A Review on Virtual Reality for Architecture Education

Hala Sirror, Amal Abdelsattar, Salma Dwidar and Amani Derbali

Architecture Department
Prince Sultan University
Riyadh, Saudi Arabia
hsirror@psu.edu.sa, aabdelsattar@psu.edu.sa, sdwidar@psu.edu.sa, aderbali@psu.edu.sa

Abstract

In March 2020, the World Health Organization (WHO) declared the COVID-19 outbreak as a global Pandemic. Therefore, lockdown measures were announced throughout the world, which included the closure of schools and universities. So, education has changed dramatically to the e-learning which is challenging in architecture education that usually contains a considerable part of practical courses. Therefore there was an emergent need for an online alternative to the practical part. In education, Virtual Reality (VR) can help students experience realistic situations that can motivate them to learn and learn through interaction with systems. This paper aims to present a brief study on VR and its applications of implementation in architecture education. This paper also reviews the main VR applications that were implemented in the different fields of architecture education. The main objective is studying VR adoption in four primary areas of architecture education, including design, construction, surveying, and structural analysis and design. The methodology adopted is reviewing high-quality sources such as Scopus and web of science to grasp relevant state-of-the-art knowledge about the application of VR technology in architectural education. Results showed adopting VR and AR technologies improved learning among students.

Keywords
Virtual Reality, Augmented Reality, Architecture Education, VR/AR Technologies.

1. Introduction
Virtual Reality (VR) technologies have been promptly acknowledged in Architecture education due to its effectiveness in improving the architecture program's quality (Wang et al., 2018). Different visualization techniques, such as VR and AR, have been adopted to boost learning experiences since the early 2000s. As an efficient tool, VR has proven to provide better capabilities for comprehension and visualization. In architectural education, students can experience various architectural spaces through a 3D object rather than viewing typical drawings. Furthermore, the use of conventional 3D approaches in education and training depends on using a mouse or keyboard to communicate with the computer. While in the VR setting, the immediate effects of interactive behaviours, such as pulling and catching, can be visualized in real-time mode (Park et al., 2015).
Technology companies are developing augmented reality (VR) technologies in addition to virtual reality (VR), which usually reflects completely interactive worlds (Killey, 2017). Augmented reality (AR) technology allows computer-generated content, such as interactive 2D and 3D multimedia objects, to be superimposed in real-time on a view of real objects (Rumiński, 2015). Thus it allows users to interact with objects that fit seamlessly into the real world (including changing the size, location and other properties) (Zhang et al., 2018). In addition to this, Killey (2017) stressed that AR environments, like a photograph of a city street, layer computer-generated details, such as utility lines, on top of real-world views. Although Thomas and Piekarski (2003) argued that augmented reality and virtual reality share similar characteristics, with knowledge anchored to 3D positions relative to the user's display, body, or environment, in that they present computer-generated images for a user to encounter. On the other hand, the distinction between AR and VR is that the VR display system does not provide visual details from the real environment (Zhang et al., 2018).).

1.1 Objectives

The main objectives of the research are to:

1. To identifying VR and AR technology and used tools.
2. To highlight the different applications of VR and AR in architecture education.
3. To review the adoption of VR and AR in four main fields of architecture education, including design, construction, surveying, and structural analysis and design.

2. Literature Review

2.1 Applications of VR/AR

AR and VR technologies have been applied in architecture and design visualization, building health and safety training, equipment and operating task training, and structural analysis, studied by Wang et al. (2018). Furthermore, Zhang et a. (2018) analyzed VR applications and grouped them into four categories, including:

1. Visualization of architecture and education in design,
2. Education in structural analysis,
3. Training in building safety and
4. Equipment and training for operational tasks.

Sacks and Brilakis (2020) argued that the spectrum of potential construction VR applications is broad, including smart tools for:

1. Design support and/or automation, topology optimization, generative design, design review,
2. Compliance monitoring of standards and codes,
3. Building performance simulations and engineering analysis
4. Construction planning,
5. Site layout design, supply chain management,
6. Digital analysis, construction simulation and
7. Engineering analysis.

Six AR and VR use cases were described by Delgadoa et al. (2020):

1. Stakeholder participation,
2. Design support, design review,
3. Construction support,
4. Support for operations and management and training.

2.2 VR/AR Technologies

Environments in virtual reality (VR) include an interactive environment in which users wear tracked glasses to display stereoscopic images, listen to 3-D sounds, and inside a 3-D world are free to explore and interact (Chan, 1997). Alsafouri and Ayer (2019) found that VR technologies adopted for education and training in architecture education can be categorized into five types, immersive VR, 3D game-based VR, desktop-based VR, BIM-enabled VR and Augmented Reality (AR).

3. Methods

Recently, a lot of articles were published on using VR/AR in architecture education. This paper aims to provide a framework and classification of VR/AR applications in architecture education. Also, it summarizes the challenges of VR/AR in architecture education. Three search criteria were established for the paper retrieval process. As the systematic review investigates VR-related research and applications in architectural engineering, only academic journal articles were selected for the review, considering their relatively high impact. Scopus and Web of Science, the largest two academic databases, were used for the searching. The keywords used in the retrieval process included virtual reality, virtual environment, 3D, game, construction, architecture, and structural engineering education. The search rule was: (virtual reality) AND (architectural education); (augmented reality) AND (architectural education). All publications which contained the above keywords in the Title/Abstract/Keywords were identified. A total of 100 articles were retrieved from 1997 to September 2017. A computer screening process was then adopted to ensure all retrieved articles were related to this study's aim. A total of 26 publications were identified for further analysis.

4. Data Collection

This study is based on retrieving the VR research and application in architecture education. For the papers retrieval, only academic journal/conferences articles were mainly considered from 2000 to 2020. Scopus and Web of Sciences, which are the most extensive academic databases, were used for searching. The keyword used in papers retrieval included VR, architecture design, construction, surveying and structural analysis and design. Analyzing collected data is based on categorizing data according to different VR/AR applications in architectural education.

4.1. Data Analysis

The 26 selected publications are analyzed based on a few keywords. The keywords are adapted from a few similar studies using content analysis. The keywords used in this study include virtual reality in architectural education, the definition of virtual reality, applications of virtual reality. Data is organized under the field of architecture where virtual reality is applied.

5. Results and Discussion

5.1 Overview of Selected Articles

Twenty-six articles were selected to cover the application of VR in architecture education. These articles included five articles in Surveying, six articles in structures analysis and design, eight articles in construction and five articles in architecture design. From the review, VR applications in architectural education can be categorized into four groups, including: (1) architecture design; (2) construction (3) surveying and (4) structural analysis and design.

5.2 VR Application in Architecture Education

5.2.1Architecture Design

VR has become a valuable visual instrument for architectural learning and teaching and is now in the study process of rapid growth (Chan, 1997). Models of virtual reality (VR) have been used in higher education to provide learners with inaccessible real-life experiences (Samarasinghe et al., 2019). Applying VR to architectural designers will allow them to understand the spatial qualities of their designs instantly. It will be able to understand their works by walking through the virtual space to envision the colour and texture of the assigned materials, the proportions of the spatial structure, and the structural elements' aesthetic expression (Chan, 1997). Also, by undertaking a pre-construction walk-through in the virtual townhouse where last-minute design ideas were tested, interactive and immersive virtual reality (VR) technology helped its building industry clients in the design, simulation, marketing and sales of new projects. (1996, Neil). From Zhang et al. (2018) via integration, AR will play a vital role in the education of cultural buildings. Using Virtual Reality (VR) technology, students can create a learning application where learners can master how to make conventional buildings by interacting with virtual models. In addition, findings on the use of VR showed that the architecture was altered, employee satisfaction increased, and costs decreased (Mobach, 2008). Alsafouri and Ayer (2019) found that AR can promote some of the actions of virtual reality and physical mock-ups, including decision-making, design alternatives, and descriptive , explanatory, in design and constructability analysis sessions and problem-solving activities.

5.2.2 Construction

In construction education students, need to visualize the different construction methods and go to field trips. This may require travelling to construction sites to relate between theory and practice. Sacks et al. (2014) reported that VR helps researchers in a controlled environment track, record, and analyze human subjects' decision-making actions, with high precision and in relatively very short periods. Pedro et al. (2015) found that by providing a creative platform for experientially improving hazard recognition capacity, transferring safety information, and engaging students, VR can combine safety with construction materials and techniques education. Chan et al. (2015) reported in a similar study on enhancing construction education that VR promotes experiential learning and offers appropriate interaction levels to transfer information to learners effectively. Wang et al. (2018) researched AR and VR technologies that have evolved for construction education and have been used in the simulation of architecture and design, training in construction health and safety, training in equipment and operational tasks, as well as structural analysis. Agirbas (2020) found that when BIM is incorporated into architecture degree programs with the teaching of basic construction courses, students grasp the building system's concepts clearly and effectively.

5.2.3 Surveying

Surveying includes determinations of the earth surface through the measurements of distances, elevations and directions. Also, it includes staking outlines and grades, which is very important to the constructions of buildings, roads, pipelines, etc. Therefore, surveying courses usually have a practical part implemented in the field. The traditional way of teaching the practical part faces several challenges such as weather conditions, expensive surveying instruments, needs to one to one training, limited availability of terrains to practice. Therefore, VR offers a good conquer these obstacles and improve the learning outcomes of surveying courses. Li et al. (2008) developed a VR learning system to fulfil the Digital Terrain Model (DTM) surveying course requirements. As implemented in actual field operations in the VR system, the students can pick the topographical control points and edit triangulated irregular network (TIN). Immediately after these operations are done, the elevation error magnitude and distribution can be measured, which give the student instant feedback. Therefore, students receive immediate performance feedback. Kue et al. (2007) developed a virtual survey instrument (SimuSurvey) that allows users to customize various simulation environments for performing different surveying tasks. SimuSurvey trains the students in two surveying skills; pointing toward a target and reading through surveying instruments' telescopic eyepiece. The study results showed that the students' learning outcomes had been enhanced; there was also positive feedback from the instructors. Ellis et al. (2006) presented an interactive multimedia levelling application. In this application, students can explore 360-degree panoramic images of the construction site, and they can gather detailed readings from level and staff.
The evaluation of the application was collected from 192 undergraduate students indicated that the application complements the traditional learning methods, enhances the understanding and sustains student's interest. Mills and Barber (2008) implemented virtual traverse learning tool (VITLT). This tool was designed to help the students understand the complexity of a traverse by simulating observation and calculating a surveying traverse. The students evaluated the application, indicating that VITLT can be used as a preparation tool for real observation. Dib and Adamo-Villani (2014) developed the Virtual Learning Environment (VLE) to help students review concepts and perform chaining exercises. Also, it contains an evaluation engine to track students' interactions and create performance reports. Evaluation of the application was conducted by collecting the students' and instructors feedback. Students reported that the application is beneficial in learning and assessing their knowledge of chaining concepts and procedures. Instructors found that the application is a very useful summative assessment tool.

5.2.4 Structure analysis and design

Structural analysis is an essential course in engineering education. However, students usually struggle in learning this course due to the high level of abstractions and the difficulty of understanding its concepts by using traditional 2D drawings. VR/AR tools were used to improve the students learning outcomes in structures analysis and design.
AR/VR was used with finite element models to create real-time simulations. Setareh et al. (2005) developed an immersive virtual structural analysis program (VSAP) to help the architecture students understand the building structures' behaviour under different environmental conditions such as gravity loads, seismic loads, wind loads, etc. In this system, the student can build a structure and subject it to specific loads. After observing the effect of the applied loads on the structure, the system allows the student to alter the structure and repeat the process. Fiorentino et al. (2009) used the AR approach to help the students understand Finite Element Analysis (FEA) in structural analysis. In this application, the results of FEA are overlaid over the physical model. The students can change the properties of the model, then evaluate the stress distribution. Similarly, Young et al. (2011) investigated the use of 3D visualization of structures and found that the finite element simulation helped the student to see the behaviour of structures which cannot be seen by bare eyes such as the stress in structures.
Another application for VR was used in laboratories which provide a cost-effective solution for nonlinear problems. Turkan et al. (2017) used interactive 3D visualization techniques to improve students' understanding of load effects, load paths, and the deformed shape of simple structures. Badías et al. (2018) developed experiments to track the motion of simply supported beams and cantilever during different loading types. Vergara et al. (2016) used VR to enhance student learning outcomes in the compression test of concrete samples for a large group of students. This application solves common difficulties found in laboratory classes in which some students
miss some of the compression test information during the teacher's description because of a lack of room in crowded groups of students.

6. Conclusion

A review of Virtual Reality (VR) applications in architecture education has been presented in this study. Based on the retrieved articles from 2000 to 2020, VR has a wide variety of applications in architecture design, construction, surveying and structures analysis and design. Main applications included Many authors reported that students found VR application is very beneficial to overcome the shortage of time resources. They also reported that VR helped the students understand the concepts of challenging courses such as structures and surveying. VR provides ways to adapt student-centred learning, especially with the recent trend to move to e-learning due to COVID-19 pandemic. Applying VR to architectural designers will allow them to understand the spatial qualities of their designs instantly and will be able to understand their works by walking through the virtual space to envision the colour and texture of the assigned materials, the proportions of the spatial structure, and the structural elements' aesthetic expression. On enhancing construction education, VR promotes experiential learning and offers appropriate interaction levels to transfer information to learners effectively. Using Virtual Reality (VR) technology, students can create a learning application where they can create standard buildings by interacting with virtual models. In addition, findings on the use of VR showed that the architecture was altered, employee satisfaction increased, and costs decreased. Improving construction education that VR promotes practical learning offers suitable interaction levels to transfer information to learners effectively.

Acknowledgements
The researchers acknowledge the support of Prince Sultan University.

References
Akeem Pedro, Quang Tuan Le, and Chan Sik Park (2015) Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality, Journal of Architectural Engineering, American Society of Civil Engineers DOI: 10.1061/(ASCE)EI.1943-5541.0000261.
Agirbas, A., (2020) Teaching construction sciences with the integration of BIM to undergraduate architecture students, Frontiers of Architectural Research, https://doi.org/10.1016/j.foar.2020.03.007
Badías, A., I. Alfaro, D. González, F. Chinesta, and E. Cueto. "Reduced order modeling for physically-based augmented reality." Comput. Methods Appl. Mech. Eng. 341 (Nov): 53–70, 2018. https://doi.org/10 .1016/j.cma.2018.06.011
Chan, Chiu-Shui (1997) Virtual Reality In Architectural Design, Conference: Computer Aided Architectural Design Research in Asia (CAADRIA 97) https://www.researchgate.net/publication/272820335_Virtual_Reality_in_Architectural_Design [accessed Oct 29 2020].
Chan Sik Park, Quang Tuan Le, Akeem Pedro, and Chung Rok Lim (2015) Interactive Building Anatomy Modeling for Experiential Building Construction Education, Journal of Architectural Engineering, American Society of Civil Engineers. DOI: 10.1061/(ASCE)EI.1943-5541.0000268.
Dib, H. and Adamo-Villani, N., An innovative software application for surveying education. Comput Appl Eng Educ, 22: 551-562, 2014. doi:10.1002/cae.20580
Ellis, R. C. T., Dickinson, I., Green, M., and Smith, M., The implementation and evaluation of an undergraduate virtual reality surveying application, Proc. of BEECON 2006 Built Environment Education Conference, London, 2006.
Fiorentino, M.; Monno, G.; Uva, A. Interactive "touch and see" FEM Simulation using Augmented Reality. Int. J. Eng. Educ. 2009, 25, 1124–1128.
Jie Zhang, Hengxin Chen, Jiahui Wang, and Mingqi Gao. 2018. Experience the Dougong Construction in Virtual Reality. In VRST 2018: 24th ACM Symposium on Virtual Reality Software and Technology (VRST '18), November 28-December 1, 2018, Tokyo, Japan. ACM, New York, NY, USA, 2 pages.
Kilkelly, Michael (2017) 5 Steps to Make VR a Reality in Your Practice, Journal of the American Institute of Architects, AIA, USA. https://www.architectmagazine.com/technology/5-steps-to-make-vr-a-reality-in-your-practice_o.
Kuo, H. L., Kang, S. C., Lu, C. C., Hsieh, S. H., and Lin, Y. H., Feasibility study: Using a virtual surveying instrument in surveying training, Proc. of ICEE 2007, Coimbra Portugal, 2007.
Li, C., Yeh, I., Chen, S., Chiang, T. & Lien, L. Virtual Reality Learning System for Digital Terrain Model Surveying Practice. 134, 335–345, 2008.
Mills H., and Barber, D., A virtual surveying field-course for traversing. E-learning in Surveying, Geo-information Sciences and Land Administration, Proc. of FIG International Workshop 2008, Enschede, The Netherlands, 2008.
Mobach, M.P. Do virtual worlds create better real worlds?. Virtual Reality 12, 163–179 (2008). https://doi.org/10.1007/s10055-008-0081-2

Neil, Michael J.. 1996. Architectural virtual reality applications. SIGGRAPH Comput. Graph. 30, 4 (Nov. 1996), 53–54. DOI: https://doi.org/10.1145/240806.240816

Park, C.S.; Le, Q.T.; Pedro, A.; Lim, C.R. Interactive building anatomy modeling for experiential building construction education. J. Prof. Issues Eng. Educ. Pract. 2015, 142, 04015019.

Peng Wang, Peng Wu, Jun Wang , Hung-Lin Chi, and Xiangyu Wang (2018) A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training, International Journal of Environmental Research and Public Health, MDPI.

Rumiński, D. An experimental study of spatial sound usefulness in searching and navigating through AR environments. Virtual Reality 19, 223–233 (2015). https://doi.org/10.1007/s10055-015-0274-4

Sacks, R., Girolami, M., Brilakis, I., Building Information Modelling, Artificial Intelligence and Construction Tech, Developments in the Built Environment, https://doi.org/10.1016/ j.dibe.2020.100011.

Samarasinghe, DAS (Samarasinghe, Don Amila Sajeevan), Abd Latif, S (Abd Latif, Suhaimi) Baghaei, N (Baghaei, Nilufar) (2019) Virtual Reality Models for Promoting Learners Engagement in Construction Studies, PROCEEDINGS OF 2019 IEEE GLOBAL ENGINEERING EDUCATION CONFERENCE (EDUCON) 1331-1335 Edited by: Ashmawy, AK, Schreiter, S, Book Series: IEEE Global Engineering Education Conference

Setareh, M.; Bowman, D.A.; Kalita, A. Development of a virtual reality structural analysis system. J. Arch. Eng. 2005, 11, 156–164.

Suleiman Alsafouri, and Steven K. Ayer (2019) Mobile Augmented Reality to Influence Design and Constructability Review Sessions, Journal of Architectural Engineering, American Society of Civil Engineers. DOI: 10.1061/(ASCE)AE.1943-5568.0000362 .

Thomas, Bruce H. and Wayne Piekarski (2003) Outdoor virtual reality, ISICT '03: Proceedings of the 1st international symposium on Information and communication technologies, September 2003 Pages 226–231.

Turkan, Y., R. Radkowski, A. Karabulut-Ilgu, A. H. Behzadan, and A. Chen. "Mobile augmented reality for teaching structural analysis." Adv. Eng. Inf. 34 (Oct): 90–100, 2017. https://doi.org/10.1016/j.aei.201709.005

Vergara, D.; Rubio, M.P.; Lorenzo, M. New approach for the teaching of concrete compression tests in large groups of engineering students. J. Prof. Issues Eng. Educ. Pract. 2016, 143, 05016009.

Young, B.; Ellobody, E.; Hu, T.W. 3D Visualization of Structures Using Finite-Element Analysis in Teaching. J. Prof. Issues Eng. Educ. Pract. 2011, 138, 131–138.

Wojciechowski, Rafal, Walczak, Krzysztof, White, Martin and Cellary, Wojciech (2004) Building Virtual and Augmented Reality museum exhibitions. In: Brutzman, Donald P., Chittaro, Luca and Puk, Richard (eds.) Proceeding of the Ninth International Conference on 3D Web Technology, Web3D 2004, Monterey, California, USA. ACM Press, New York, NY, USA, pp. 135-144. ISBN 1581138458

Biographies

Hala Sirror is currently working as Assistant Professor in Prince Sultan University in KSA. since 2015. Dr Hala had a PhD is in Architecture from 2014, a Master degree in Environmental Studies from 2002, and a Bachelor degree in Architecture 1966 from the University of Khartoum. Previously, she was as Assistant Professor at University of Science and Technology and during 2014-2015. She worked as a lecturer in Sudan University of Science and Technology 2002-2014. Her research interests are in the field of construction and sustainability. She is a senior fellow of Advance HE and is a LEED accredited professional in building design and construction.

Amal Abdelsattar is currently working as an Assistant Professor at the College of Engineering, Prince Sultan University, Saudi Arabia. Dr Amal has received her PhD in Environmental Engineering, from Ain Shams University, Egypt. She received her Master degree her Bachelor in Civil Engineering from Cairo University, Egypt. She is a Fellow of the UK Higher Education Academy. She worked in the field of Geographic Information System and Remote Sensing applications for 12 years. Dr Amal research interests include environmental engineering, and higher education teaching and learning.

Salma Dwidar received her PhD, Master Degree and Batchelor degree in Architecture from the University of Alexandria. She is currently working as Associate Professor in Prince Sultan University in KSA since 2010. Previously, she was as Assistant Professor at the University of Alexandria. She also worked previously as a lecturer at Mansoura University. Her research interest spans heritage, urban design and sustainability.

Amani Derbali
Amani had a PhD is in Architecture from Kartaj Universitynin Tunisia 2018. She is currently working as Assistant Professor in Prince Sultan University in KSA since 2015. Previously, she was a practising architect. Her research interests are in the field of urban planning.