The incorporation of Virtual Reality (VR) technology into architectural design education: An investigation into the student perspective

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Abstract

Visual communication is vital in architecture. Designers can improve project understanding and realism by immersing themselves in virtual reality. Technical advancements may improve design. Over the past 20 years, the necessity to adapt virtual reality situations in design has grown. If academia and industry collaborate, students will be better equipped for job. Education must include virtual reality in the architecture curriculum.

Long-term goals include creating a virtual reality lab for Ain Shames University architecture students and integrating VR into design studios. This paper describes how VR experiences are being integrated into Architectural Science. Before using VR in the classroom, a pilot study examined the pros and cons of VR in design education. This study explains and examines a junior student's virtual reality experience to speed up architectural design learning. Virtual reality allowed the student to completely experience the architectural framework using a headset and hand controls. Based on experimental data, the authors examined VR's classroom use and demonstrated its instructional value.

Scholars have examined student-centered perspectives in VR-enhanced design workshops. Student responses show the importance of architectural design training in creating an innovative and contextually appropriate curriculum. This study examines the development and usage of VR in architectural design education.

To define digital design approaches, this study analyses how modelling tools, virtual reality tools, students, and material interact. The current study uses two models based on course-specific teaching and learning activities. Approach I use 3D printing to create design models, whereas Approach II uses virtual reality. Students actively use 3D form-finding, building information modelling, visual programming, coding, and real-time rendering in both approaches. Rhinoceros, Unity, Grasshopper, and 3D max are used to create *complex virtual worlds in this study. A User Experience Questionnaire (UEQ) compares digital design techniques' performance. The data show that interaction varied across two distinct but related trait levels that cannot be directly compared. The results show that student engagement clarity characteristics may lead to "complex" and "confusing" software. Task-oriented and non-task-oriented properties differ. Virtual reality (VR) technologies in architectural design education have been shown to be stimulating and novel, despite receiving lower ratings for pragmatic attributes like clarity, effectiveness, and reliability. The study's findings on VR and digital methodology integration in architectural education design studios can inform strategic planning. Thus, this work advances contextualization research in design education.*

Keywords: *Virtual Reality, 3D Printing, VR Tools, Education Process, Egyptian University*

1. Introduction

The revolutionary advancement of the artificial, computer-generated environment is virtual reality (VR). Although there isn't a one accepted definition of virtual reality, many scientists, academics, and computer users have come up with their own interpretations based on their backgrounds. Virtual reality was described by Pimentel and Teixeira[1] as an interactive, immersive experience produced by a computer. "Computer-generated simulations of three-dimensional objects or environments with seemingly real, direct, or physical user interaction" [2] is how Dionisio and Gilbert define VR as it pertains to more contemporary technology. From the definitions, it can be inferred that virtual reality (VR) is experimental in nature and consists mostly of immersion, interactivity, and multi-sensory input.
The 1960s saw the debut of the first virtual reality system, and around 1965 the first Head-Mounted Display (HMD) for VR was created. The fast development of technologies and applications in the 1980s increased interest in VR, and the first cave was introduced in 1990 [2]. Since then, virtual reality technology has seen major use in the gaming and film sectors. However, after 2016 when major tech companies like Facebook, Microsoft, Apple, Google, and HTC announced and released their commercial VR products into the market and made VR inexpensive, VR became more widely available in different contexts[3].

Different fields have been impacted by this technological development, especially the architecture sector, which heavily relies on visual communication. By immersing themselves in virtual reality environments while developing, designers can build a higher sense of realism and a better grasp of a project. This technical development could enhance the design process. As a result, during the past 20 years, there has been a growth in the need for adapting the usage of virtual reality environments in the architecture sector. Foster + Partners, for instance, uses VR settings to assist in creating intricate design visualisations and walkthroughs for their clients. Furthermore, according to Paul Renner of the international architecture firm Kohn Pedersen Fox, by utilising VR, design teams have been able to experience any stage of the design process in real-time thanks to the immersive experience that the technology offers. The final statement is made by Jamie Casas of Wood & Grieve Engineers, who claims that "VR environment is important in our industry, where design changes require clear communication." These testimonials demonstrate the enormous potential that virtual reality holds for the architecture sector[1].

In order to prepare students for a future dominated by technology, architecture schools must also create a curriculum. The Architectural Science programme at Ain Shames University is now integrating VR settings, as described in this paper. This study describes a junior student's experience using virtual reality to speed up learning about architectural design. Using a headset and hand controllers, the student used virtual reality to fully immerse themselves in the created building. The authors looked into the actual use of VR in the classroom environment based on the outcomes of the student experience[2].

Prior to implementing VR in the classroom, this research is a pilot study to examine the benefits and difficulties of integrating a virtual reality system in design education. The study was carried out as a part of a collaboration between faculty and undergraduate students. The experience that students had while developing virtual reality hardware, software, and architectural designs is described in the parts that follow[2].

2. VR Software

The selection of software was a significant challenge due to the nascent nature of virtual reality as a technological domain. Many programmes utilise a computer gaming headset and modify it for architectural engagements. Several variables were considered in the selection of virtual reality (VR) software. The software necessitated compatibility with both the intended hardware as well as architecture programmes. Furthermore, it was necessary for the system to possess the ability to simulate prevalent architectural design issues, including but not limited to lighting, spatial perception, and precise material production. Furthermore, it was necessary for it to possess compatibility with design software[4].
According to the literature, the two virtual reality programmes that exhibit the highest level of development and are compatible with the Oculus platform are IrisVR Prospect and Enscape[4]. Furthermore, these programmes provided complimentary licences to students and educators who sought to evaluate the application of virtual reality in architecture design. The Oculus Prospect platform provides a range of valuable functionalities, including tabletop model perspectives, immersive walkthrough experiences, and collaborative capabilities for teams within the virtual reality environment. The Oculus VR Prospect software is compatible with several file formats including SketchUp, Revit, Rhino, FBX, and Navisworks. Enscape is a comprehensive software solution that combines virtual reality with real-time rendering capabilities. It seamlessly integrates with popular 3D modelling software such as 3D Max, Sketchup, Rhino, and ArchiCAD. Enscape is available as both a standalone application and as a tool for creating immersive 360° panorama views[5].

3. Virtual Reality in Architecture

In the area of architecture, computer-generated images help architects replace the old way of drawing designs by hand with three-dimensional designs that look like the buildings have already been built. This cuts down a lot on the time it takes to make designs, since computers make it easy for builders to make different designs quickly that fit their style[6]. Also, it is easy to make the lighting fixtures look like they are lit in the real world. This lets builders choose the best places and designs for lighting fixtures in buildings and spaces. So, planners could see how the buildings would turn out or look even before they were built[3], [6].

With virtual reality's capabilities, architects and other professionals can use it as a tool to help them make a prototype and improve their ideas. As a whole, virtual reality can also help construction companies speed up their work with computer-aided designs and simulations that give more trust in the quality of the structure being built. Not only is virtual reality used to make prototypes or visual designs of building structures, but it is also used to improve the designs of buildings' interiors and exteriors. Virtual reality is also used to build towns and model how they would run or look with the new ideas and designs that virtual reality makes possible[7].

While this is going on, there are still problems with using virtual reality in design and other fields where it is used. In architecture and construction, where virtual reality is used to make models, the word "augmented reality" is also used to describe how virtual reality and real life are mixed together. There are three main problems in this area: (1) getting information from the business world, (2) making a model of the real world, and (3) technical boundaries[4].

When so much information is stored in software that helps build virtual reality, it is hard to get at the industrial world. So, integrating 2-D models into 3-D models is hard because there are secret objects in 2-D that need to be in 3-D models, but the database might not have all the information about where the hidden objects would go[5].
The making of reality models is another problem. Since most of the virtual reality will be based on the real world, a detailed description of the real world should come first. Only then can the virtual reality version of that world be made. On top of that, the environment should be measured so that a virtual reality version of it is correct[8].

Creating systems from virtual reality is also hard because the technology we have now isn't as good as it could be. Trackers are sometimes needed when making plans, and small mistakes on these trackers could cause mis-registrations. If the cameras and trackers don't work right, it can be bad for the virtual reality system. But these are part of the hardware domain, which means that the future of virtual reality depends on the growth of hardware technology along with virtual reality programmes and systems[9].

Even though we don't know what will happen in the future, many experts have made predictions about the future of virtual reality. These people think that this technology is still in its early stages, which means that it can be improved further [4]. As hardware companies improve their goods, virtual reality is likely to become even more like real life. To make it feel more real, the cameras and trackers should be better, and many systems should let users do more physical things to make them feel like they are in the real world. Virtual reality is also expected to help the field of building grow. Architects will build an artificial world where they can see and study everything. The experts think that virtual architecture will be just as believable as real architecture in five years. The 3-D imaging used in designs would be more interactive, as if the model were already the real building, with information about the weather and settings [6].

4. Importance of Virtual Reality in Architecture

In order to comprehend virtual reality technology, it is important to facilitate novel possibilities or enhance the worth of current options within the field of architecture. The categorization and direction of study and expansion in the field of virtual reality systems for architecture can be organised into three conceptual levels. The principles encompass various technologies, systems, applications, and processes. Virtual reality systems can exhibit variations in their technological configurations, ranging from desktop systems to elaborate setups featuring one to six large projection displays. These configurations encompass a diverse variety of hardware and software components, presenting numerous research and development difficulties that require sufficient attention and resources. The imposition of standards has created a scenario in which selecting a development platform for industrial applications has become a highly uncertain decision[2].

In several domains, researchers have identified numerous uses for virtual reality visualisations spanning a wide range of activities, including early design evaluations and marketing endeavours. This pertains to the need for novel approaches that enable the direct visualisation and comprehension of the performance of a constructed facility or environment. This includes scenarios where the facility is still to be constructed or during the ongoing construction process[1], [2].

The integration of virtual reality technology into architectural procedures is a relatively recent development. Traditional processes have the potential to undergo changes or become deemed superfluous, while other processes may emerge. The technological revision that occurs during this process is typically not widely recognised or adequately considered[10].

5. The Usage of Virtual Reality in Architecture

It is clear that the trends in using virtual reality for visualisation walkthroughs, analytical simulations like energy, circulation, facilities management, and virtual reconstruction, design decision-making, teamwork, marketing, and construction are important and thought-out. One of the best real-world uses of virtual reality might be in architecture. It can be used to help people feel more comfortable walking on a building that doesn't exist. BMI also improves 2D and 3D CAD by merging 4-D (time) and 5-D (cost), which lets information be managed smartly throughout the life cycle of a project [3].

For example, blueprints only show how a building looks in two dimensions, but 3D copies on a normal computer screen show how a building looks in space in a very simple way. Virtual reality lets you explore the building in a way that makes you feel like you're really there. Virtual reality can be used to see the virtual environment, but it can also be used to build the environment itself.
This is a fairly new way to use virtual reality in design, and the point is to show that it makes sense. For instance, the Shadow Light Mirage project is a third-generation piece of software that can be used to create and explore fully immersive areas in virtual reality. It lets people use room itself as a design medium, which encourages artistic creativity and speeds up the design process a lot[3], [5].

When looking at how virtual reality is used in design, it is likely that people will be able to do their jobs better every day. It looks at the potential of Head-Mounted Displays (HMD), Computer Audio-Visual Environment (CAVE) technologies, Single Wall Projection Displays / Power Walls, Workbenches, and WIMPs (windows, icons, menus, and pointing) listed in order of decreasing level of immersion for possible practical applications in the practise of architecture. Figure 1 shows how landscape, construction, inner design, and exterior design can be used with virtual reality in architecture[5].

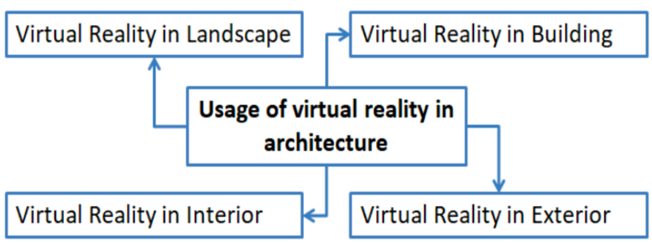


Figure 1 Application of virtual reality in architecture, source:[5]

6. Challenges of Virtual Reality in Architecture and Education

The primary challenges encountered by system developers in the realm of architecture and virtual reality pertain to the extraction of industrial domain knowledge, the preparation of authentic models, and technical limitations. The aforementioned issues can be categorised into multiple domains, as depicted in Figure 2.

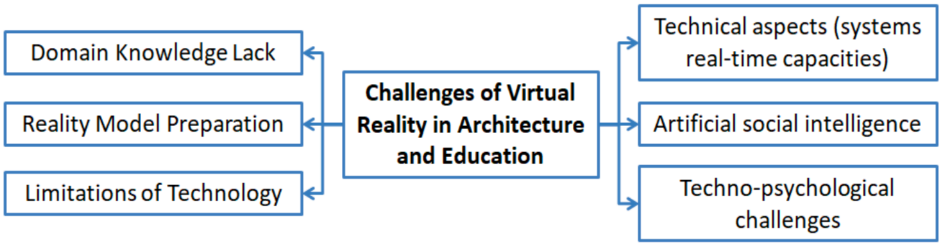


Figure 2 Challenges of virtual reality in the field of architecture and education, source:[5]

6.1. Domain Knowledge Lack

In the process of creating facilities, a significant volume of design and completion information is generated across multiple professional disciplines, including mechanical, electrical, structural, and others. Regrettably, in current practise, a significant amount of information is commonly recorded and saved in the format of two-dimensional (2D) drawings rather than three-dimensional (3D) models. It is evident that a deficiency exists in the availability of a comprehensive and organised 3D database that can be seamlessly utilised by virtual reality systems to facilitate the retrieval of information sources. This is primarily due to the designer's lack of commitment to delivering information[2].

6.2. Reality Model Preparation

In order to record digital data within the physical environment, it is necessary for the virtual reality system to acquire a precise representation of the actual surroundings, sometimes referred to as a real model [9]. A precise representation of reality can be established for the environment that has been correctly assessed. A crucial concern in the advancement of virtual reality systems for architecture and design pertains to the utilisation of appropriate systems and precise methodologies for the generation of said reality models.

6.3. Limitations of Technology

The primary challenge faced by virtual reality systems pertains to the constraints imposed by technology. In order to ensure accurate alignment between actual and virtual elements, it is imperative for virtual reality systems to employ monitors of exceptional precision. Even minor errors in the monitor can lead to noticeable mis-registrations, as highlighted in previous research [9]. Furthermore, a significant challenge in the development of efficient virtual reality systems lies in the requirement for accurate and remote sensors and monitors that provide real-time data on the user's position and the surrounding entities inside the virtual environment [4], [5], [11]. The advancement of tracking and sensing technologies is heavily reliant on the collaborative endeavours of both industry and academic sectors within the hardware domain. In the field of education, there are some problems that impede the progress of virtual reality, as depicted in Figure 3.

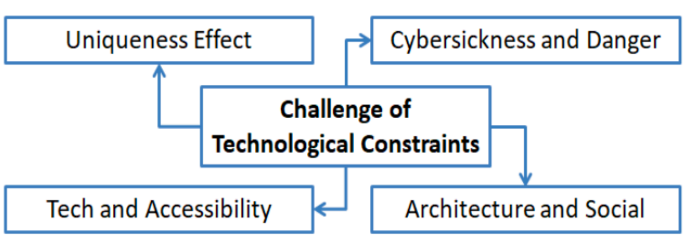


Figure 3 Challenges hindering the development of virtual reality, source:[5]**.**

6.3.1. Challenge: Uniqueness effect

There is a chance that any improvement in performance or interest seen in students who use virtual reality is due to the novelty effect. This is when performance tends to get better when a new technology is introduced. This has been seen with computer-assisted schooling and other e-learning tools. The worst thing that could happen is that students become so used to virtual reality in school and maybe even in their daily lives that it loses all of its charm. Even though this is a real worry, it's kind of a moot point because a teacher shouldn't use virtual reality just because it's the cool new thing, but because it helps students learn better. People think that virtual reality will become more interesting as it becomes more common. It will give learners a better way to experience material than what they can do now[3], [11].

6.3.2. Challenge: Cybersickness and danger

Cybersickness is the elephant in the room when it comes to the future of virtual reality in any field. It's a feeling that's a lot like being sick when you're moving, and it can happen during or after a virtual reality experience. This would be especially bad in a place where people learn, since sick students don't learn well. Like motion sickness, the signs can be different for each person, with gender, race, and age all being possible factors. Also, if motion sickness is a good model, people between the ages of 2 and 12 would be most likely to get cybersick. This would make it hard to use virtual reality in elementary school. It will be interesting to see if managers, teachers, and parents think that virtual reality is too dangerous for a school setting because kids could get sick or hurt[3], [6], [11].

6.3.3. Challenge: Tech and accessibility

Today, not many people have access to virtual reality technology. A smartphone and Google Cardboard are the fastest and cheapest way to bring technology into the classroom. If students can use their computers in class, teachers could use this great idea right now. Still, the library of material is just getting started, and it is not yet clear that it is "educational." Virtual reality in education will depend on how well the merged learning, producer, and ed-tech movements inspire teachers to see the teaching value of different media and tech tools and a way to use them virtually[3], [6], [11].

6.3.4. Challenges in architecture and social

Virtual reality technology currently falls short in replicating a fully immersive real-life experience across various aspects. The assertion holds considerable validity when including the "social dimension" into the virtual realm. Nevertheless, it is evident that the development of persuasive virtual characters and virtual entities capable of effectively communicating significant and suitable social behaviours is an ongoing obstacle for the field of virtual reality in the forthcoming years. This difficulty encompasses both technological elements, such as the system's real-time capability, and psychological elements, such as human communication procedures. Despite the importance of the social factor in attributing social background intelligence to autonomous agents, virtual reality systems continue to exhibit deficiencies in social perception[3], [6].

These issues encompass both technical and psychological aspects, and their resolution may prove to be arduous or even formidable. Numerous instances of social meaning models exist, which possess a compelling nature solely at the dual level, wherein the ultimate significance is embedded within temporal possibilities. The aforementioned facets of interpersonal synchronisation exemplify the burgeoning domains and primary obstacles within the realms of social psychology and social neuroscience. The constraints associated with these procedures are to their physical restrictions, scope of applicability, and the extent of intervention in human variations and gestures. Identifying the various levels of intervention poses a formidable challenge for those with interdisciplinary orientations. The process of translating abstract concepts into practical applications within the field of psychology is a topic of ongoing inquiry[11].

7. Concept and method

7.1. Mapping Interaction: Digital Design Approaches (DDAs)

Architectural design education is facilitated inside dynamic studio environments that foster participatory learning experiences. Within studio settings, students engage in a reciprocal exchange of ideas, utilising both physical and digital media, in order to generate fictional scenarios that align with specific design requirements. The monitoring of students' learning process has emerged as a crucial component of intricate design methodologies that have evolved from the use of virtual environments and digital resources. In order to enhance the level of engagement with virtual reality (VR) tools and environments, supplementary courses were provided to assist students in acquiring proficiency in digital design methodologies. Nevertheless, towards the conclusion of design processes, an evaluation is conducted to analyse a student's development in order to analyse the learning processes associated with virtual reality (VR) and digital technologies, which are predominantly acquired within the studio environment. This study offers a comprehensive examination to assess various digital design methodologies that vary in their utilisation of digital modelling and virtual media. The examination of digital design methodologies can be conducted by examining the proposed material within associated fields, such as interactive and participatory design.

This study examines the interconnected relationships between modelling tools, virtual reality (VR) tools, students, and content to delineate the fundamental components of the digital design methodologies being discussed. The current study encompasses two distinct models of approaches, characterised by the specific teaching and learning activities employed in respective courses. Approach I is centred around the use of 3D printing technology for the creation of design models, while Approach II focuses on the implementation of virtual reality technology for the development of design models.

This study utilises a User Experience Questionnaire (UEQ) to examine the influential role of students in comprehending the contextual development of physical modelling and virtual reality (VR) infrastructure in design education.

7.2. Measuring Interaction: Student-Centered Design Education

This study utilises the User Experience Questionnaire (UEQ) to initially assess the quality of teaching architectural design in both physical model and virtual reality (VR) environments, as perceived by students. The User Experience Questionnaire (UEQ) has been developed with the purpose of facilitating comprehension of the effectiveness of interactive experiences [1], [2]. The questionnaire consists of 10 questions that assess the dimensions of attractiveness, perspicuity, efficiency, reliability, stimulation, and novelty in designed experiences. The user assigns a numerical value ranging from 1 to 5 to evaluate each scale.

Similarly, the criteria for evaluating the pedagogy of teaching architectural design using physical models and virtual reality (VR) may encompass factors such as aesthetic appeal, clarity, effectiveness, reliability, engagement, and innovation. Upon the conclusion of the course, a comprehensive survey consisting of 10 questions was administered to gauge the level of involvement. The poll requested students to evaluate their encounters with 3D printing and virtual reality (VR) creative tools[1], [2].

8. Application

8.1. Approach I: 3d printing for design model

Initially, the students were tasked with creating a shade structure that serves as a representative model of garden furniture. The designs were modelled using the 3D Rhinoceros 7 software. After the completion of the models, they were transferred to PrusaSlicer 2.6 software in order to undergo the necessary preparations for 3D printing. PrusaSlicer 2.6 is a software application designed to facilitate the conversion of 3D models into G-code. This G-code is then utilised by the Prusa i3 MK3S and MK3S+ machines to execute the 3D printing process and produce the desired product.

8.1.1. Results and Analysis

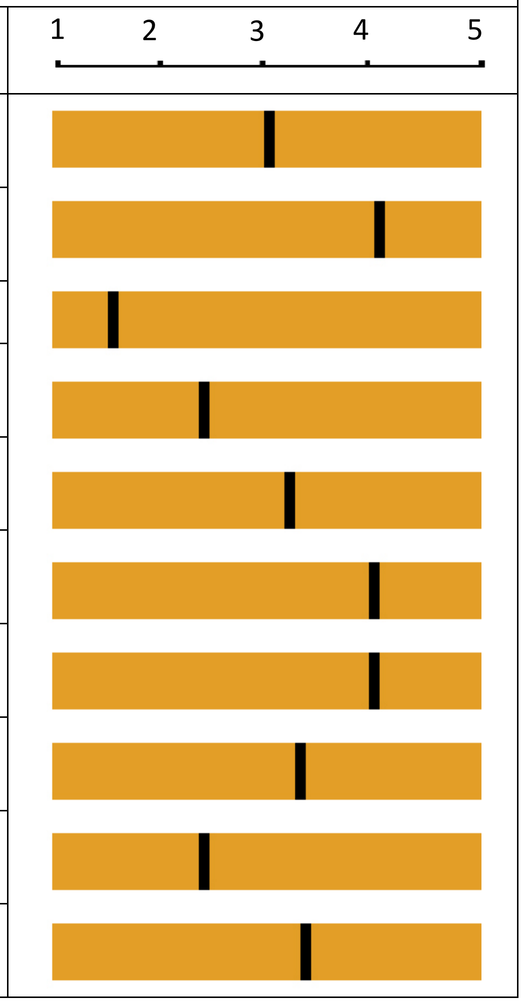
By using 3D printing into its instructional process, Ain Shams University is able to provide students with improved opportunities to design shadow models. Students are given the opportunity to realize their design concepts and obtain practical insights through the utilization of this innovative approach, which promotes hands-on learning. Students are given the opportunity to express their creative potential, improve their design abilities, and bridge the gap between academic knowledge and practical application in the ever-evolving field of design through the implementation of 3D printing technology at Ain Shams University.

Figure 4 3D printing model product, source: the author, 2023

When it comes to the initial evaluation of the teaching quality in architecture design with physical models, the User Experience Questionnaire (URQ) is an extremely helpful instrument. Through the collection of feedback from students, the URQ offers insights into the efficacy of the teaching methods that are utilized, thereby guaranteeing that an approach that is centred on the student is followed. It is possible to provide a continual development of the teaching experience in architecture design with a focus on physical models by utilizing this assessment, which not only measures the overall happiness of students but also reveals areas for improvement.

Table 1 User Experience Questionnaire (UEQ) for approach I, source: the author, 2023

Questions
3D printing enhances students' understanding of complex concepts by providing tangible, physical representations.
the use of 3D printed models encourages students to engage more actively in the learning process.
3D printing promotes spatial reasoning and problem-solving skills among students.
The cost and availability of 3D printing technology can be a barrier for educational institutions.
3D printing enables customization of educational materials to cater to different learning styles.
3D printed models are particularly effective for subjects that involve studying intricate structures or designs.
Integrating 3D printing into the curriculum can result in increased enthusiasm and motivation for learning.
Lack of expertise in operating 3D printers may hinder the implementation of this technology in classrooms.
3D printing can bridge the gap between theoretical concepts and real-world applications.
Regular exposure to 3D printed models can help students develop a deeper understanding of abstract ideas.



8.2. Approach I I: virtual reality for design model.

During the subsequent step, the participants were exposed to their designs through the use of virtual reality technology. The individuals acquired fundamental knowledge of Unity, a virtual reality (VR) programming platform, and successfully imported their models into the software. Subsequently, the individuals proceeded to employ other materials in order to enhance their models, acquiring the ability to go through their projects and manipulate objects within them.

8.2.1. Results and Analysis

Through the utilization of virtual reality (VR), Ain Shams University is able to revolutionize the educational process in the field of design shadow modelling. Virtual reality (VR) technology allows students at the institution to visualize and engage with their design concepts in a simulated environment, which provides them with the opportunity to benefit from an immersive learning experience. By integrating these elements, not only do they improve their comprehension of design concepts, but it also makes it possible for them to dynamically investigate the links between spaces. In order to give students with a cutting-edge platform for creative expression and to bridge the gap between academic knowledge and practical application in the field of design, Ain Shams University has integrated virtual reality (VR) into its curriculum.

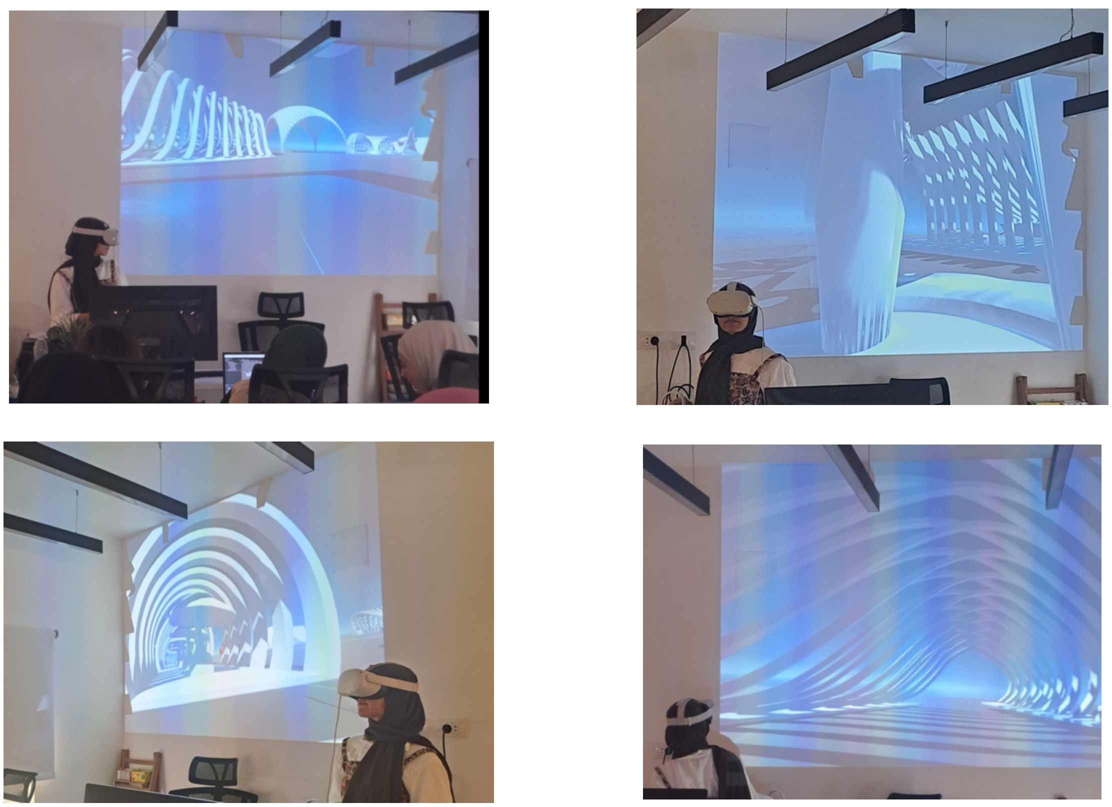


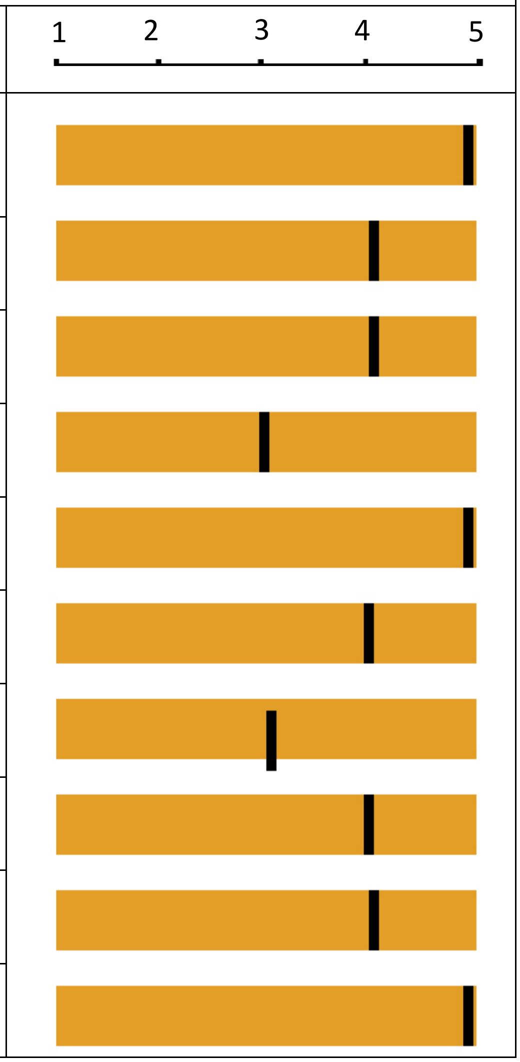
Figure 5 virtual reality (VR) product model, source: the authors 2023

The utilization of the User Experience Questionnaire (URQ) appears to be an effective tool for conducting the preliminary assessment of the quality of instruction in the design of virtual reality-based architecture. Through the process of seeking feedback from students, the Virtual Reality Questionnaire

(URQ) evaluates the efficacy of virtual reality technologies and instructional approaches, thereby assuring a learning experience that is both individualized and engaging. This evaluation not only determines the level of pleasure experienced by students, but it also pinpoints areas that could be improved, so fostering a constant improvement in the manner in which architecture design education is conducted through the use of virtual reality platforms.

Table 2 User Experience Questionnaire (UEQ) for Approach II, source: the author, 2023

Questions	1 2 3 4 5
Virtual Reality enhances students' understanding of complex concepts by providing immersive, interactive experiences.	
The use of VR technology encourages students to engage more actively and passionately in the learning process.	
VR experiences promote spatial reasoning and problem-solving skills among students.	
The cost and availability of VR devices can be a barrier for educational institutions.	
VR technology enables customization of educational content to accommodate various learning styles.	
VR simulations are particularly effective for subjects that involve exploring realistic or dynamic environments.	
Integrating VR into the curriculum can result in increased enthusiasm and motivation for learning.	
Lack of expertise in operating VR devices may hinder the implementation of this technology in classrooms.	
VR experiences can bridge the gap between theoretical concepts and real-world applications.	
Regular exposure to VR simulations can help students develop a deeper understanding of abstract ideas.	



9. Conclusion

Upon completion of the workshop, students acquired the proficiency to modify three-dimensional models utilising Rhinoceros 7, PrusaSlicer, and Unity. The students acquired a fresh outlook on their academic endeavours by their active engagement in this session, which proved to be an irreplaceable opportunity for their personal growth and development. In the phase of 3D printing, the researchers successfully acquired a tangible manifestation of their designs. Conversely, in the phase of virtual reality, they were able to immerse themselves in a simulated environment to experience their works. By engaging in this process, they acquired a more comprehensive understanding of the magnitude and dimensions of their concepts, as well as the manner in which these designs would engage with users in real-world scenarios.

Despite the fact that a significant proportion of the student body already held a three-dimensional (3D) printed version of their designs, they expressed that the utilisation of the virtual reality (VR) technology afforded them a novel and distinct means of engaging with their models. The individuals indicated their ability to discern the perceptions of others regarding their designs and their real-world manifestations. Additionally, they asserted their ability to visualise the practical manifestation of the designs. As a result, students developed a more profound understanding of the feasibility and visual attractiveness of the concepts they had formulated.

Furthermore, the students were provided with the chance to gain knowledge pertaining to the various practical applications of 3D printing and virtual reality (VR). The individuals acquired knowledge on the application of these technologies across several domains such as industry, healthcare, education, and entertainment. As a consequence, their understanding of the potential impact of these technologies on the world was more profound.

10. Acknowledgments

This research couldn't have been accomplished without the support of important people. First, I acknowledge my beloved wife for support and assistance. Second, I thank my supervisors and co-authors of this paper for their time, support, and knowledge in collecting and analysis of data, also I would like to acknowledge the support from smart and future cities laboratory (SFCL) for conducting the workshop.

References

[1] S. Aydin and B. Aktaş, "Developing an Integrated VR Infrastructure in Architectural Design Education," Front Robot AI, vol. 7, Oct. 2020, doi: 10.3389/frobt.2020.495468.

[2] M. J. Edward and W. Iii, "Integration of Virtual Reality (VR) in Architectural Design Education: Ex-ploring Student Experience."

[3] "The development of Augmented Reality as a tool in Architectural and Urban design TOPIC: ARCHITECTS IN THE 21ST CENTURY-AGENTS OF CHANGE?"

[4] E. Hu-Au, J. J. Lee, E. Hu-Au, and J. Lee, "Virtual reality in education: a tool for learning in the experience age," 2017.

[5] Y. Lotfi, "Virtual Reality as A Tool to Enhance Students' Perceptions of Architectural Historical Spaces," MSA Engineering Journal, vol. 2, no. 2, pp. 596–607, Mar. 2023, doi: 10.21608/msaeng.2023.291904.

[6] E. M. Thompson, M. Horne, and D. Fleming, "Virtual Reality Urban Modelling-An Overview." [Online]. Available: http://www.casa.ucl.ac.uk/3dcities/table_all.htm

[7] K. Sunesson et al., "Virtual Reality As a New Tool in the City Planning Process," vol. 13, 2008.

[8] user, "@," 2020.

[9] “vr-heliopolis-workshop-responses”.
[10] L. Fakahani, S. Aljehani, R. Baghdadi, and A. M. El-Shorbagy, “The Use and Challenges of Virtual Reality in Architecture,” Civil Engineering and Architecture, vol. 10, no. 6, pp. 2754–2763, Nov. 2022, doi: 10.13189/cea.2022.100638.
[11] S. Afifi and A. Aya Ezzat, “Virtual reality and traditional design methods in the Egyptian context,” 2023. [Online]. Available: https://erjsh.journals.ekb.eg-27-ORCiD:https://orcid.org/0000-0003-2315-9850