceptions Regarding Construction Safety

From the analysis, as shown in Figure 3, the current perceptions of stakeholders are such that 39% of the respondents were satisfied when it comes to the use of VDC tools to improve job-site safety conditions. It was found that 21% of the respondents were dissatisfied with the rate at which these tools are being incorporated to improve construction safety.

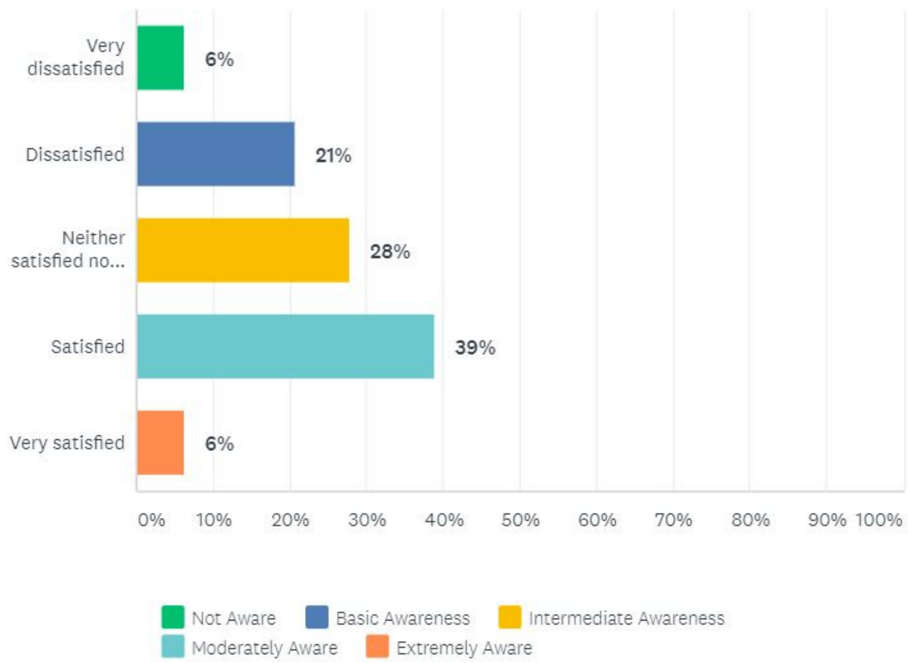

Figure 3. Satisfaction levels regarding using virtual design construction (VDC) tools to improve safety.

The reason for this lack of satisfaction is rooted in the observation that as long as these technologies are not mandatory, contractors are not contractually bound to adopt and incorporate them into workflows and lifecycle processes and will follow a traditional mindset.

In the last stage of this part, respondents were asked if they had any awareness pertaining to digital tools being used to mitigate safety hazards. A total of 63% of the respondents confirmed having knowledge of how digital means can be used to improve safety. These respondents were directed toward Parts 4 and 5 of the survey, whereas people lacking this knowledge skipped these sections and moved to the last part, i.e., barriers impeding the use of technology to improve safety.

5.3. Potential of VDC Tools to Improve Safety

Table 11 shows the different aspects of construction safety ranked by their perceived potential to be improved using VDC technologies. Overall, "designing of emergency and evacuation plans" and "fall-hazard prevention strategies" (RII = 86% and RII = 85%, respectively), were considered to be the most important factors that could be improved using digital design tools. Construction workers usually use their prior experience to ascertain and react to safety hazards. One of the most challenging tasks for them, therefore, is to reckon and respond when they are exposed to such threats. Hazards that are difficult to predetermine are very difficult to assuage, and this leads to flaws in the design of a safety program [59].

The 3D visualization aspect of these tools helps improve traditional constructability analysis schemes, which are predominantly based on 2D-drawing-based methodologies. Traditional schemes can create confusion, as important decisions are made on inadequate information. With the advent of BIM, the constructability analysis for safety managers has become easier, and suitable mitigation strategies are now devised proactively to avoid threats.

"Hazard identification" and "safety designing and planning of temporary structures (scaffolds, stairs, and frameworks)" were ranked second, with RII = 85%. Similarly, "safety induction of workers" was ranked fifth, with RII = 84%. Ganah et al. [60] noted that BIM is not only being widely used at the design stage but also has the potential to improve on-site safety induction, reducing probable hazards.

Since BIM is mandated in many regions of the Middle East, different studies [15,51] have shown that its integration with different rule-checking algorithms and VR can help in the earlier detection of hazards. The same 3D model can be integrated with drones and RFID packages for the invigilation of workers on site. Similarly, it is possible to proactively monitor the health conditions of workers on site. The high temperatures in the GCC countries tend to cause causalities, and the application of VDC tools to active health monitoring has the potential to be very useful to ensure active on-site treatment and avoid lapses.

"Better communication between stakeholders", "risk assessment and mitigation", and "active site safety monitoring for critical activities" were all ranked similarly (sixth) by the stakeholders (RII = 83%). These factors are related to bridging the communication gap between stakeholders. Since it was established earlier in the research that major language differences exist between stakeholders of the construction industry, 3D visualization techniques can better identify safety hazards and enable stakeholders to avoid risk. Similarly, the language barriers in GCC countries could be minimized by VR-based safety training of workers. Pre-construction visualization training could help workers to get a feel for real-life safety hazards before construction commences. This training could enhance the hazard-determination ability of workers, showing a real-time construction environment and providing continual feedback throughout training [61]. This has been ranked as the ninth-most-important factor that can be improved using VDC tools. Various studies have shown a significant increase in workers' abilities to proactively detect hazards and make suitable decisions accordingly. "Emergency drills" and "analyzing confined and congested spaces" were also ranked ninth, with RII = 81%.

Table 11. Relative importance index and ranking of safety factors that can be improved using VDC tools.

		Client		**Consultant**		**Project Management Consultant (PMC)**		**Prime Contractor**		**Subcontractor**		**Academic**		**Overall Rank**	
Sr. No	Safety Factors	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank
1	Designing of emergency and evacuation plans	88.00	5	87.50	1	73.33	15	80.69	5	89.33	1	95.00	1	86	1
2	Fall-hazard prevention strategies	80.00	14	81.25	11	86.67	1	83.45	1	82.67	4	95.00	1	85	2
3	Safety designing and planning of temporary structures (scaffolds, stairs, and frameworks)	88.00	5	83.75	8	86.67	1	81.38	5	82.67	4	85.00	3	85	2
4	Hazard identification and recognition	92.00	3	85.00	6	86.67	1	81.38	5	77.33	16	85.00	3	85	2
5	Safety induction of workers	88.00	5	87.50	1	80.00	6	79.31	10	86.67	2	80.00	6	84	5
6	Risk assessment and mitigation	96.00	1	78.75	15	77.78	11	80.69	5	86.67	2	80.00	6	83	6
7	Active site safety monitoring for critical activities	88.00	5	80.00	13	86.67	1	82.07	2	82.67	4	80.00	6	83	6
8	Better communication between stakeholders	96.00	1	87.50	1	71.11	16	80.00	9	82.67	4	80.00	6	83	6
9	Analyzing confined and congested spaces	92.00	3	86.25	4	80.00	6	82.07	2	76.00	17	70.00	13	81	9
10	Safety training and capacity building of workers	84.00	12	83.75	8	80.00	6	79.31	10	82.67	4	75.00	11	81	9
11	Emergency drills	80.00	14	83.75	8	80.00	6	76.55	15	78.67	12	85.00	3	81	9
12	Inspection of heavy equipment and machinery	88.00	5	76.25	16	82.22	5	78.62	10	80.00	10	75.00	11	80	12
13	Safety inspections	88.00	5	86.25	4	75.56	13	77.93	14	81.33	9	70.00	13	80	12
14	Site layout	80.00	14	85.00	6	80.00	6	82.07	2	78.67	12	65.00	16	78	14
15	Safety reports, Internal and external audits	84.00	12	76.25	16	75.56	13	73.79	17	78.67	12	80.00	6	78	14
16	Compliance with OSHA rules and regulations	76.00	17	81.25	11	77.78	11	78.62	10	80.00	10	70.00	13	77	16
17	Toolbox talk meetings	88.00	5	80.00	13	71.11	16	75.17	16	78.67	12	65.00	17	76	17

Factors such as "safety inspections" and "inspections of heavy equipment and machinery" were ranked in 12th place, with a RII of 80%. With the help of digital design tools, the inspection of dangerous formwork, equipment, and machinery can become very easy, without putting the lives of safety personnel at risk.

"Site layout" and "safety reports, internal and external audits" were ranked by the respondents with RII = 78%. Three-dimensional simulations can play a key role in determining actions that should be proactively taken so that particular activities can be conducted safely at the actual site. "Compliance with OSHA rules and regulations" and "toolbox talk meetings" were ranked at 16th and 17th place, with relative importance indices of 77% and 76%, respectively.

5.4. Barriers to Adopting Digital Design Tools for Construction Safety in the GCC

Table 12 lists the barriers with respect to the rank obtained, according to their RII. The final devised ranking is a cumulative score for each barrier from the scores provided by individual stakeholders (clients, consultants, PMCs, prime contractors, sub-contractors, and academics). This helps to dissect the problem from each individual construction industry stakeholder's perspective and therefore devise a suitable strategy to improve the application of technology to hazard prevention. Overall, "lack of knowledge about return on investment for VDC" was the predominant barrier in the implementation of technology to improve construction safety, with an RII of 77%. For both PMCs (79%) and prime contractors (77%), this was the major barrier to adopting digital design methodologies to improve safety. Consistent with the findings of this study, different studies [62] of similar nature also indicated that lack of knowledge is why these technologies have not been accepted widely in industries. For clients, with an RII of 78%, "not demanded by clients" was a predominant factor impeding the use of technological advancements for construction safety. This finding is in line with the study [63], which also indicated that the primary reason for lack of BIM implementation is "lack of demand of client". This is because most of these initiatives are initiated by local authority bodies (RTA, Qatar Rail, and ADA), and if the technological implications are not reinforced, other stakeholders will not show an active interest in their implementation.

"Lack of knowledge about VDC" and "lack of effective training" tools were the second and third major barriers impeding the use of technology to improve job-site safety. Similar studies [64,65] conducted across different regions also pointed out that lack of training was an essential issue in BIM implementation. Even though advanced research-based solutions and frameworks have been defined, most of these prototypes are in the initial stages of industrial acceptance and implementation. With the constraint of limited time, it therefore becomes a complex task of building the capacity of employees to adopt these technologies and extract their benefits.

A related barrier, "lack of guidance and standard operating procedures (SOP) for proper implementation of VDC technology for safety" was ranked in fifth place, with an RII of 72%. This shows that, primarily, the training and educational aspects of these technologies needs a push from industries in the region to promote H&S.

The difficulty of introducing new technology into existing rudimentary workflows can lead to resistance across the board among stakeholders. As per Kartam et al. [66], the lack of management commitment to safety is one of the reasons behind the poor safety culture observed in Kuwait. This "resistance to technological adaptation" has been ranked as the sixth-most-important barrier, with an RII of 71%. According to a study by Hatem et al. [67], the presence of older employees and people's familiarity with existing software can prevent them from adapting to new software and tools. Similarly, "high setup, implementation, and maintenance costs" also ranked sixth in the list of barriers. It is difficult to generate VR-based simulations and manage all the equipment involved, such as unmanned aerial vehicles and drones, at the construction site. Software related to BIM is quite expensive, and with shrinking profitability and debilitating economic conditions, it becomes difficult for those in the sub-contractor stratum to invest in these technologies.

Table 12. Rankings of barriers to improve construction safety using VDC.

		Client		**Consultant**		**Project Management Consultant (PMC)**		**Prime Contractor**		**Sub-Contractor**		**Academic**		**Overall Rank**	
Sr. No	Barriers	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank
1	Lack of knowledge about return on investment for VDC technologies	70%	4	80%	2	79%	1	77%	1	75%	2	84%	1	77%	1
2	Lack of knowledge about VDC technologies	70%	4	80%	2	79%	1	72%	4	72%	3	82%	3	76%	2
3	Lack of effective training	73%	2	76%	8	68%	8	74%	3	77%	1	84%	1	75%	3
4	Not demanded by clients	78%	1	80%	2	70%	6	76%	2	68%	6	73%	6	74%	4
5	Lack of guidance and SOP for proper implementation of VDC technology for safety	68%	6	79%	5	68%	8	71%	5	72%	3	77%	4	72%	5
6	Resistance to technological adaptation	65%	9	81%	1	71%	5	69%	7	63%	10	75%	5	71%	6
7	High setup, implementation, and maintenance costs	73%	2	78%	7	73%	4	70%	6	63%	9	68%	8	71%	6
8	Contractual limitations	68%	6	79%	5	63%	10	63%	10	66%	7	70%	7	68%	8
9	Overall poor safety culture in construction industry	68%	6	70%	11	75%	3	63%	10	64%	8	68%	8	68%	8
10	Lack of standard practices in construction industry	63%	10	76%	8	70%	6	65%	9	71%	5	61%	9	68%	8
11	Temporary nature of construction projects	58%	11	74%	10	57%	11	66%	8	64%	8	61%	9	63%	11

Even with the acceptance of these technologies into traditional construction workflows, a major problem in construction management is "contractual limitations" (ranked eighth). Although the benefits of these novel practices might mitigate construction safety hazards, there may also be implications for the contractual bindings of the project. It can be difficult to contractually embrace new technology because all stakeholders try to refrain from legal bindings. Other similar construction management problems include "overall poor safety culture" and "lack of standard practices" in the construction industry; both shared the eighth rank, with RII = 68%.

Although the construction industry of the GCC is well-developed and considered to be one of the most up-to-date construction industries, its safety culture is only mandated by strict restrictions set by the regulatory authorities. This safety culture could be improved if the same bodies engaged with BIM, VR, and AR tools to mitigate construction safety problems.

Finally, the "temporary nature of construction projects" (RII = 63%) was found to be a contributing barrier that can make stakeholders refrain from investing too much in these strategies.

6. Conclusions

Virtual design and construction tools and technologies have changed the dynamics of global construction. Although the construction industry is late in adopting these tools, using them has improved its various intrinsic problems, including job-site safety. A large amount of research is being conducted into VDC tools, including in the GCC region, where some of these tools are already being applied due to its well-established and advanced construction industry.

This paper evaluates the current state of the safety aspects in the GCC's construction industry and the potential for improving it using virtual design and construction (VDC) tools. Countries in the region are embracing massive vertical constructions, each bringing innovative designs and architecture. This leads to complexity in execution, which may, in turn, lead to safety lapses. Keeping this in view, strict H&S policies are being enacted throughout the region to avoid these issues as much as possible. Using VDC technology, this region can extract the maximum benefit in terms of ensuring safety. The GCC's construction industry comprises people from different cultures and of different nationalities. Being a "melting pot" for specialized workers from different regions, it can be labeled as a multilingual industry. This study revealed that safety-related information tends to be delivered in a different language from that actually spoken on-site. Similarly, there is not a single language that is spoken consistently throughout the workforce, and different languages are spoken at different hierarchical levels. These differences in language may be a reason that safety information is not delivered properly.

This paper concludes that the use of VDC tools (e.g., BIM and virtual reality) can reduce the language barriers in communicating job-site safety to such a multilingual industry, which would improve overall safety practices in the region. This paper presents the results of a questionnaire survey, which also confirms that VDC tools should be widely used to bring more clarity to traditional constructability review techniques to improve safety. For example, when asked about the aspects of construction safety that could be improved by incorporating VDC, the respondents claimed that "design of emergency and evacuation plans", "fall-hazard prevention strategies", and "safety designing and planning of temporary structures (scaffolds, stairs, and frameworks)" have the most potential for improvement if VDC technology were incorporated into traditional workflows. Similarly, when respondents were asked about the major barriers that could impede the implementation of VDC to improve construction safety, they claimed that "lack of knowledge about return on investment for VDC technologies" and "lack of knowledge about VDC" were the most significant barriers to the implementation of these tools to improve safety.

This study holistically examined construction safety, VDC, and the current market scenario in the GCC and is a steppingstone for researchers and stakeholders to understand the current conditions across all these dimensions. Some GCC countries have already enforced BIM and safety-related policies, but more work needs to be done to infuse the concept of using VDC for safety. Researchers need to develop tools and plugins incorporating local safety clauses to enhance safety. Steps should also be taken across all stakeholder levels to implement initiatives to improve construction safety. Industry and academia should work together to improve construction safety. Joint ventures between government municipalities, universities, and private entities can drive forward the current path of VDC to improve construction safety.

Author Contributions: Conceptualization, M.T.S.; data curation, M.A.; formal analysis, M.A.; investigation, M.A.; methodology, M.A.; writing—original draft, M.A.; writing—review and editing, M.T.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zou, P.X.W.; Lun, P.; Cipolla, D.; Mohamed, S. Cloud-based safety information and communication system in infrastructure construction. *Saf. Sci.* **2017**, *98*, 50–69. [CrossRef]
2. Mo, Y.; Zhao, D.; Du, J.; Liu, W.; Dhara, A. Data-driven approach to scenario determination for VR-based construction safety training. *Constr. Res. Congr.* **2018**, 116–125. [CrossRef]
3. Koehn, E.; Kothari, R.K.; Pan, C. Safety in Developing Countries: Professional and Bureaucratic Problems. *J. Constr. Eng. Manag.* **1995**, *121*, 261–265. [CrossRef]
4. Malekitabar, H.; Ardeshir, A.; Sebt, M.H.; Stouffs, R. Construction safety risk drivers: A BIM approach. *Saf. Sci.* **2016**, *82*, 445–455. [CrossRef]
5. Fischer, M.; Kunz, J. The scope and role of Information Technology in construction. *Tech. Rep.* **2004**, *156*, 1–31. [CrossRef]
6. Azhar, S. Role of visualization technologies in safety planning and management at construction jobsites. *Procedia Eng.* **2017**, *171*, 215–226. [CrossRef]
7. Rajendran, S.; Clarke, B. Building Information Modeling: Safety benefits and opportunities. *Prof. Saf.* **2011**, *56*, 44–51.
8. Staff, E. Deloitte GCC Powers of Construction 2018 Report—Has the Industry Turned the Corner? 2019. Available online: http://www.dubaichronicle.com/2019/03/06/gcc-powers-of-construction-2018-report-has-the-industry-turned-the-corner/ (accessed on 1 October 2019).
9. GCC Construction Project Value Exceeds Dhs9.25 Trillion in June. Available online: https://www.gulftoday.ae/business/2019/07/02/gcc-construction-project-value--exceeds-dhs9-25-trillion-in-june (accessed on 15 October 2019).
10. Umar, T.; Egbu, C.; Honnurvali, M.S.; Saidani, M.; Al-Bayati, A.J. Briefing: Status of occupational safety and health in GCC construction. *Proc. Inst. Civ. Eng. Manag. Procure. Law* **2019**, *172*, 137–141. [CrossRef]
11. HRW (Human Right Watch). *Qatar: Take Urgent Action to Protect Construction Workers*; Human Right Watch: New York, NY, USA, 2018; Available online: https://www.hrw.org/news/2017/09/27/qatar-take-urgent-action-protect-construction-workers (accessed on 10 October 2019).
12. Bahrain: Over 200 Workplace Accidents, Including 12 Deaths, Documented in 2018: Business & Human Rights Resource Centre. 2018. Available online: https://www.business-humanrights.org/en/bahrain-over-200-workplace-accidents-including-12-deaths-documented-in-2018 (accessed on 25 October 2019).
13. GOSI (General Organization for Social Insurance). Riyadh, Saudi Arabia: Open Data Library. 2018. Available online: https://www.gosi.gov.sa/GOSIOnline/Open_Data_Library&locale=en_US (accessed on 28 October 2019).
14. Paulson, B. Designing to reduce construction costs. *J. Constr. Div.* **1976**, *102*, 588.
15. Azhar, S.; Khalfan, M.; Maqsood, T. Building information modeling (BIM): Now and beyond. *Australas. J. Constr. Econ. Build.* **2012**, *12*, 15–28.
16. Hayne, G.; Kumar, B.; Hare, B. The development of a framework for a design for safety BIM tool. *Comput. Civ. Build. Eng.* **2014**, 49–56. [CrossRef]
17. Hossain, M.A.; Abbott, E.L.; Chua, D.K.; Nguyen, T.Q.; Goh, Y.M. Design-for-Safety knowledge library for BIM-integrated safety risk reviews. *Autom. Constr.* **2018**, *94*, 290–302. [CrossRef]

18. Zhang, S.; Lee, J.-K.; Venugopal, M.; Teizer, J.; Eastman, C.M. A framework for automatic safety checking of building information models. *Constr. Res. Congr.* **2012**, 574–581. [CrossRef]
19. Schwabe, K.; König, M.; Teizer, J. BIM Applications of Rule-Based Checking in Construction Site Layout Planning Tasks. In Proceedings of the 33rd international symposium on Automation and Robotics in Construction (ISARC), Auburn, AL, USA, 18–21 July 2016. [CrossRef]
20. Zhang, S.; Boukamp, F.; Teizer, J. Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA). *Autom. Constr.* **2015**, *52*, 29–41. [CrossRef]
21. Goulding, J.; Nadim, W.; Petridis, P.; Alshawi, M. Construction industry offsite production: A virtual reality interactive training environment prototype. *Adv. Eng. Inf.* **2012**, *26*, 103–116. [CrossRef]
22. Pena, A.M.; Ragan, E.D. Contextualizing Construction Accident Reports in Virtual Environments for Safety Education. In Proceedings of the IEEE Virtual Reality (VR), Los Angeles, CA, USA, 18–22 March 2017. [CrossRef]
23. Froehlich, M.; Azhar, S. Investigating Virtual Reality Headset Applications for Construction Education and Practice. In Proceedings of the 52nd ASC annual international conference, Provo, UT, USA, 13–16 April 2016; pp. 13–16.
24. Hilfert, T.; Teizer, J.; König, M. First person virtual reality for evaluation and learning of construction site safety. In Proceedings of the 33rd international symposium on Automation and Robotics in Construction (ISARC), Auburn, AL, USA, 18–21 July 2016. [CrossRef]
25. Jeelani, I.; Han, K.; Albert, A. Development of immersive personalized training environment for construction workers. *Comput. Civ. Eng.* **2017**, 407–415. [CrossRef]
26. Sacks, R.; Whyte, J.; Swissa, D.; Raviv, G.; Zhou, W.; Shapira, A. Safety by design: Dialogues between designers and builders using virtual reality. *Constr. Manag. Econ.* **2015**, *33*, 55–72. [CrossRef]
27. Teizer, J.; Cheng, T.; Fang, Y. Location tracking and data visualization technology to advance construction ironworkers education and training in safety and productivity. *Autom. Constr.* **2013**, *35*, 53–68. [CrossRef]
28. Pedro, A.; Le, Q.T.; Park, C.S. Framework for integrating safety into construction methods education through interactive virtual reality. *J. Prof. Issues Eng. Educ. Pract.* **2016**, *142*, 04015011. [CrossRef]
29. Limsupreeyarat, P.; Yabuki, N.; Tongthong, T. Toward the Improvement of Safety Planning for Construction Activities Performed at High Elevation by Using Augmented Reality. In Proceedings of the International Conference on Computing in Civil and Building Engineering, Nottingham, UK, 30 June–2 July 2010; Volume 30.
30. Chen, A.; Golparvar-Fard, M.; Kleiner, B. SAVES: A Safety Training Augmented Virtuality Environment for Construction Hazard Recognition and Severity Identification. In Proceedings of the 13th International Conference on Construction Applications of Virtual Reality, London, UK, 30–31 October 2013; pp. 373–384.
31. Chen, A.; Golparvar-Fard, M.; Kleiner, B. Design and development of SAVES: A construction safety training augmented virtuality environment for hazard recognition and severity identification. *Comput. Civ. Eng.* **2013**, 841–848. [CrossRef]
32. Park, C.-S.; Kim, H.-J. A framework for construction safety management and visualization system. *Autom. Constr.* **2013**, *33*, 95–103. [CrossRef]
33. Cheung, W.-F.; Lin, T.-H.; Lin, Y.-C. A Real-Time Construction Safety Monitoring System for Hazardous Gas Integrating Wireless Sensor Network and Building Information Modeling Technologies. *Sensors* **2018**, *18*, 436. [CrossRef] [PubMed]
34. Riaz, Z.; Parn, E.A.; Edwards, D.J.; Arslan, M.; Shen, C.; Pena-Mora, F. BIM and sensor-based data management system for construction safety monitoring. *J. Eng. Des. Technol.* **2017**, *15*, 738–753. [CrossRef]
35. Bennett, L.; Mahdjoubi, L. Construction Health and Safety, BIM and Cloud Technology: Proper Integration Can Drive Benefits for All Stakeholders. In Proceedings of the IEEE 5th International Conference on Cloud Computing Technology and Science, Bristol, UK, 2–5 December 2013; Volume 2013. [CrossRef]
36. Mohd, N.I.; Ali, K.N.; Bandi, S.; Ismail, F. Exploring gamification approach in hazard identification training for Malaysian construction industry. *Int. J. Built Environ. Sustain.* **2019**, *6*, 51–57. [CrossRef]
37. Miller, G.A.; Dawood, N.N.; Kassem, M. Building an emergent learning environment for construction health and safety by merging serious games and 4D planning. *Comput. Civ. Eng.* **2012**, 129–136. [CrossRef]
38. Dzeng, R.J.; Hsueh, H.H.; Chang, R.N. 3D Game-Based Training System for Hazard Identification on Construction Site. In Proceedings of the 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Zhangjiajie, China, 15–17 August 2015. [CrossRef]

39. Setayeshgar, S.; Hammad, A.; Vahdatikhaki, F.; Zhang, C. Real-time safety risk analysis of construction projects using BIM and RTLS. In Proceedings of the 30th international symposium on Automation and Robotics in Construction and Mining (ISARC 2013): Building therapeutic future in automation and robotics, Montreal, QC, Canada, 11–15 August 2013. [CrossRef]
40. Cheng, T.; Teizer, J. Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications. *Autom. Constr.* **2013**, *34*, 3–15. [CrossRef]
41. Sattineni, A.; Azhar, S. Techniques for Tracking RFID Tags in a BIM Model. In Proceedings of the 27th International Symposium on Automation and Robotics in Construction, Bratislava, Slovakia, 25–27 June 2010. [CrossRef]
42. Li, B.; Du, Z.; Xie, D.; Huang, L. Research on Engineering Construction Safety Integration based on BIM and RFID. *MATEC Web Conf.* **2018**, *246*, 03035. [CrossRef]
43. Costin, A.M.; Teizer, J.; Schoner, B. RFID and BIM-enabled worker location tracking to support real-time building protocol and data visualization. *J. Inf. Technol. Constr.* **2015**, *20*, 495–517.
44. Zhang, C.; Chen, J.; Yang, Y.; Hammad, A. Experimental Investigation of Using RFID Integrated BIM Model for Safety and Facility Management. In Proceedings of the 13th international conference on Construction Application of Virtual Reality, London, UK, 30–31 October 2013.
45. Hassan, M.A. Implementation of Building Information Modeling (BIM): Practices and Barriers in Construction Industry in GCC. Master's Thesis, Heriot-watt University, Edinburgh, UK, 2012.
46. Gerges, M.; Austin, S.; Mayouf, M.; Ahiakwo, O.; Jaeger, M.; Saad, A.; El Gohary, T. An investigation into the implementation of Building Information Modeling in the Middle East. *J. Inf. Technol. Constr.* **2017**, *22*, 1–15.
47. Lavrakas, P.J. *Encyclopedia of Survey Research Methods*; SAGE Publications: Newbury Park, CA, USA, 2008.
48. Israel, G.D. Determining Sample Size. In *Institute of Food and Agricultural Sciences (IFAS)*; University of Florida: Gainesville, FL, USA, 2013; Volume 6, pp. 1–5.
49. Forza, C. Survey research in operations management: A process-based perspective. *Int. J. Oper. Prod. Manag.* **2002**, *22*, 152–194. [CrossRef]
50. Wu, W.; Issa, R.R. BIM education and recruiting: Survey-based comparative analysis of issues, perceptions, and collaboration opportunities. *J. Prof. Issues Eng. Educ. Pract.* **2014**, *140*, 04013014. [CrossRef]
51. Enshassi, A.; Ayyash, A.; Choudhry, R.M. BIM for construction safety improvement in Gaza Strip: Awareness, applications and barriers. *Int. J. Constr. Manag.* **2016**, *16*, 249–265. [CrossRef]
52. Enshassi, L.; AbuHamra, S.M. Barriers to implementation of building information modelling (BIM) in the palestinian construction industry. *Int. J. Constr. Proj. Manag.* **2016**, *8*, 103.
53. Suermann, P.C.; Issa, R.R. Evaluating industry perceptions of building information modelling (BIM) impact on construction. *J. Inf. Technol. Constr.* **2009**, *14*, 574–594.
54. Fischhoff, B.; Slovic, P.; Lichtenstein, S.; Read, S.J.; Combs, B. How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy Sci.* **1978**, *9*, 127–152. [CrossRef]
55. Garson, G.D. *Validity and Reliability (Statistical Associates Blue Book Series 12)*; Statistical Associates Publishers: New York, NY, USA, 2013.
56. Ghasemi, A.; Zahediasl, S. Normality tests for statistical analysis: A guide for non-statisticians. *Int. J. Endocrinol. Metab.* **2012**, *10*, 486–489. [CrossRef]
57. Suresh, S.; Renukappa, S.; Alghanmi, I.; Mushatat, S.; Olayinka, R. Examining the Satisfaction Level of Construction Workers Regarding Safety Management in the Kingdom of Saudi Arabia. *J. Constr. Dev. Ctries* **2017**, *22*, 97–113. [CrossRef]
58. Vazquez, R.F.; Stalnaker, C.K. Latino workers in the construction industry. *Prof. Saf.* **2004**, *49*, 24–28.
59. Al-Hammad, A.M.; Assaf, S. Assessment of work performance of maintenance contractors in Saudi Arabia. *J. Manag. Eng.* **1996**, *12*, 44–49. [CrossRef]
60. Ganah, A.A.; John, G.A. BIM and project planning integration for on-site safety induction. *J. Eng. Des. Technol.* **2017**, *15*, 341–354. [CrossRef]
61. Pereira, R.E.; Gheisari, M.; Esmaeili, B. Using panoramic augmented reality to develop a virtual safety training environment. *Constr. Res. Congr.* **2018**, 29–39. [CrossRef]
62. Chan, C.T. Barriers of Implementing BIM in Construction Industry from the Designers' Perspective: A Hong Kong Experience. *J. Syst. Manag. Sci.* **2014**, *4*, 24–40.

63. Bosch-Sijtsema, P.; Isaksson, A.; Lennartsson, M.; Linderoth, H.C. Barriers and facilitators for BIM use among Swedish medium-sized contractors—"We wait until someone tells us to use it". *Vis. Eng.* **2017**, *5*, 3. [CrossRef]
64. Liu, S.; Xie, B.; Tivendal, L.; Liu, C. Critical barriers to BIM implementation in the AEC Industry. *Int. J. Mark. Stud.* **2015**, *7*, 162. [CrossRef]
65. Kassem, M.; Brogden, T.; Dawood, N. BIM and 4D planning: A holistic study of the barriers and drivers to widespread adoption. *J. Constr. Eng. Proj. Manag.* **2012**, *2*, 1–10. [CrossRef]
66. Kartam, N.A.; Flood, I.; Koushki, P. Construction safety in Kuwait: Issues, procedures, problems, and recommendations. *Saf. Sci.* **2000**, *36*, 163–184. [CrossRef]
67. Hatem, W.A.; Abd, A.M.; Abbas, N.N. Barriers of adoption building information modeling (BIM) in construction projects of Iraq. *Eng. J.* **2018**, *22*, 59–81. [CrossRef]