A Review of VR in Undergraduate Construction Education and Training: Unveiling the Opportunities to Address Content Areas from ACCE's SLOs

by

Sara Magdy ElGamal

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved July 2023 by the
Graduate Supervisory Committee:

Steven Ayer, Chair
Kristen Parrish
Anthony Lamanna

ARIZONA STATE UNIVERSITY

August 2023

ABSTRACT

Virtual Reality (VR) has been used in the sphere of training and education in the construction field. Research has investigated the different applications of VR in construction-focused simulations to report its benefits and drawbacks in training and education. Although this is significant, they were not albeit explicitly studied through the lens of accreditation at undergraduate educational levels. The American Council for Construction Education (ACCE) established twenty Students Learning Outcomes (SLOs) that equip students with essential knowledge and industry-oriented technical and managerial skills that maintain quality education in undergraduate construction programs. This paper analyzes the trends in VR literature through reported benefits and unexplored learning outcomes of VR in construction training and education and investigates the ways by which these trends do or do not contribute to the learning experience by targeting the content areas associated with the ACCE's SLOs. To accomplish this, the author reviewed 59 articles from 2014 to 2023 found through a keyword search for "Virtual" AND "Reality" AND "Construction" AND ("Training" OR "Simulation" OR "Education") AND "Students". The learning outcomes of the VR training reported in the 59 articles were mapped to their corresponding content areas from ACCE's SLO(s). The results demonstrate the content areas of SLOs that were addressed in literature (1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 13, 15, 16, 18, 19, and 20) and the SLOs that were not explored (4, 12, 14, and 17) due to lack of studies in some contexts. This study reveals trends and patterns of VR training, some of which exemplify benefits of addressing content areas of SLOs through virtual on-site immersion, manipulation of time, cost efficiency, and ethical measures, while others indicate unexplored learning outcomes of VR training in targeting content areas of SLOs that involve human interaction, complex quantitative calculations or require construction management tools, delivery method and stakeholders' management, and risk management. While this research does not seek replacement of traditional trainings, it encourages consideration of VR training under the lens of ACCE's accreditation. This research's findings propose guidance to educational researchers on how VR training could address content areas from ACCE's SLOs.

DEDICATION

This Thesis is dedicated to my loving sister: Dina

To my supportive family: Mona, Magdy and Zeinab

To my soulmate: Kareem

Thank you for being my bedrock

ACKNOWLEDGMENTS

Throughout this research work, I have received great support and assistance. First and foremost, I want to acknowledge and express my gratitude to my thesis advisor Dr. Steven Ayer whose expertise guided this research. His continuous support and feedback influenced me on both personal and professional bases.

I would also like to dedicate special acknowledgement to Dr. Kristen Parrish whose constructive comments and invaluable feedback supported the development of this work. I am also grateful for Dr. Timothy Becker and Dr. Anthony Lamanna for their participation in reviewing this paper.

Last but not least, I want to thank the ETBIMLab Group at Arizona State University and dedicate special thanks to Karan and Rita for their time, kind advice and thoughtful feedback.

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CHAPTER 1

Virtual Reality (VR) is a promising technology in the sphere of education and training, providing learners with immersive and engaging experience (Merchant et al., 2014; Hafsia et al., 2018). Virtual Reality provides simulations of real environments that enable interaction with a synthetic three-dimensional visual or other sensory world via computer modelling (Gigante, 1993). VR creates an experience that is immersive, interactive, and viewer-centered through simulated environments that imitate real-world scenarios, thus promoting experiential learning and enhancing comprehension of intricate concepts (Cruz-Neira, 1993; Messner et al., 2003; Kwon, 2018). Consequently, educators and curricular developers from a variety of fields research VR in students' education and training within their domains, e.g., aviation (Rupasinghe et al. 2011; Dymora et al. 2021), mechanical engineering (Syed et al., 2019; Liu et al., 2020), and medicine (Akhtar et al., 2005; King et al., 2018).

In the construction industry, extensive efforts have been directed towards VR training and education to mimic complex site settings, potentially unsafe conditions, and work processes that are nearly impossible to recreate for students in a traditional classroom environment (Mastli and Zhang, 2017; Lucas, 2018; Eiris et al., 2021; Eiris et al., 2022; Shojaei et al., 2022). Indeed, in providing students the ability to interact with realistic construction scenarios, VR is considered a promising tool for bridging the knowledge gap between theory and real-world application (Li et al., 2003). The immersive nature of VR and its capacity to support students' learning and training through an engaging and immersive learning environment makes it an ideal tool for education and training in the field of construction engineering and management.

The American Council for Construction Education (ACCE) is responsible for setting a high standard for education in the field of construction engineering and management. The ACCE establishes learning outcomes for undergraduate construction engineering students (ACCE, 2021). The ACCE's Students Learning Outcomes (SLOs) guarantee that students who complete accredited programs have the knowledge and skills required for success in the construction sector (Burt et. al., 2013). The ACCE set twenty SLOs that comprise incorporating technical knowledge, hands-on expertise, communication and collaboration skills, decision making, project and risk management, and comprehension of industry practices with respect to adherence to ethical standards (ACCE, 2021; Clinton Community College, 2015). These outcomes provide a framework for evaluating the educational expertise, skills, and competencies necessary for construction engineering and management students (Shupe, 2007; Bhattacharjee et al., 2013). ACCE has enabled an unprecedented amount of flexibility for educators to adapt pedagogical strategies that enable students to attain the content areas of the SLOs (ACCE, 2013; McCord et al., 2021). ACCE's SLOs integrate the knowledge acquired from construction programs with industrial demands.

The flexibility of ACCE allows educators and curriculum developers to provide construction engineering and management undergraduate students with learning experiences that incorporate innovative teaching strategies, including the use of emerging technologies. While this flexibility theoretically offers the ability to leverage emerging teaching and learning technologies, this is not generally done for accreditation. However, there is extensive literature that explores VR for learning in content areas that are related to ACCE's SLOs, albeit not explicitly studied through the lens of accreditation. A thorough investigation of this literature would help educational researchers to strategically use, or expand the use of VR, to address ACCE learning competencies in ways that are supported by evidence from research. To that end, this research investigates the following questions: What are the trends that emerged from the literature of VR in undergraduate construction training and education? And what are the ways by which these trends report benefits or indicate unexplored learning outcomes of VR training that do or do not contribute to the learning experience with respect to the content areas associated with the ACCE’s SLOs?

CHAPTER 2

BACKGROUND

Virtual Reality: Definition and Development

Virtual Reality (VR) is defined as “an experience in which a person is surrounded by a three-dimensional, computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it.” (Rheingold, 1991). VR creates an experience that is immersive, multi-sensory, interactive, and viewer-centered (Cruz-Neira, 1993). VR is thought to first emerged in the 1950s, but it received widespread popularity in the late 1980s and 1990s (Mandal 2013). The progress of VR is attributed to the advancements in computers and technology. VR usually provides visual and auditory simulations typically through headsets or devices that display visuals and audio; such as head-mounted devices (HMD), controllers, data gloves, avatars, game engines, and computers (Bhoir and Esmaeili, 2015; Schleubinger 2021)

Since Virtual Reality can mimic real environments, different field experts sought to employ it in their domains to simulate the experience within their work setting. Extensive efforts were directed towards VR to mimic complex site settings and conditions as well as challenging work processes. “A System Framework for Smart Class System to Boost Education” collected data from the World Bank Intranet indicated that learning by practicing or by doing, like learning through VR, corresponds to enhancing the learning experience by 75% (World Bank Intranet, 2016). As a result, researchers classified the immersive virtual reality technology as a potential tool that offers a practical, educative application to prepare students for workplace practices (Pedro et al. 2016).

VR in Training and Education: Examples and Implementations

Researchers started investigating the use of digital technologies to deliver a more immersive and interactive educational experience as far back as 1969 (Lin et al. 2011). The benefits of employing virtual training and education are documented in professions like firefighting, medicine, military, aviation, and other critical fields (Aurich et al. 2009; Sampaio et al. 2010). VR was applied in the context of safety and rescue activities in flammable and explosive environments (Irimia et al. 2021), pain management and surgical training in healthcare (Akhtar et al., 2005; King et al., 2018), and pilot training in aviation (Dymora et al. 2021). Through the incorporation of VR in training and education, significant improvements have been achieved because students are provided access to practical learning opportunities and simulations that would be hazardous or impractical to recreate in the real world (Xie et al., 2021).

VR in Construction Training and Education

Researchers in the construction engineering field sought to incorporate the benefits of VR trainings to create an authentic learning experience for students in the construction domain (Rogers, 2019; Jensen & Konradsen, 2018; Merchant et al., 2014). Consequently, abundant studies were directed toward employing VR technology in training simulations. These studies demonstrated that students’ learning experience has been improved since VR made the learning experience less complicated and created an ease to comprehend new ideas and skills, through the interactive and immersive experience (Li et al., 2012; Le et al., 2014; Merchant et al., 2014). VR training allows students to practice critical skills and knowledge in various construction applications. For instance, VR training was stated to enhance the performance of training in hazard identification (Wu et al., 2019; Akula et al., 2020; Wang et al., 2020; Abotaleb et al., 2022), structural behaviors comprehension (Chung et al., 2020; Beh et al., 2022), equipment training, and materials and methods recognition (Song et al., 2021; Castronovo et al., 2022; Eiris et al., 2022). Wang et al. (2018) concluded that immersive educational training via VR simulations allows students a level of control over the environment, which immerses students in the experience, promotes their concentration and retention, and enhances their decision-making skills (Wang et al., 2018). Similarly, Chavez and Bayona (2018) examined the characteristics of VR in training and education that assess the success rate and benefits of its implementation on the learning outcomes of undergraduate students. The authors listed 24 attributes of VR in training and education including "interactive capability, immersion interfaces, animation routines, free movement, and simulated virtual environment, living experiences that are closer to reality, intrinsic motivation, increasing level of interest in learning, and improving learning outcomes" (Chavez & Bayouna, 2018). These studies illustrate a range of construction engineering-specific studies that suggest potential value for VR in training and education, and also a range of studies that have systematically identified benefits reported for VR in learning in general (Radianti et al., 2020; Wang et al., 2018; Chavez & Bayouna, 2018). However, the body of knowledge is missing a structured review of construction engineering-specific competencies that have been reported to be impacted by VR.

The American Council for Construction Education (ACCE) and Students Learning Outcomes (SLOs)

The American Council for Construction Education (ACCE) was established in 1974 in the United States as a leading body in the field of worldwide construction education advocacy (Hatipkarasulu and Hatipkarasulu, 2022). The mission of the ACCE is to promote and develop construction education and prepare undergraduate students for their careers. ACCE includes criteria that maintain quality education in construction education programs and well-equip undergraduates with essential knowledge and industry-oriented technical and managerial skills (ACCE, 2021; Pedro et al. 2016). In 2014, ACCE officially designed guidelines, that demonstrates and validates the students' learning experience and proficiencies, recognized as the Students' Learning Outcomes (SLOs) (ACCE, 2021; Mehany & Gebken, 2017). The learning outcomes demonstrate a set of 20 learning outcomes through which a construction engineering student is assessed upon graduation; as illustrated in Table 1.

CHAPTER 3

METHODOLOGY

To address the research questions, the author conducted a structured literature review to identify content areas covered in VR trainings as well as how this content relates to content areas associated with the ACCE's SLOs. The methodology is explained in the following sections, including a discussion of the publication selection process, eligibility criteria, and analysis of the selected publications to report the ACCE's SLO content areas covered in VR trainings exercises reported in the literature.

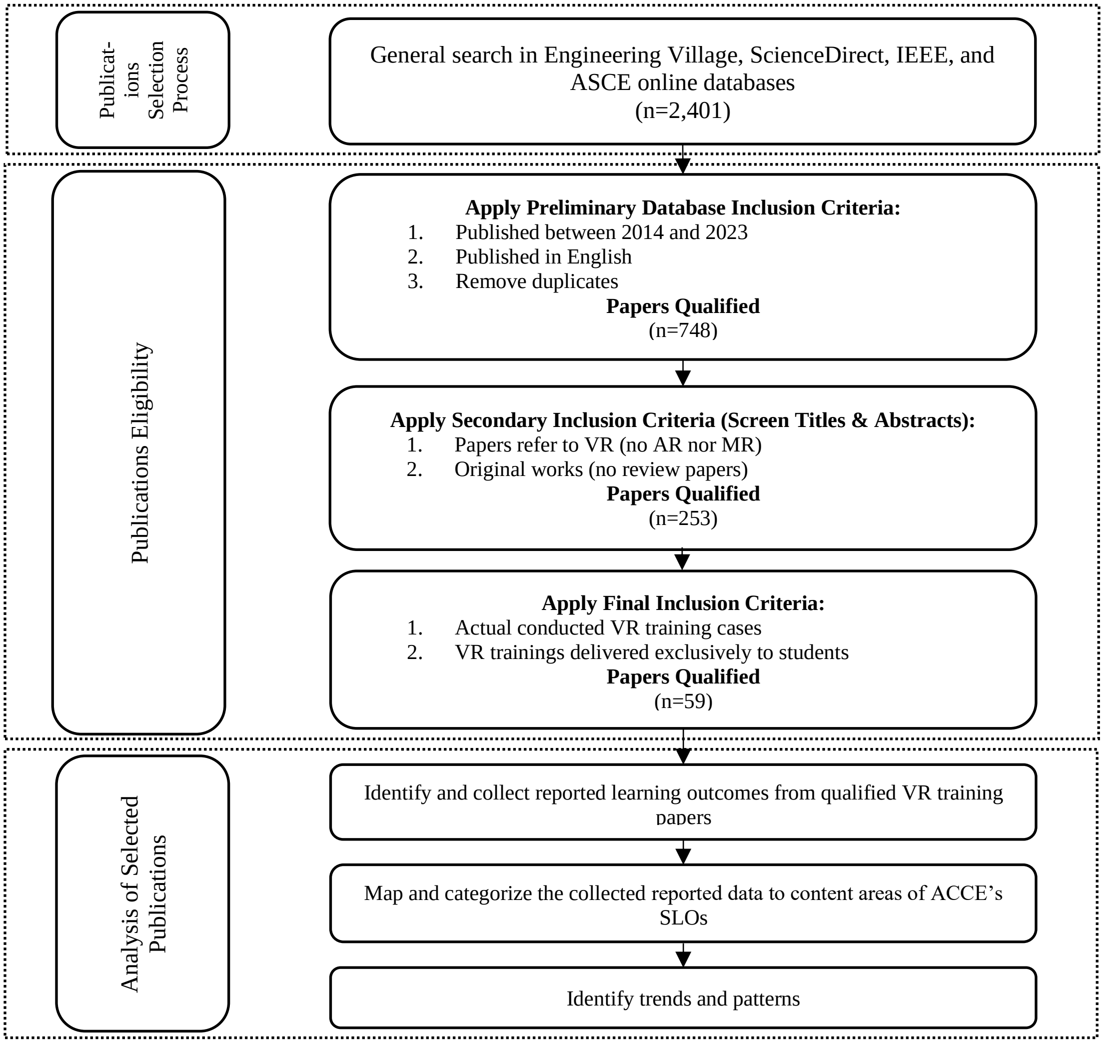

Figure 1: Publications' Selection, Inclusion, and Analysis Flowchart

PUBLICATIONS SECLECTION PROCESS

The author implemented a set of criteria to select publications. First, the author defined a set of keywords and identified relevant online databases to search for relevant publications. The keywords used were: “Virtual” AND “Reality” AND “Construction” AND (“Training” OR “Simulation” OR “Education”) AND “Students” These terms were entered into each of the databases listed in Figure 1 to research VR education and training in the construction engineering field. The author searched Engineering Village, ScienceDirect, IEEE, and ASCE online databases for academic journal articles and conference papers using the aforementioned key words.

PUBLICATIONS ELEIGIBILITY CRITERIA

Subsequent to the publication selection process, preliminary filters were applied to ensure that the selected publications address the research questions. This was done by limiting the publications to those published between 2014 and 2023, through which VR technology became accessible and modern commercially VR Head-Mounted Display (HMD) became available. Thus, limiting the dates helps ensure that publications describe VR technology that is currently available. The papers were then filtered to only those that were published in English. Zotero, a reference management software tool was used to collect, organize, and cite the selected publications as well as remove duplicate publications.

Next, secondary inclusion criteria were implemented. The author screened publication titles and abstracts to ensure that the selected publications addressed the research question. Only papers that reported on VR were considered, according to Gigante’s definition of Virtual Reality: “The illusion of participation in a synthetic environment rather than external observation of such an environment." (Gigante, 1993). Papers related to Augmented Reality (AR) or Mixed Reality (MR) were dismissed. Moreover, review papers were excluded such that the author only included original works.

Finally, the identified papers were further screened based on scope-related inclusion criteria. The author selected papers that reported on actual VR construction education and training cases; publications describing training on or off site in Architecture, Engineering, and Construction (AEC) were included. Papers whose authors depended on reviews, recommendations, or theoretical applications were excluded. Finally, this review only considered VR trainings delivered exclusively to undergraduate students, as the ACCE's SLOs relate to undergraduates. Papers that describe VR trainings for graduate students, practitioners, or field experts were not included in this analysis. Finally, this down selecting process ensured that papers reviewed were relevant in terms of technology, discipline, and types of learners.

ANALYSIS OF SELECTED PUBLICATIONS

ACCE's SLOs Content Areas

The ACCE's learning outcomes demonstrate a set of 20 learning outcomes (Table 1) through which a construction engineering student is assessed upon graduation. This work explores how researchers have studied VR for construction engineering and management students' education and training, but recognizes that the vast majority of studies have not formally used VR as a mode of measuring ACCE accreditation outcomes. Therefore, rather than making assumptions from published content about the

Bloom's levels of learning, at which students addressed ACCE's content areas with VR, the author focused on the presence or absence of studies targeting each content area; as illustrated in Table 1. This leaves exploration of specific levels of learning with VR to future work, while providing evidence of potential, or lack of evidence, for VR to inform these future studies. Moreover, based on the 20 content areas of the SLOs, the author created terms that were used to guide the mapping process; as illustrated in Table 1.

Table 1

Table of Original ACCE's SLOs, Content Areas Targeted in This Work, and Terms Used for Categorization of Research Papers

ACCE's SLO	**Content Areas of ACCE's SLOs (Without Bloom's Verbs)**	**Terms Used to Guide Mapping Categorization**
SLO 1- Create written communications appropriate to the construction discipline.	SLO 1- Written communications appropriate to the construction discipline.	Written Communications
SLO 2- Create oral presentations appropriate to the construction discipline.	SLO 2- Oral presentations appropriate to the construction discipline.	Oral Presentations
SLO 3- Create a construction project safety plan.	SLO 3- A construction project safety plan.	Safety
SLO 4- Create construction project cost estimates.	SLO 4- Construction project cost estimates.	Cost Estimates
SLO 5- Create construction project schedules.	SLO 5- Construction project schedules.	Schedules
SLO 6- Analyze professional decisions based on ethical principles.	SLO 6- Professional decisions based on ethical principles.	Professional Decisions & Ethical Principles
SLO 7- Analyze construction documents for planning and management of construction processes.	SLO 7- Construction documents for planning and management of construction processes.	Documents
SLO 8- Analyze methods, materials, and equipment used to construct projects.	SLO 8- Methods, materials, and equipment used to construct projects.	Methods & Materials & Equipment
SLO 9- Apply construction management skills as an effective member of a multi-disciplinary team.	SLO 9- Construction management skills as an effective member of a multi-disciplinary team.	Effective Member of a Multi-Disciplinary Team
SLO 10- Apply electronic-based technology to manage the construction process.	SLO 10- Electronic-based technology to manage the construction process.	Electronic-Based Technology
SLO 11- Apply basic surveying techniques for construction layout and control.	SLO 11- Basic surveying techniques for construction layout and control.	Surveying

SLO 12- Understand different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process.	SLO 12- Different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process.	Methods of Project Delivery & Roles and Responsibilities of Constituencies
SLO 13- Understand construction risk management.	SLO 13- Construction risk management.	Risk Management
SLO 14- Understand construction accounting and cost control.	SLO 14- Construction accounting and cost control.	Accounting & Cost Control
SLO 15- Understand construction quality assurance and control.	SLO 15- Construction quality assurance and control.	Quality Assurance & Control
SLO 16- Understand construction project control processes.	SLO 16- Construction project control processes.	Control Processes
SLO 17- Understand the legal implications of contract, common, and regulatory law to manage a construction project.	SLO 17- The legal implications of contract, common, and regulatory law to manage a construction project.	Legal Implications & Contracts & Law
SLO 18- Understand the basic principles of sustainable construction.	SLO 18- The basic principles of sustainable construction.	Sustainable Construction
SLO 19- Understand the basic principles of structural behavior.	SLO 19- The basic principles of structural behavior.	Structural Behavior
SLO 20- Understand the basic principles of mechanical, electrical and plumbing systems.	SLO 20- The basic principles of mechanical, electrical and plumbing systems.	Mechanical & Electrical & Plumbing systems

Analysis Process

The identified publications were thoroughly analyzed through consecutive steps. First, the author reviewed the abstract of each publication to determine whether the publication addressed one or more content area from the ACCE’s SLOs (Table 1 lists the content areas of ACCE’s SLOs). If the abstract was not clear about how VR was used to support learning related to the content area(s) from an ACCE’s SLO, the paper was excluded from this research. Additionally, if a study did not report any students’ learning outcomes that could correspond to any of the twenty ACCE’s SLOs, the paper was discarded. Furthermore, this research focuses on undergraduate construction engineering students. The author did not include “undergraduate” as a search keyword because some publications referred to students by level or general academic standing, e.g., “sophomore students”, “senior students”, “students in their first year”, or “bachelors’ students,” rather than “undergraduates.” The author mapped publications to content areas related ACCE’s SLOs. (e.g., VR actively facilitated students’ acquisition of safety knowledge and development of hazard identification abilities in which students could virtually perceive the site hazards related to concrete works construction methods and reflect on the consequences of their actions, as reported in (Pedro et al., 2016), maps to SLO 3, SLO 8, and SLO 10). After mapping the publications to the content areas of the ACCE’s SLOs, the data were compiled into a structured format using spreadsheets. Finally, the author identified trends and patterns from the literature with relation to content areas from the ACCE’s SLOs.

CHAPTER 4

RESULTS AND DISCUSSION

The general search initially generated 2,401 papers from the online databases. Following, the papers' screening process based on the inclusion criteria eventually yielded a total number of 59 papers. The selected studies encompassed publications of years ranging 2014-2023, with undergraduate students being the targeted population. The sample sizes varied from as large scale as 370 students to small scale of 4 students. Table 2 shows the number of selected papers in reference to the journals and conferences from which the eligible papers were selected.

Table 2

Table of the Selected Publications

Publications Venue	No. of Selected Papers	References
Advanced Engineering Informatics	1	(Castronovo *et al.*, 2022)
Advances in Science and Engineering Technology International Conferences (ASET)	1	(Ahmed, 2020)
AHFE	1	(Ma and Li, 2021)
Alexandria Engineering Journal	1	(Bashabsheh *et al.*, 2019)
American Society for Engineering Education	4	(Tan *et al.*, 2017; Pradhananga *et al.*, 2020; Sengupta and Sparkling, 2021; Sippel *et al.*, 2022)
Automation in Construction	5	(Sampaio and Martins, 2014; Wanga *et al.*, 2020; Eiris *et al.*, 2021; Wang *et al.*, 2020; Song *et al.*, 2021)
Buildings	1	(Gomez-Tone *et al.*, 2022)
Built Environment Project and Asset Management	1	(Samarasinghe and Piri, 2022)
Computers and Education	1	(Eiris *et al.*, 2021)
Construction Research Congress	7	(Kandi *et al.*, 2020; Eiris *et al.*, 2020; Eiris *et al.*, 2020; Wen and Gheisari, 2022;

		Shojaei *et al.*, 2022; Abotaleb *et al.*, 2022; Eiris *et al.*, 2022)
Creative Construction Conference (CCC)	1	(Kim, 2022)
Electronics	1	(Chung *et al.*, 2020)
Engineering, Construction and Architectural Management	1	(Beh *et al.*, 2022)
Eurasian Conference on Educational Innovation (ECEI)	1	(Jong *et al.*, 2022)
Frontiers in Education Conference (FIE)	1	(Erdogmus *et al.*, 2021)
HCII	2	(Pena *et al.*, 2019; Yang and Wu, 2020)
International Conference of the Immersive Learning Research Network (iLRN)	1	(Akula *et al.*, 2020)
International Conference on Audio, Language and Image Processing (ICALIP)	1	(Jin and Nakayama,2014)
International Conference on Computer Supported Education (CSEDU)	1	(Ceylan, 2020)
International Conference on Engineering and Product Design Education	1	(Strand *et al.*, 2022)
International Conference on Engineering, Technology and Education (TALE)	1	(Walker *et al.*, 2019)
International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)	1	(Dzeng *et al.*,2015)
International Journal of Architectural Computing	1	(Sahbaz, 2022)
International Journal of Emerging Technologies in Learning	3	(Gao and Wu, 2017; Terentyeva *et al.*, 2020; Espinoza et al., 2021)
International Journal of Engineering Education	2	(Pedro *et al.*, 2016; Pham *et al.*, 2018)
International Structural Engineering and Construction Conference (ISEC)	1	(Newton and Lowe, 2015)
Journal of Architectural Engineering	1	(Kandi *et al.*, 2020)
Journal of Computing in Civil Engineering	4	(Dib and Adamo-Villani, 2014; Mastli and Zhang,

		2017; Eiris *et al.*, 2022; Wen and Gheisari, 2023)
Journal of Construction Engineering and Management	1	(Yu *et al.*, 2022)
Journal of Information Technology in Construction	3	(Lucas, 2018; Lucas, 2020; Shojaei et al., 2021)
Journal of Intelligent and Robotic Systems: Theory and Applications	1	(Le *et al.*, 2015)
Journal of Professional Issues in Engineering Education and Practice	1	(Pedro *et al.*, 2016)
Journal of Surveying Engineering	1	(Bolkas *et al.*, 2022)
Sustainability	1	(Kuncoro *et al.*, 2023)
Technology in Society	1	(Sepasgozar, 2022)
Universal Access in the Information Society	1	(Wu *et al.*, 2019)
Virtual Reality Software and Technology (VRST)	1	(Zhang *et al.*,2018)

The eligible 59 papers were analyzed and mapped to the identified SLOs of the VR training and education with reference to the content areas of the 20 ACCE's SLOs in Table 2. The following sub-sections demonstrate how literature reports benefits or unexplored learning outcomes of VR that do or do not contribute to the learning experience with respect to the content areas associated with the twenty ACCE's SLOs

Table 3

Table of the Mapped Publications to the Corresponding ACCE's SLOs Content Areas

ACCE Content Areas SLOs	SLO 1	SLO 2	SLO 3	SLO 4	SLO 5	SLO 6	SLO 7	SLO 8	SLO 9	SLO 10	SLO 11	SLO 12	SLO 13	SLO 14	SLO 15	SLO 16	SLO 17	SLO 18	SLO 19	SLO 20
Wen and Gheisari, 2022								✓												✓
Eiris *et al* ., 2022			✓							✓			✓							
Shojaei *et al* ., 2022								✓		✓						✓				
Abotaleb *et al.* , 2022			✓			✓				✓			✓							
Eiris *et al.* , 2022								✓		✓										
Kandi *et al.* , 2020							✓			✓										
Eiris *et al.* , 2020			✓							✓										
Eiris *et al.* , 2020								✓		✓										
Wanga *et al.* , 2020					✓			✓	✓	✓						✓		✓		
Eiris *et al.* , 2021								✓	✓	✓									✓	
Wang *et al.* , 2020	✓		✓					✓		✓										
Ahmed, 2020							✓			✓									✓	
Jong *et al.* , 2022										✓									✓	
Walker *et al.* , 2019										✓										
Erdogmus *et al.* , 2021						✓		✓												
Akula et al., 2020			✓							✓			✓							
Samarasinghe and Piri, 2022						✓	✓			✓						✓				
Kim, 2022										✓										
Beh *et al.*, 2022										✓					✓				✓	✓
Yu *et al.* , 2022			✓							✓			✓							
Bolkas *et al.* , 2022										✓	✓									
Sepasgozar, 2022								✓		✓										
Gomez-Tone *et al.* , 2022		✓						✓		✓									✓	
Eiris *et al.* , 2021								✓		✓										
Wen and Gheisari, 2022							✓			✓										✓
Castronovo *et al.* , 2022								✓	✓	✓									✓	
Strand *et al.* , 2022							✓		✓	✓					✓					
Sahbaz, 2022								✓		✓										
Sippel *et al.* , 2022										✓									✓	

Table 3 (continued)

Table of the Mapped Publications to the Corresponding ACCE's SLOs Content Areas

ACCE Content Areas SLOs	SLO 1	SLO 2	SLO 3	SLO 4	SLO 5	SLO 6	SLO 7	SLO 8	SLO 9	SLO 10	SLO 11	SLO 12	SLO 13	SLO 14	SLO 15	SLO 16	SLO 17	SLO 18	SLO 19	SLO 20
Kuncoro *et al.* , 2023										✓									✓	
Wu *et al.* , 2019			✓				✓			✓										
Ma and Li, 2021								✓		✓										
Kandi *et al.* , 2020							✓	✓		✓										
Pena *et al.* , 2019			✓							✓										
Song *et al.* , 2021								✓		✓										
Pradhananga *et al.* , 2020		✓																		
Sengupta and Sparkling, 2021										✓										✓
Lucas, 2020								✓		✓										
Chung *et al.* , 2020			✓			✓	✓	✓		✓					✓				✓	
Yang and Wu, 2020										✓	✓									
Bashabsheh *et al.* , 2019								✓		✓	✓								✓	
Terentyeva *et al.* , 2020			✓		✓		✓	✓	✓	✓					✓	✓			✓	
Espinoza *et al.* , 2021										✓										✓
Shojaei *et al.* , 2021								✓												
Ceylan, 2020		✓													✓					
Dzeng *et al.* ,2015			✓							✓										
Le *et al* ., 2015	✓	✓	✓					✓					✓		✓				✓	
Pedro *et al.* , 2016			✓					✓					✓		✓					✓
Tan *et al.* , 2017								✓		✓										
Gao and Wu, 2017										✓	✓									
Zhang *et al.* ,2018								✓		✓										
Pedro et al., 2016			✓					✓		✓			✓							
Lucas, 2018								✓		✓									✓	
Dib and Adamo-Villani, 2014																		✓		
Newton and Lowe, 2015								✓		✓										
Sampaio and Martins, 2014								✓		✓									✓	
Pham *et al.* , 2018			✓							✓										
Jin and Nakayama,2014			✓					✓					✓							
Mastli and Zhang, 2017								✓		✓										

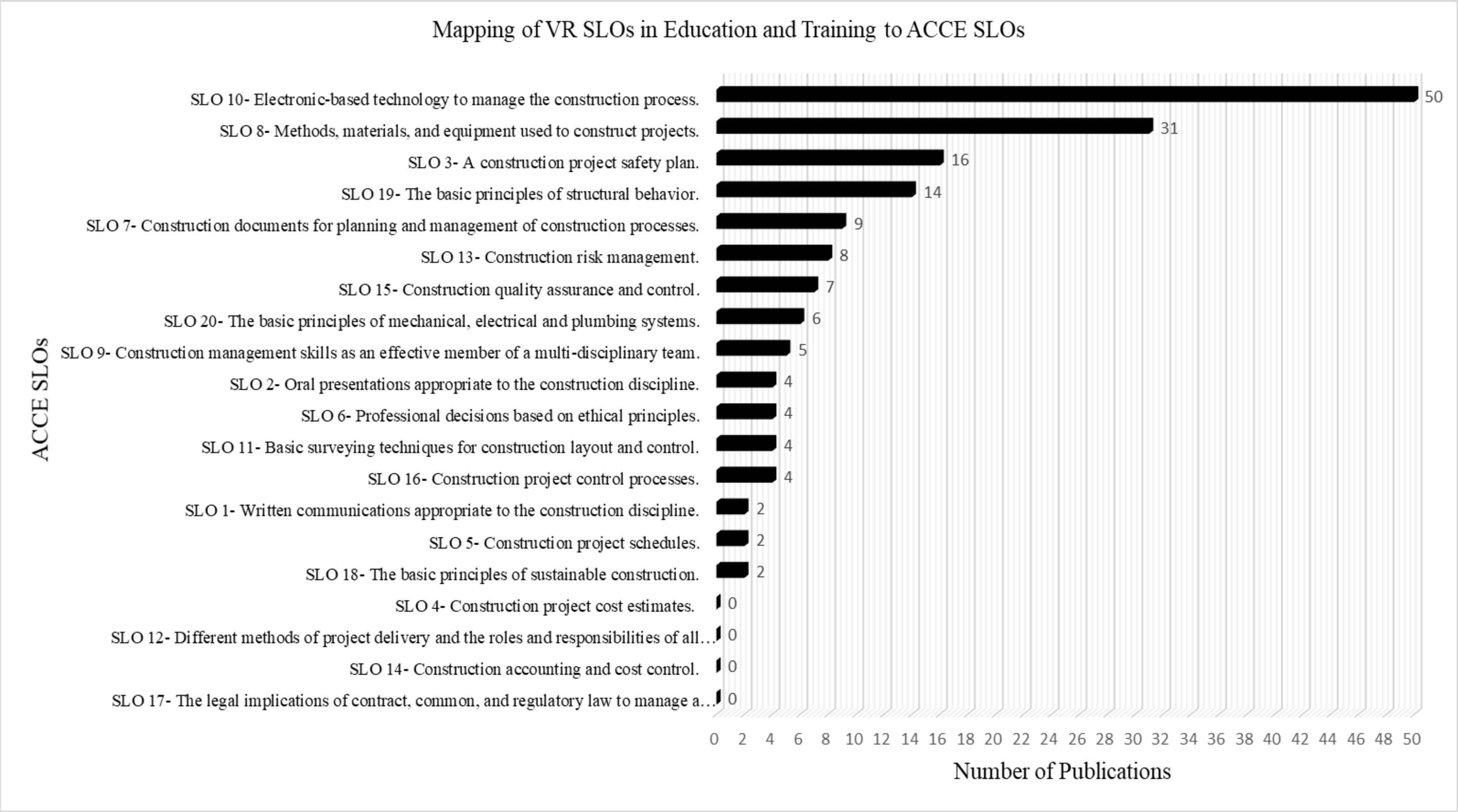

Figure 2. Mapping of Reported VR Training SLOs to Content Areas from ACCE's SLOs.

This figure maps the students' learning outcomes of the conducted VR trainings, of the selected publications, with reference to the twenty ACCE's SLOs.

Figure 2 summarizes the mapping of reported VR training learning outcomes to content areas from ACCE’s SLOs. It could be noticed that there are some SLOs that are addressed frequently in the literature, while others are limitedly explored. For example, Figure 2 shows that the content area of SLO 10 (electronic-based technology to manage construction processes) is predominantly addressed. Indeed, since VR is an electronic tool that assists in managing construction processes, it is logical and expected that the content area of SLO 10 is the highest distinguished. Furthermore, content areas of SLOs such as SLOs 8 (Methods, materials, and equipment), 3 (Safety plan), 7 (Construction documents for planning and management), and 19 (Basic principles of structural behavior) are frequently addressed in studies that utilized VR trainings. On the other hand, there is scarcity of studies that explore the use of VR training addressing SLOs with content areas of for example SLO 1 (written communication skills), 5 (project schedules), and 18 (basic principles of sustainable construction). Interestingly, the methodology of this research yielded no findings regarding targeting content areas of SLO 4 (cost estimates), 12 (Different methods of project delivery and the roles and responsibilities of all stakeholders), 13 (risk management), 14 (accounting and cost control), and 17 (Legal implications). To summarize, the analyzed literature predominately addressed SLO 10, 8, 3, and 19 and frequently addressed SLO 7, 15, 20, and 9, whereas the least frequently addressed SLOs are 2, 6, 11, 16, 1, 5, and 18 and the unexplored SLOs are 4, 12, 13, 14, and 17. The SLOs are further discussed in the following sections.

BENEFITS OF VR TRAINING

Interesting patterns and trends emerged from analyzing the literature that highlight the potential benefits and unexplored learning outcomes of VR training to target content areas from the ACCE’s SLOs. The following sections discuss patterns that indicate benefits of VR training, including virtual on-site immersion, manipulation of time, cost efficiency, and ethical measures.

Virtual On-Site Immersion

One notable pattern indicated from the analyzed literature is that VR was employed in construction education when being virtually immersed on-site is advantageous. It was reported that VR trainings provided students with immersive experiences that enabled addressing content areas from SLO 7 (Construction documents for planning and management), 8 (Methods, materials, and equipment), 11 (Basic surveying techniques), 15 (Construction quality assurance and control), 18 (Basic principles of sustainable construction), 19 (Basic principles of structural behavior), and 20 (Basic principles of MEP). It was reported that VR immersive view allowed students to virtually recognize composite structures and identify element relationships between wood frames in interactive and immersive simulations (Eiris et al., 2021). In another study, students reported that the VR immersive simulated walkthroughs guided them to discover errors in their models, such as small holes in the floor or excessively narrow passages (Strand et al., 2022). In a retail store design course, an immersive experience offering VR training for students contributed to their understanding of the site conditions for onsite surveying, leading to an improvement in the students’ accuracy (Yang and Wu, 2020). These reports demonstrate that the level of visual immersion provided by the VR may be one of the fundamental reasons that enabled VR training to address content areas from SLO 7, 8, 11, 15, 18, 19, and 20.

Construction engineering and management is a dynamic, practical field that requires intensive visualization of construction activities. In the light of this, ACCE’s aim is to prepare students for their careers in this dynamic field through setting specific learning outcomes. While visualization plays a crucial role in achieving some of the ACCE’s SLOs, it might be challenging for students to visualize complex construction tasks if not presented properly due to some limitations in mimicking or simulating on-site conditions in traditional classrooms (Messner et al., 2003; Hartless et al., 2018). The pattern of utilizing VR in trainings that fundamentally require immersiveness, to enhance students’ visualization and consequently targeting some of the content areas of ACCE’s SLO, could be attributed to a couple of reasons. VR creates an experience that is immersive, interactive, and viewer-centered through simulated environments that imitate real-world scenarios, thus promoting experiential learning and comprehension through enhanced visualization (Yu, 2021). This immersive environment improves learners' understanding of the basic construction principles, project dynamics, and practical applications thus aligning with content areas from ACCE’s SLOs. It provides simulations of real environments that enable interaction with synthetic three-dimensional visuals or other sensory worlds (Cruz-Neira, 1993; Cipresso et al. 2018). These reports indicate that VR training could provide the needed immersiveness for addressing ACCE SLOs (such as SLO 7, 8, 11, 15, 18, 19, and 20) that require enhanced visualization along with understanding of construction dynamics within an immersive and controlled learning environment.

Manipulation of Time

Analyzing the literature revealed another emergent pattern through which VR trainings are reported to be utilized in conducting certain trainings in which time manipulation is required, that align with content areas such as SLO 8 (Methods, materials, and equipment), SLO 11 (Basic surveying techniques), 19 (Basic principles of structural behavior), and 20 (Basic principles of MEP). This pattern could be mainly attributed to the fact that VR training allows simulating on-site complex settings that are not feasible and time consuming to bring to traditional classrooms (Eiris et al., 2021; Erdogmus et al., 2021; Shojaei et al., 2022). VR trainings enable manipulation of time in a manner that cannot be done in physical onsite environments (e.g., show months of construction in minutes or slow certain activities down to see fundamental processes at speeds that can be understood by students). In the context of a virtual site tour, the time required to train and explain to students the methods of excavation and concrete works (with all its various steps: reinforcement, formwork, casting, and proofing) was reduced since it allowed to cover such content in one comprehensive session (Bashabsheh et al., 2019). Moreover, it was reported in the literature that students can visualize the performance of various construction methods, e.g., project feasibility and anticipated challenges, and engage with construction materials and equipment (Song et al., 2021; Castronovo et al., 2022; Eiris et al., 2022; Sepasgozar, 2022). Conversely, traditional training methods could be limited to an extent in terms of providing students the chance to witness various time-consuming construction activities and their methods in an entitled course with a restricted timeframe (Sacks et al., 2013; Mai and Li, 2021; Sahbaz, 2022). Therefore, it is likely that the benefits reported related to VR training being a time efficient approach is by large because VR could manipulate time through simulating the lengthy construction activities and be delivered to students at any time regardless of their physical location or the availability of physical resources.

Cost Efficiency

Cost efficiency is another discernible pattern that emerged indicating that VR training has been predominantly employed in situations where the traditional learning alternatives are prohibitively expensive or resource intensive. In an application of virtual simulation of experimental system for curtain wall, the results indicated that the virtual training was more efficient in terms of cost control of the experiment itself when compared to the traditional curtain wall design laboratory (Ma and Li, 2021). The analyzed literature highlights the cost-effectiveness and efficiency of VR training as a viable solution for providing realistic training experiences that would otherwise be financially unfeasible to replicate using traditional methods. Additionally, the employment of VR can overcome, to an extent, the financial constraints associated with accessing real construction sites or training using real equipment. This enables addressing content areas from ACCE’s SLOs including SLO 3 (Safety plan), SLO 7 (Construction documents for planning and management), 8 (Methods, materials, and equipment), SLO 11 (Basic surveying techniques), 18 (Basic principles of sustainable construction), 19 (Basic principles of structural behavior), and 20 (Basic principles of MEP). The employment of VR in these contexts suggests its potential as a valuable tool for tackling the financial constraints associated with hands-on training in costly and intricate construction environments.

Ethical Measures

Another interesting pattern, that emerged from the literature discussion, is the role of VR trainings in simulating instances when experiencing failure or other adverse outcomes are beneficial to support learning, but not possible or unethical to be done on actual sites. This is relevant to addressing content areas from ACCE's SLOs such as SLO 3 (Safety plan), SLO 7 (Construction documents for planning and management), 8 (Methods, materials, and equipment), 13 (Risk Management), 19 (Basic principles of structural behavior), and 20 (Basic principles of MEP). A VR-based safety training was reported to simulate safety hazards scenarios that are unethical to be mimicked in real site in a way that allowed students to better select proper PPE; otherwise, if they selected the wrong PPE, the training would virtually simulate the experience of being in an incident (Yu et al., 2022). It was also reported that VR trainings improved students' ability to identify safety hazards, recognize fall hazards, and follow safety protocols (Wu et al., 2019; Akula et al., 2020; Wang et al., 2020; Abotaleb et al., 2022). Indeed, VR environments have been of particular interest because unsafe events could be simulated without any real threats to students. For instance, VR training provides setting for students to pay close attention to complex environments, recognize potentially dangerous situations, and repeatedly practice under non-stressful conditions (Pena et al., 2019; Chung et al., 2020; Noghabaei et al., 2020; Yu et al., 2022), which might be illegal or unethical to be done in traditional settings due to the potential harm it could cause. The limited resources involved in simulating such scenarios in traditional academic environments restrict the effectiveness of the knowledge required for students (Pedro et al. 2016). As a result, it is shown in the literature that there is a pattern in which researchers are investigating the use of VR trainings to allow students experience failure or other adverse outcomes that are beneficial to support learning without illegal or unethical implications.

UNEXPLORED CONTENT AREAS OF ACCE's SLOs

Although the analyzed literature highlights some advantageous patterns of VR training and education in construction management and engineering, some patterns emerged indicating unexplored content areas associated with ACCE's SLOs by VR training. The following sections discuss patterns that indicate unexplored learning outcomes of VR training in targeting content areas of SLOs that require human interaction, quantitative calculations, and construction management tools, delivery method and stakeholders' management, and risk management.

Human Interaction

Analyzing the literature revealed a pattern which is a lack of VR training in addressing SLOs that involve human interaction and interference as conferred in content areas of SLOs 1 (written communication skills), 2 (oral presentation skills), 9 (management skills within multidisciplinary team), and 17 (Legal implications). This could be contributed to the availability of other alternatives, such as traditional classrooms and workshops, that are commonly used in training written and oral communication skills and students' management skills within multidisciplinary teams. It seems reasonable that such SLOs require human-to-human interaction and that there is no need to implement VR as a replacement of the traditional training environments. Studies indicated that students do not see VR replacing traditional learning methods; however, they expressed interest in integration of VR along with the existing traditional learning methods in the educational system as they believed that by this, the learning experience would be overall more comprehensive and engaging (Abotaleb et al., 2022).

Quantitative Calculations

The methodology of this research yielded no findings regarding content areas that fundamentally require quantitative calculations or data-driven analyses, such as estimating, accounting, and controlling projects' costs as of ACCE's SLOs 4 (cost estimates) and 14 (accounting and cost control). The lack of employment of VR training in these aspects might be because efforts have been commonly directed towards other more frequently used tools like BIM for the quantitative complex processes, e.g., quantity takeoffs and cost estimations (Li et al., 2014; Babatunde et al., 2019). Such findings indicate that within the analyzed literature, there is scarcity of studies that investigated the adoption of VR training in addressing SLOs that require quantitative calculations. This highlights opportunities for future research to explore and discover the potential of VR in effectively targeting some of these SLOs' content areas.

Construction Management Tools

The literature analyzed shows a pattern in which VR trainings are less commonly targeted when addressing content areas that mainly require data-driven management processes; such as content areas of SLO 5 (project schedules) and 16 (project control processes). Rather than the use of VR, robust software management tools such as Primavera P6 have been rigorously employed in training and educating students about creating construction project schedules (SLO 5) and understanding project control processes (SLO 16) (Mallick et al., 2019; Narlawar et al., 2019). Hence, this demonstrates why VR trainings are not predominantly targeted to address these content areas that are rather targeted through other more commonly used construction management tools. This might reveal why VR was addressed the least in content areas from SLOs 5 and 16 while the most in SLOs 3, 8, and 19; that are intrinsically visual in nature and might be unethical or time consuming or expensive to be done without VR.

Delivery Method and Stakeholders' Management

The methodology of this research yielded no findings regarding content areas of SLO 12 (Different methods of project delivery and the roles and responsibilities of all stakeholders). Despite the fact that targeting this SLO by large requires simulating different scenarios for project delivery methods and different roles and responsibilities of all constituencies involved in the design and construction process to be available to students at any time, VR training, which is capable of providing such simulations as reported in the literature, was not explored to address this SLO's content. This seems to indicate that future research is needed to explore the potential of VR in effectively targeting content areas of SLO 12 and allowing students to explore and understand the complexities of project delivery methods and roles and responsibilities in a realistic virtual environment.

Risk Management

The literature analyzed shows a pattern when addressing risk management, such that when VR trainings were reported in the literature to address content areas of risk management (SLO 13), it was only utilized in mimicking safety hazardous scenarios or risk identification in safety context. However, the multidimensional nature of risk management, as it involves a broader range than safety management, was not targeted in the studies. For example, risk management entails operational and financial risks, and developing mitigation skills. Risk management also involves the integration of other fields such as contracts, scheduling, and cost control. Despite the scarcity of research on VR training in the construction education context addressing SLO 13, various domains including military, aviation, and medicine used VR for risk management (Filigenz et al., 2000; Akhtar et al., 2005; Suto et al., 2020). This demonstrates a promise for the use of VR training in construction to simulate risk scenarios that would be unethical to be done without VR yet beneficial to support learning.

CHAPTER 5

CONCLUSION

This paper analyzes the trends in VR literature through the reported benefits and unexplored learning outcomes of VR in construction training and education, and investigates the ways by which these trends do or do not contribute to the learning experience by targeting the content areas of the ACCE's SLOs. The analyzed literature of the 59 papers from 2014-2023 predominately addressed SLO 10, 8, 3, and 19, and frequently addressed SLO 7, 13, 15, 20, and 9, whereas the least frequently addressed SLOs are 2, 6, 11, 16, 1, 5, and 18 and the unexplored SLOs are 4, 12, 14, and 17. The analyzed literature showed emerging patterns of VR training, some of which were reported to have beneficial contribution to content areas from some of the ACCE's SLOs, whereas others were not explored within the pool of the literature analyzed in this research work. Some of the beneficial patterns emerged from VR training that were reported to address content areas from ACCE's SLOs are "Virtual On-Site Immersion" that targeted content areas of SLOs including 7, 8, 11, 15, 18, 19, and 20, "Manipulation of Time" that attributed to content areas of SLOs including 8, 11, 19, and 20, "Cost Efficiency" that tackled content areas of SLOs such as 3, 7, 8, 11, 18, 19, and 20, and "Ethical Measures" that addressed trainings that involved content areas of SLOs encompassing 3, 7, 8, 13, 19, and 20. On the other hand, there are some patterns that indicate unexplored learning outcomes of VR training in targeting content areas of SLOs that require human interaction, e.g., SLOs 1, 2, 9, and 17, complex quantitative calculations, e.g., SLOs 4 and 14, construction management special tools, e.g., SLOs 5 and 16 or delivery method and stakeholders' management of SLO 12, and risk management of SLO 13. Indeed, the high frequency of addressing specific ACCE’s SLOs while having less studies on other SLOs does not mean that there are SLOs that are more important or worth more investment in VR training than others. The results of this research simply depend on the pool of literature to which the inclusion criteria of this study’s methodology yielded. All in all, while this research does not express interest in replacement of traditional trainings by those simulated by the VR technology, VR training is concluded to possess benefits that can contribute to some content areas associated with the ACCE’s SLOs which accordingly contribute to the training and education of construction engineering and management in the undergraduate levels accredited by the ACCE. Therefore, it is encouraged to consider the integration of VR training along with the existing traditional trainings for a comprehensive learning experience. This research’s findings propose guidance to educational researchers to strategically use or expand the use of VR to address ACCE’s SLOs in future work while providing evidence of potential, or lack of evidence, for VR to inform these future studies.

CHAPTER 6

LIMITATIONS AND FUTURE RECOMMENDATIONS

The demographics targeted in this study's methodology might have resulted in limitations in the findings since the study was exclusive to undergraduate students. It is possible that specific SLOs were not scrutinized and some trends might have not been disclosed at the undergraduate education level while being addressed in other frameworks that include graduates and field practitioners or experts. Furthermore, many studies have not formally used VR as a mode of measuring ACCE accreditation outcomes with respect to Bloom's Taxonomy levels of learning. Since this study focuses on the presence or absence of studies targeting each content area while excluding the Blooms verbs, this leaves exploration of specific levels of learning with VR to future work.

Future research is encouraged towards further investigations of the limitedly addressed SLOs that are seemingly a good fit for VR, yet are still unexplored by current literature. Moreover, future research on the pedagogical integration of VR is recommended to fully comprehend the ways by which VR can effectively contribute to the construction education curricula. This includes investigations of the following: the feasibility and cost of VR implementation within the current educational systems, the optimum duration of VR training, the frequency of the sessions, and the roles and responsibilities of the instructors.

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