VR Systems into the Construction Industry

Subjects: Construction & Building Technology

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The construction industry is characterized by its diversity and competitiveness, encompassing a wide range of numerous and interconnected operations and materials. These factors have a significant impact on various aspects of society, such as culture, economy, and environment, throughout the entire lifespan of construction projects.

Keywords: construction innovation ; construction revolution ; digital construction ; project performance ; virtual reality

1. Application of Virtual Reality Practices

The integration of VR systems into the construction industry could be applicable in the whole life cycle of a construction project, which includes the design, construction, and post-construction phases. Behzadi [1] and Ahmed [2] asserted that VR is effectively utilized as a visualization tool, worker training technology, safety management, time management, cost management, design development and quality, and defects management tool. They also added that it could be used to recruit and preserve new workers and methods in cases of shortage of fit workforce.

1.1. Pre-Construction/Design Phase

VR has earned its relevance in the construction industry as a result of its numerous application areas in the whole life cycle of a construction project [3][4]. According to Ahmed [2], VR could be used for design development and clash detection, as it helps designers interact with real-world project and deal with any shortcoming of the design before it occurs. Bashabsheh et al. [5] asserted that the use of VR is worthwhile in the design phase of construction, as it increases the designer's realization of the building component assembly and correlates the relationship between the structural system and the architectural design. Wang et al. [6] also corroborated that VR helps the design team have a firm idea of the client's perspective and ascertain their commitment to the project, thereby reducing the time spent on unnecessary variations in design to accommodate the client's preferences. VR in connection with BIM could also help quantity surveyors to minimize the number of assumptions during taking off 2D drawings, as they could make automated measurements of work either from the immersive or the non-immersive systems.

1.2. Construction Phase

The construction phase of any project involves implementing the detailed design that was already planned during the pre-contract stage and proper performance monitoring [7]. The construction phase encompasses the diver's construction activities and process, which when put together under proper management and monitoring, helps achieve the sole aim of the construction [8]. This section will briefly review the important construction activities in which VR could be applied.

Sacks et al. [9] used 3D-immersive VR to train students on in situ concrete works. They found that using VR during training is more effective, as it helps to maintain the trainee's attention and concentration. They further encouraged the adoption of VR for safety training programs. Similarly, in a study conducted by Shi et al. [10], it was justified that VR is indeed effective in training students for cast-in-situ concrete works. Traditional masonry construction is characterized by its heavy reliance on labor and time, encountering challenges arising from the use of modern materials and construction methods [11]. In the past years, techniques were developed to meet these requirements and needs. Nevertheless, these techniques are still labor-intensive, which are scarce and expensive [12]. To this end, a mortarless masonry system has been introduced to improve the constructability and performance of masonry. Sampaio et al. [13] took advantage of the VR simulation capability to visualize the construction processes of a masonry cavity wall and a bridge in a learning environment. They further stated that VR is very effective in demonstrating the sequential construction processes of the cavity wall and bridge, thereby improving the learning of the students in the construction of cavity walls and bridges. According to Moynihan et al. [14], over one-quarter of steel produced annually is used in the construction of buildings, which climate change experts advise against. Yang and Chan (2018) also asserted that structural steel works for a building have grown worldwide, as the number of steel-framed buildings is less than 2% of all buildings. They further stated that cost has been

the primary setback to the adoption of steel structures. Their research aimed at addressing the relevant cost issues concerning structural steel works. The researchers discovered that the expenses associated with constructing structural steel works are unavoidably expensive, and opting for steel-framed structures does not offer a notable advantage in terms of enhancing the construction timeline [15].

Interior finishing work often exhibits traits of uncertainty, instability, and inefficiency, with a tendency towards generating waste. It is not bound by technical limitations necessitating floor-by-floor execution, leading to multiple subcontractors being involved in its implementation [16]. Alrashed and Asif [17] revealed that there still exists a lack of awareness regarding glazing and thermal insulation, despite the improvement in the development of energy-efficient homes. To save energy in constructed or existing buildings, different measures could be taken into consideration, such as external insulation of the building. The utilization of glazed external walls can enhance the insulation of the building envelope by minimizing heat transmission losses through the outer walls [16]. Wall cladding in buildings is the application of insulation material over the building envelope. Cladding is employed in construction to offer thermal insulation and protection against weather conditions, as well as to enhance the aesthetic appeal of the buildings [18]. Their study focused on the environmental impact assessment of various chosen cladding materials and, importantly, the effect of the construction technique employed on the environment itself. Arif et al. [19] stated that cladding systems have the potential as substitutes for traditional systems, as they help reduce construction time and increase quality. Femi [20] emphasized the crucial significance of proper surface preparation and application techniques when it comes to paint, as inadequate preparation and technique are leading factors in paint failure. The study also highlighted that the primary objective of painting is to provide surface protection and decoration. However, this purpose can be undermined if the painting is executed improperly. Since the performance of a building project is evaluated based on maintenance costs, workmanship quality, and standards, it underscores the importance of ensuring these aspects are taken into account. Dadu et al. [21], in their research on “Quality Control in Abuja Mass Housing”, revealed that an average of 98.5% of the buildings under Abuja mass housing had fading paints defect, followed by 82% of the mass housing buildings showed paint staining defects while 63% showed paint flaking defects.

In recent times, building with timber has become a huge trend in the construction sector around the world [22]. It is very evident now that the market is tilting to the use of wood as a structural material, as it is now understood that concrete and steel are energy-intensive and contribute significantly to the portion of global warming, and timber is becoming the obvious way to reduce it. Wiberg et al. [23] utilized VR to visualize the amount of timber used for building construction and also the number of virtual logs stacked. Khanzode et al. [24] opined that the use of virtual design and construction tools together with lean construction techniques can ease the complex process of Mechanical and Electrical (M&E) projects and other challenges, which include proper organization of the design team, technicality of logistics, and coordination of teams in a big room. M&E installations are essential components of construction projects, encompassing multiple trades involved in building services, including air-conditioning, fire services, plumbing, electrical wiring, and lift installations. However, the safety aspect of M&E works has not received the necessary attention it deserves. This is evident from the lack of easily accessible official accident statistics concerning M&E works in the public domain [25]. The authors further highlighted that the two primary types of fatal accidents in both new construction projects and repair, maintenance, alteration, and addition work fall from heights and electrocutions. These accidents can be attributed to inadequate safety management practices. Dadu et al. [21] revealed that low water supply, leakages in connections, and irregular pressure are the most frequent mechanical and water supply defects in Abuja mass housing.

Portman et al. [26] stated that the adoption of VR as 3D-immersive simulation software for landscape planning and architecture has increased over the years. They noted that the emergence of digital landscape visualizations occurred simultaneously with the initial phase of landscape planning and design. Since then, the application of VR has played a significant role in pushing the boundaries of the profession. Its impact extends to various aspects, such as site planning, landscape restoration, parks and recreation planning, green infrastructure planning, and residential landscape master planning, among others. Over the past few decades, digital landscape representations utilizing VR technology have evolved from basic, static depictions to highly realistic visualizations, enabling immersive exploration with real-time movement across multiple spatial and temporal scales. Berg and Vance [27] described VR as a technology that enables and enhances participants’ complete immersive experience more like or beyond reality. They further stated that VR presents a peculiar way of interacting with the growing digital landscaping.

1.3. Post-Construction Phase

Shi et al. [10] argued that facility management is a critical component of building sustainability because a late response to the needs of facility management will lead to unnecessary waste of resources. They further stated that a lack of communication has been identified as an impediment to the mutual understanding of facility management requirements

among the stakeholders. The recent development of VR in the design and construction of buildings has encouraged further research on the interpersonal relationship between VR and facility management through VR-immersive experience ability. Their research revealed that VR could help the stakeholders examine the requirement of facility management from their respective locations, thereby improving the efficiency of communication among the stakeholders. According to Carreira et al. [28], the objective of facility management is to establish and sustain an efficient built environment that facilitates the smooth operation of the industry. To navigate the complexities and professional demands of modern facilities management, practitioners have recognized the importance of employing specialized computerized tools. These tools serve to automate routine tasks, manage information, monitor the performance of buildings, and aid in decision-making processes. For the successful completion of any construction project, several back-office operations need to take place, such as project scheduling and planning as well as logistics planning. Alizadehsalehi et al. [29] highlighted that VR has been used effectively to tackle issues of project scheduling and planning over the years. Ahmed [2] also corroborated that VR is the future of construction as it is used in various important applications of the project, including project scheduling and logistics management.

Zhao et al. [30] asserted that safety management practices are critical for the construction industry. Additionally, they emphasized that effective training programs can have a direct influence on reducing human error, which accounts for over 50% of occupational incidents. Therefore, their research focused on the use of VR-based immersive simulations for safety training programs, where participants can easily practice their construction task in a hazard-free environment, thereby improving their consciousness when replicating such activities in the real-world environment. Getuli et al. [31] opined that VR technologies save cost during construction projects, as it enables workers to be trained and simulate real-world activity in a hazard-free environment, thereby saving the organization the cost of implementing the activity in the real-scale physical environment.

The fragmented nature of the construction industry resulted in the urgent need for a convenient communication mechanism to foster proper collaboration among the stakeholders throughout the life cycle of the construction project. VR-immersive features ensure proper dissemination of vital information about the construction project to the stakeholders, including the client in real-time, ensuring timely achievement of the shared objectives [1]. Getuli et al. [31] asserted that in practice, communication among professionals is often poor, and misunderstandings are common, resulting in inadequate support for workers. Due to the intricate nature of construction projects and the fragmented nature of their supply chains, it becomes extremely challenging for any individual stakeholder to possess all the required safety-related information and knowledge. Consequently, they argue that the implementation of VR technologies within the construction industry can enhance communication and collaboration throughout the project delivery process.

2. Benefits of Using Virtual Reality for Construction Projects

Given the enormous application areas of VR in the construction industry, this technology is beneficial to communication management, construction project delivery, design development, safety management, and risk management [2][5][32].

2.1. Pre-Contract Stage Planning

VR-immersive walkthrough experience allows the proper improvement in the efficiency of communication and collaboration among construction participants in an immersive virtual environment to achieve sustainable goals [10]. Similarly, Zhang et al. [33] asserted that inefficient communication between stakeholders has been the source of conflict in the construction industry. In this regard, VR has recently gained popularity for its capability to enhance proper communication and collaboration among stakeholders. According to Zhao et al. [30], the safety problem is becoming more urgent in the construction sector as a result of the anticipated risks and hazards. To this note, VR technologies have been adopted to ensure conducting of an adequate immersive safety training program in a hazard-free environment to enhance proper safety planning protocols within a construction site. Alizadehsalehi et al. [29] also stated that VR is effective for use in safety training and planning programs. Behzadi [1] claimed that the building industry has utilized VR technology to attract and retain new workers and approaches in the construction sector to address the scarcity of a fit workforce. VR technologies enhance and improve project performance, which improves organizational culture and overall productivity [34]. According to Wang et al. [6], VR increases the precision of the quantity take-off and reduces the number of assumptions made while taking off 2D drawings. Mutesi and Kyakula [35] and Vasista and Abone [36] revealed that the most beneficial aspect of VR is to help reduce mistakes in documentation.

2.2. Post-Contract Stage Planning

Getuli et al. [31] agreed that VR can be used to enhance construction scheduling, as it enables the participant to view the 3D model, thereby giving enough information on the requirements needed for the execution of the construction project.

Similarly, Alizadehsalehi et al. [29] revealed that VR technologies are very effective in construction project scheduling. According to Zhang et al. [33], VR provides interactive data visualization of construction projects, which has a direct impact on how the projects are planned. Davila Delgado et al. [34] asserted that VR is utilized to enhance site planning. Vasista and Abone [36] emphasized that the adoption of VR practices brings about the advantage of reducing construction errors.

2.3. Quality Control and Sustainability

Vasista and Abone [36] asserted that the adoption of VR practices in the construction industry helps to ease complex tasks, improve productivity, and improve the quality of construction work. Moshood et al. [37] highlighted the benefits associated with the use of VR methods in the construction sector through the integration of workflow and the facilitation of sustainable building.

2.4. Design Flexibility and Reputation

Getuli et al. [31] and Alizadehsalehi et al. [29] identified that VR is very effective when utilized for design clash detections. This feature helps the design team to understand the relationship between the architectural components of the building in relation with the structural, electrical, and mechanical components of the building. Agrawal et al. [38] took advantage of the immersive capabilities of VR to conduct a hazard-free mitigation driving training program. Findings from their research identified that VR can help improve the driving skills of the participant and the capacity to deal with unanticipated hazards. Given the visualization capabilities of VR, Zhao et al. [30] and Alizadehsalehi et al. [29] stated that VR has been utilized to tackle design flaws before the construction phase. It is believed that every successful company must be a technology-developing company [34]. In this regard, strong motivators of VR technologies have begun to utilize VR to rebrand themselves as a smart engineering company, thereby improving their company's image.

2.5. Resource Management

Wang et al. [6], Ahmed [2], and Alizadehsalehi et al. [29] opined that when taking advantage of the immersive capabilities of VR for design review, design flaw detection, and clash detection, considerable cost and time could be saved, as poor design, errors, and resource wastage would be eradicated. Zhao et al. [30], Alizadehsalehi et al. [29], and Bashabsheh et al. [5] highlighted the enhancement of safety training as one of the areas, where VR is beneficial in the construction industry.

2.6. Risk Management and Digitalization

The immersive visualization capabilities of VR could help the participant identify potential risk zones since the construction site could be simulated in a virtual environment. In this regard, proper risk and safety protocols could be developed and adhered to by Getuli et al. [32]. Lew et al. [39] highlighted digitalization as one of the benefits of ICTs.

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