Virtual Reality and Construction Industry: Review of Current State-of-Practice and Future Applications

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ABSTRACT

Virtual reality systems are making significant headway in the construction industry for design, training, planning, and management applications. With research continuing to show the virtues of adopting virtual reality in blue-collar occupational environments, the industry is making rapid and substantial investments to facilitate institutional innovation that supports adoption. Despite a push from both the research and professional community, the widespread adoption of virtual reality remains hindered because details on practical application remains unclear. This study used a social constructionist approach to capture the perspectives of industry professionals on the challenges and opportunities associated with use of virtual reality for construction safety applications. The interviews with professionals revealed that the application of virtual reality in the workplace is currently in its infancy stage and lacks standardization primarily due to scalability and quality concerns. Additionally, the cost associated with large-scale adoption also remains prohibitive to date. The experiential learnings of professionals are used in this paper to determine where future research and practice efforts need to focus to pave the way for future of virtual reality within the construction industry.

INTRODUCTION

In 1957, a major technological device that would make an enormous impact in society was created named *sensorama* (Grau, 2003). Created by Morton Heiling, sensorama was the first multimedia device designed to have an interactive theatre experience. It simulated a motorcycle ride through New York and created the experience by having the spectator sit in an imaginary motorcycle while experiencing the street through a 2-D screen, fan-generated wind, and simulated noise and smell of the city (Regrebsubla, 2015). This early form of virtual reality included a stereoscopic color display, fans, odor emitters, stereo-sound system, and a motional chair (Srivastava et al., 2014). Throughout the years, sensorama evolved to become the virtual reality technology as we know today. Typically, virtual reality (VR) is referred to the computer simulation that mimics the nuances of the real world or physical reality as perceived by our senses (Craig et al., 2009).

After almost seven decades later from its initial introduction, VR has been adopted by many various industries and sectors including, but not limited to, gaming (Yildirim, 2019), construction (Getuli et al., 2021), automotive (Lawson et al., 2015), energy (Gulf Industry, 2020), healthcare (Almufareh et al., 2018), education (Johnson-Glenberg, 2018), architecture (Thompson, 2020), entertainment (Chirico et al. 2016), and even tourism (Lee and Kim, 2021). VR-based technology has been used in these industries for product development, engineering design, project management, advertising, entertainment, and training (Li et al. 2018; Kim and Kano, 2008; Ismail, 2017). For example, VR in the tourism industry has been adopted to develop destination experiences for its consumers to encourage them to visit and engage in particular travel activities and behaviors (Kim and Hall, 2019). In fact, it is anticipated that VR could significantly assist the tourism industry in recovering from the financial losses experienced due to the COVID-19 closedowns (Lee and Kim 2021). In the education sector, VR has been demonstrated to enhance learning outcomes through experiential learning and sensations of presence that improve the engagement and interest levels of learners (Johnson-Glenberg, 2018). The healthcare industry has not only used VR-based platforms to improve cognitive and physical functioning of individuals after serious injury or disease (Glize et al. 2017) but also to train professionals on complicated medical interventions and procedures (Olasky et al,. 2015).

There is no doubt that VR can have great utility across numerous domains; however, some have found that it lacks widespread applicability (Alcañiz et al., 2019), especially within traditional blue-collar occupational environments (Forde et al., 2011; Kizil, 2003). Not only have there been financial and logistical constraints associated with the adoption of VR, the research and development of VR have been highly focused on academic and technical endeavors. For example, a plethora of research has been conducted on studying the impacts of VR technology on learning outcomes (Zhang et al., 2020) and on improving the technical features that would allow users to improve their learning experience (Johnson-Glenberg, 2018). While these technological enquiries and validation efforts are critical for continued innovation, it does not directly address the lack of VR adoption in occupational settings.

Within construction industry, there has been a substantial amount of research on VR in academic literature (Ahmed, 2019; Li et al., 2018; Wang et al., 2018). It has been validated for training (Sacks et al., 2013), design (Wolfartsberger, 2019), and management (Davila Delgado et al., 2020) purposes yet there are only a few organizations utilizing VR in workplace *regularly*. As further investment is made into VR, it is critical to understand the state-of-practice within the construction industry and the critical gaps that need to be addressed to facilitate its adoption. Thus, this paper intends to explore the perspectives and experiences of construction industry professionals on adopting, using, and improving VR technology. The findings presented in this paper can allow a) future researchers to determine the areas in which the VR adoption process needs to improve and b) future practitioners to identify the pathways for seamless and successful adoption of VR.

BACKGROUND

VR technology was first used in the construction industry in late 1980's as a tool to aid designers with the planning and visualizing of construction drawings (Adjei-Kumi and Retik, 1997). Since then, the use of VR technology has expanded to aid training, production, quality, contract acquisition, and even safety activities (Wolfartsberger, 2019; Wang et al., 2018). Initially, VR technologies used to be bulky, fixed to one location, hard to operate, extremely expensive, and consisted of poor-quality graphics. However, with time VR systems have become mobile, financially feasible (as cheap as $300 USD), have better quality graphics, and an easier user interface (Whyte et al., 2000; Regrebsubla, 2015). As with most emerging technologies, the price decline of VR technologies is projected to continue as big corporations, such as Google, Facebook, and Samsung enter the VR market; the increasing market competition is contributing to VR devices becoming more affordable with time (Fink, 2017). In other words, it is fair to assume that VR will become financially accessible to most construction organizations in the near future.

VR in Design

Design has been one of the areas within the construction industry that predominantly adopted VR. Most design companies that adopted VR have used it for design applications, for collaborative visualization, and as a tool to improve construction processes. (Bouchlaghem, et al., 2006). Research in this area has proven that VR is effective tool that allows the practitioners to identify more faults in a 3D model compared to a CAD software-based approach on a PC screen (Wolfartsberger, 2019). Additionally, research also shows that VR can potentially enhance the performance of industry professionals in developing project schedules, estimations, and logistical plans by interacting with realistic virtual representations of construction projects that support intuitive assessments (Whyte et al. 2000). For example, architects have found that VR devices can allow them access all architectural drawings anywhere at any time, even on site. The VR 3D format tool provides them with the opportunity to more efficiently plan, design, construct, and manage their infrastructure (Ismail, 2017). As a result, issues and challenges can be addressed early or in real-time on the project leading to significant financial savings for companies by minimizing errors and subsequent change orders (Johnston et al. 2016).

VR in Training

VR has been primarily used on jobsites for workforce training and development purposes. Due to the nature of the work that must be completed, the construction industry is inherently dangerous (Sacks et al., 2013). VR has been used to visualize of details of essential components of the typical tasks and work environments (Sampaio and Martins, 2014) to improve identification and management of risks on jobsites (Sacks et al. 2013; Zhao and Lucas 2015). Indeed, having the safety information in visual form can support workers with low levels of literacy or experience to learn and retain safety knowledge (Edirisinghe and Lingard 2016). Research has suggested that the VR is a useful tool for training and communication due to its ability to simulate an interactive real-world environment, which produces the sensation of the user actually being in situ (Freeman et al. 2017). In other words, VR can allow participants to experience and learn from safety situations that they would not routinely encounter and experience the consequences of an accident without actually sustaining any bodily or property damage. This notable advantage can allow construction workers to improve their ability to identify risks, analyze the magnitude of those risks, and be better prepared to encounter an actual safety-related incident (Sacks et al. 2013).

Other Uses of VR

Just as any other business, each organization within the industry is highly dependent on the bottom line. There is always a need to continually improve the quality, productivity, and cost-effectiveness of projects (Shehab, 2009). For example, in 2020, researchers proposed an immersive experience through BIM modeling and VR modeling to combine visual aesthetics and cost estimation in real time (Balali et al. 2020). The approach consists of utilizing a VR system to interact with stakeholders by enabling the visualization and selection the finishing elements of the construction project (such as color and texture of a carpet, window types and styles, wood types, etc.) within the simulation. The decisions taken by clients are saved into a BIM model and the cost estimates can be updated in real time. This approach not only saves time in design reviews, optimizing the construction schedule, and preventing potential issues with change orders (Balali et al., 2020) but also allows the clients to make more informed decisions.

In summary, the majority of research findings suggest that VR could provide potential value to construction companies by enhancing numerous current industry practices, such as the design review, training, and constructability reviews processes. These positive findings have prompted a number of organizations to seriously consider making substantial investments into adopting VR-based technologies despite the risks. Yet, there is a need to traverse the chasm in widespread of *practical* application of VR-technology within the industry. Although, the challenges associated with practice of VR in the construction industry remains understudied and based on conjecture. Thus, this paper intends to better understand the challenges associated with the adoption of VR in construction as perceived by industry professionals. To improve the acceptability and adoptability of VR within construction, it important to understand how much value practitioners find and what challenges they have typically encountered when using VR.

RESEARCH METHODS

Adopting and adapting the VR technology for different purposes (e.g., design, workforce training) within a construction organization present unique technological, feasibility, and human resource challenges. Here, the authors have adopted a social constructionist approach to collect data on the perspectives of industry professionals on the use and future of VR. A social constructionist approach examines the jointly constructed definitions of the reality around us that form the basics of shared assumptions (Leeds-Hurwitz et al., 2006). Social constructionist is a method that has widely been used in the sociology, psychology, philosophy, and science fields. This method accepts that the world is experienced through a socially constructed perception created by the people within it and through their interactions, systems, and practices (Gergen and Gergen, 2004). This approach was utilized in this research because it laid the foundational idea that topics and trends could be identified throughout the analysis of the conversations the researchers had with industry professionals. The purpose of a social constructionist approach is to avoid a realist perspective and emphasize socially constructed knowledge. The conversations with participants were held throughout the month of March 2021 and due to COVID-19 travel restrictions, the interviews were conducted on virtual platform Zoom Communications.

A series of questions stimulated the conversation with the professionals. These questions were carefully selected and reviewed to avoid implicated biases and promote validity of the procedure. The questions were designed to standardize the data collection process but also to allow the participants to generate a conversation on their own terms and conditions (Sherratt et al., 2018). Having pre-determined questions allowed to focus the discussion on the VR theme. Naturally, participant's personalities varied, and, although some participants were talkative and willing to share every minute detail, others were more soft-spoken. Having the questionnaire helped with guiding the conversation with these soft-spoken participants. Figure 1 shows the flow of questions used to facilitate a comfortable conversation with the participants.

After transcribing the recorded interviews, NVIVO platform was used to code and compare the information provided by the professionals. Thematic analysis was used to identify the main themes and patterns from the transcribed data. This type of analysis is a method for identifying, analyzing, organizing, describing, and reporting themes found within a data set (Braun & Clarke, 2006).

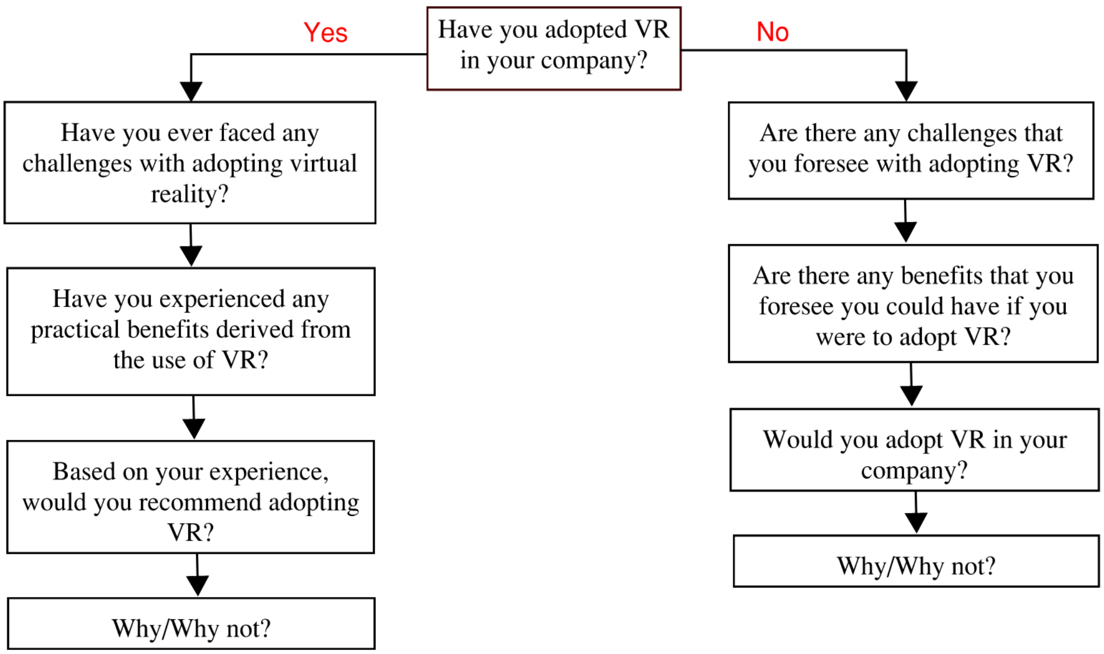

Figure 1: Social Constructionist Questions

Finally, the researchers also took reasonable steps to promote internal validity. Participants were recruited through an open call (i.e. participation was voluntary and uncompensated) for this project, thereby eliminating any coercion, and all participants had at least five years of experience within the construction industry. In other words, the experts interviewed in this study were passionate about sharing their perspectives on the subject matter. Anonymity of the participant's identity was guaranteed (i.e. participant's identity was not to nudge participants to share more candid opinions freely. Furthermore, all the interviews were conducted on virtual platform (Zoom), which did compromise the authors' ability to maintain a controlled environment, however, the ease of scheduling and familiar settings for participants allowed for more comfortable environment for a conversation in line with the social constructionist research methodology.

RESULTS

Participants were scheduled for a conversation to learn about their experience with VR, the challenges (if any) they have faced while adopting VR, and the benefits (if any) that they have perceived while using the VR systems. These conversations were conducted until the information gathered by the participants reached saturation. In other words, the researchers stopped interview process when there was no new or additional information being given by the participants. Table 1 shows the demographics of the nine industry professionals that participated in this study. Eight of the participants had been exposed to VR with their respective companies, and one participant shared his/her expert opinion on the foreseeable challenges and benefits that he/she would have to face to implement VR with his/her company. The participants interviewed represented different sectors (oil and gas, design, education and training, and trade association) of the industry.

Table 1: Participant Demographics

Number of participants	Number of Sectors	Average Years of Experience	Average Conversation Time
9	4	21.1 years	25 minutes

FINDINGS

Overall, the interviews showed that perceptions on applicability of VR are generally positive; however, much work on technological and logistical front remains to facilitate widespread adoption. The qualitative analysis revealed a number of themes that have been edified upon in the sections below.

Technological Challenge

One of the challenges that was expressed by the majority of the professionals was the technological challenge involved with developing a simulation that meets their targeted needs. Despite rapid technological advancements, the quality of the graphics on occasions is considerably lacking. Additionally, the VR devices require regular and cumbersome updates and the software presents constant connectivity issues since most require Wi-Fi connection. The Wi-Fi connection limits applicability of VR on jobsites. Finally, the VR systems were considered fairly fragile and not designed for the *roughness* of a job site (which is where the place that has the most need for a VR system). Investing the time and resources to develop high quality simulations is still financially prohibitive for most contractors. As noted by a participant "... the big issue that we're facing with VR in general is that these headsets are built for entertainers, they're not built for the construction department. Dust is really bad friend for VR headsets, especially on job sites." The reality is, in such a fast-phasing industry, the VR system needs to be simple to utilize, have mobile capabilities (since it has to constantly travel from one job site to another), and be resilient to rough environments.

Financial Constraints

Cost challenges were also a common theme. This cost of VR adoption is primarily associated with the development of the hardware and software. However, there are many indirect costs associated such as hiring individuals to maintain and manage the VR devices. Most participants mentioned that, although adopting VR sounds great, the additional responsibilities of maintaining and troubleshooting these devices requires proficiency and bandwidth that most managers and workers on jobsites do not possess. One of the participants stated that, "the reality is for virtual reality to work well, you're going to have the additional expense of an IT professional, so the IT systems are going to grow." Thus, in addition to purchasing the equipment, the total cost implicates having a dedicated team of professionals that construct and maintain the system.

Scalability and Time Constraints

Additionally, duration of the simulation was a common concern for the professionals. Majority of the industry professionals mentioned that most people, regardless of age, tend to have an eye strain after approximately 15 minutes of use. There are limited devices on jobsites which means that not all workers may get the opportunity to directly engage with the learning environment. A professional commented "…if we did it in three-minute increments. Like modules. It would be significantly better for retention and just engagement from the class because we're finding people want to participate. They don't want to watch someone for 15 minutes. They want to watch for 120 seconds and then get their turn." There is a need to validate the timeframes associated with significant attention drop among construction workers when using VR. Additionally, future investigations also need to focus on components of effective practical application of such learning environment so as to engage all workers equally and effectively.

Acceptability and Learning Curve

A common theme brought up by the professionals was around the average age of the workforce. All professionals mentioned that, although the feedback for VR adoption within their companies is primarily positive, it is significantly harder for older workers to get used to the new technology. In fact, this did not apply to construction workers alone, but also the more senior leaders and managers that are less familiar with changing technologies. This is a significant discovery as upper management of organization makes the decisions around new technologies and organizational setups. Their reluctance due to skill deficiency, biases, or perceptions can derail the potential application of VR within the organization. How VR-based technologies can be made more accessible to different stakeholders within a typical construction organization will be the key to not only its effectiveness but also acceptability.

Safe Exposure to Risks

In addition, one of the primary benefits of VR is that it provides an opportunity for the participant to be exposed to situations that he/she would not otherwise be exposed to. VR also provides an entertaining experience that keeps people interested, engaged and tends to attract clients. Industry professionals even shared that the initiative of their company to adopt VR has won them clients because it improved their competency advantage from their competitors. Thus, more than just a tool, it could also be used as leverage platform to perform good business practices. Additionally, an industry professional added "[VR] is a really good way to get [workers] trained on doing very high-risk activities that would be difficult to safely simulate on physical world." Hence, VR systems thrive on simulating high-risk environments that would be challenging to safely simulate in the real world. This type of experience is beneficial not only for the training workforce, but also for the company because it differentiates them from competitors that have not adopted innovative practices.

Future of VR

It is important to note that all of the participants argued that VR, although is still in its infancy state, it is the way of the future. Compared to incoming recruits who have been traditionally more exposed to similar technologies, the older generation struggles to interface with changing landscape of technology. A professional commented "The challenge is that VR technology and construction workers technology don't quite balance; there's not enough synergy yet. It's starting to happen. The old generation of moving out, retiring, and the newer ones are coming in." Thus, it is predicted that, in the near future, companies will find themselves in the need to adopt VR systems in order to relate to its workforce. The thoughtful adoption and transition of newer technologies to hire and retain skilled workers is already a norm within most other industries (Thompson, 2020). Another participant added "I think it's the way the future. No doubt about it. I think that it is a great opportunity, especially when it comes to operating equipment." The evolving demographics of the construction industry's workforce would necessitate accepting newer technologies such as: VR to support future management, learning, and training practices.

CONCLUSION

The conversations with industry professionals indicate that VR as a technology still has a long way to go to become a standardized proactive practice within the industry. There are some significant technological and logistical barriers that make VR cost prohibitive. Moreover, the construction organizations typically lack human resources with technical prowess to successfully deploy and deliver VR based applications consistently. Finally, it will be a constant and significant challenge to engage the entire workforce to accept and engage with VR given the individual differences (e.g., age, educational status, and personal experience). Nevertheless, industry professionals interviewed here were unanimous in their agreement that VR will become an integral part of construction practices in future.

The construction jobsites and workforce present unique challenges associated with scalability (e.g., training a large group of people in non-traditional learning environments) and logistics (e.g., need for mobile and durable devices), minimal technological interventions (e.g., realistic graphics and minimal updates), and continuing learners (e.g., adult learners with varying educational and technological backgrounds) that future VR researchers and developers need to address. Additionally, organizations need to be aware of and plan for hidden costs related to adopting a VR system, training personnel on using VR, hardware maintenance, and incorporation of VR within existing practices for successful application.

Research suggests that experimental learning (also known as work-based learning or learning by doing) plays an essential role on how humans cognitively process and retain new information (Kolb, A. Y., & Kolb, D. A. (2009). Undoubtedly, one cannot learn how to play the piano with just reading a book; learning how to play requires practice, reflection, and dedication (Fowler, 2008). VR is a technology that could provide the workforce with an opportunity to gain experimental learning through simulations that cannot cause themselves, their peers, nor the organization any loss. Additionally, the visual realism afforded by VR can improve design, engineering, and management practices within the organization. If VR is to be the "way of the future," researchers and practitioners need to be focus on technical innovations as well as practical considerations to truly revolutionize the industry.

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