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Students' Perception of Virtual Reality Applications to Analyse Daylighting and Spatial Functions in Architecture and Environment

*Sujatavani Gunasagaran[1], Tamilsalvi Mari[1], Razif Mohamed[2], Veronica Ng[1] and Sucharita Srirangam[1]

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Abstract: The use of various pedagogies is essential to aid the complex learning of architectural students, especially due to tools for visualising design becoming advanced. Accordingly, experiential learning by simulation or physical presence and case study-based learning in teaching and learning architecture are essential. Using virtual reality (VR), students are able to experience the simulation of daylighting virtually in their modelled case study from various places in the world. Thus, this study investigated the students' perception of using VR in learning daylighting in architecture. The study's objectives were to (1) understand the learning process using VR, (2) assess students' acceptance level of the use of VR, (3) compare VR and traditional methods of architectural learning and (4) suggest improvements needed for using VR for teaching and learning in architectural undergraduate programmes. A mixed methodology consisting of a questionnaire and observation was used for this study. A questionnaire was distributed to 15 students who had gone through a workshop on visualising a case study that was modelled in three dimensions to simulate daylight. Students found that using VR was very useful in understanding daylight and daylight use in space. The study found almost all students (93.4%) agreed that using VR enhanced their learning skills and 80% of the students responded that visualising daylight in VR enabled them to establish their tasks more quickly. This workshop helped students construct their knowledge, enhance the learning experience and motivate learning of daylight using VR. This study concludes that VR is a great tool for teaching and learning.

Keywords: VR in architectural education, Daylight simulation, Daylighting in architecture, Spatial functions and quality, Architectural design tools

INTRODUCTION

Technology assisting the learning process is one of the fundamentals of success in education. Mardiana and Daniels (2019) mentions that technological determinism has changed the learning process for future learning. She concludes that the most important thing in technological determinism is having the knowledge of education technology, having a belief to change and being able to adopt technological change.

[1]School of Architecture, Building and Design, Faculty of Innovation and Technology, Taylor's University, Taylor's Lakeside Campus, 47500 Subang Jaya, Selangor, MALAYSIA
[2]The Design School, Faculty of Innovation and Technology, Taylor's University, Taylor's Lakeside Campus, 47500 Subang Jaya, Selangor, MALAYSIA
*Corresponding author: sujatavani.gunasagaran@taylors.edu.my

It is expected that virtual augmented reality (AR) will be of general use in education between 2023 and 2028 (Lowendahl et al., 2018). New mobile device designs and capabilities and increased investment in technological development are some of the enablers for the adoption of virtual reality (VR). VR hardware will be a necessity in the future complementing mobile devices. VR content is actively being developed in many areas, especially teaching and learning (Ipsita et al., 2024), resulting in VR being commonly used at all levels of modern education (Bhatnagar and Boruah, 2024). According to Hernandez-de-Menendez, Díaz and Morales-Menendez (2020), VR is one of the technologies that have been reviewed and are transforming engineering education, particularly in the acquisition of technical knowledge and development of competencies in engineering and science education. The collaborative and innovative aspects of using technology allow students to become more committed and motivated toward their course (Kartiko, Kavakli and Cheng, 2010; Webster, 2016; Ghazali et al., 2024). Studies argue that VR improves the academic performance of students as well as developing their social, collaborative, psychomotor and cognitive skills (Martín-Gutiérrez et al., 2017).

LITERATURE REVIEW

The evaluation of daylight in the design process is always intuitive and does not have a visualisation format. The design thinking of sketching spaces and daylight inclusion in two-dimensional (2D) is not substantiated by the sun path. According to Sugati (2022), architects use a solution-based strategy to propose multiple solutions, whereas scientists use a problem-based strategy that intends to discover the rules through an optimising process. Sugati (2022) further elaborates that unlike in engineering, the solution for architectural design is not hidden in the data, but in the designer's creativity that includes their experience and imagination.

The quality and intensity of daylight vary according to geographical latitude, season in a year, time of day, local weather, sky conditions and building geometry. The numerous design parameters that must be considered, such as view factor, aperture size and room depth, make the process of characterising indoor daylighting difficult (Wong, 2017). Traditional methods have been used for designing are sketching and model making, but these may not adhere to scientific data. Meanwhile, the use of a computer-generated three-dimensional (3D) model allows the designer to simulate all the required data by choosing the tab or relevant data input, resulting in digital design output having the closest accuracy to the built environment. However, modelling 3D performance assessments using simulations or selected systems using standard monitoring methods in test rooms (Lindh and Billger, 2021) under various types of skies is tedious and is not suitable as a design tool.

The emphasis in the monitoring procedures for test rooms is on effective daylight utilisation, electrical energy savings and user acceptability. Daylighting studies are usually aimed to provide a guide on the application of daylighting strategies and daylight-responsive lighting control systems to enhance daylight, as well as increase electrical energy savings and user comfort (Fontoynont, 2002; Budhiyanto and Chiou, 2024; Hakimazari et al., 2024). Accordingly, VR can be an excellent visualising and designing tool that quickly analyse the inclusion of daylight and evaluate spatial quality in architectural designs.

Wong (2017) concludes that the advancement in computer technology and computer-based simulation studies can offer cost-effective solutions and accurate predictions of daylighting performance. Wong (2017) also highlights that it is crucial and ideal especially at the initial stage of the studies or building design before the application of more expensive real technologies or systems. The simulated results, however, must be validated by experimental or measured results. Therefore, architectural education needs to move forward to embrace the potential of digital technology use such as AR/VR in teaching and learning as well as research on developing it as a learning and designing tool for architecture.

Virtual Reality in Education

VR, AR and mixed reality (MR) are advanced technologies in interactions among people, computers and reality (Verma et al., 2021; Yenduri et al., 2024). By allowing digital and physical objects to coexist and providing an intuitive sense of how it might feel to live in an animated environment, they become effective tools for building designers (Delgado et al., 2020). AR refers to the technique of overlaying virtual objects in the real-world environment (Shi and Zhao, 2024) while MR refers to techniques of not just overlaying but anchoring virtual objects to the real world (Brunzini et al., 2024).

Research on the building design process in virtual environments can be found as early as the 1990s. Some researchers (i.e., Broll et al., 2004; Postema, 2005) explored AR usage during the conceptual design stage. Following them, scholars (i.e., Wang et al., 2014; Wang, 2017; Banfi and Previtali, 2021) integrated building information modelling (BIM) with AR for interactive visualisation. Evidence suggests that VR technologies are effective in construction safety training (Li et al., 2018), project schedule control (Fu and Liu, 2018) and site layout optimisation of construction projects (Muhammad et al., 2019). VR technologies can also provide environments for better collaboration among stakeholders (Alizadehsalehi, Hadavi and Huang, 2019), enable a better understanding of complex designs (Sutcliffe et al., 2019), identify design issues (Romano et al., 2019) and depict building geometry to aid collaborative decision-making (Du et al., 2018). As a result, users can make sense of a project and reach a better design decision (Bille et al., 2014; Zhao, Zhang and DeAngelis, 2019).

In general, there is a growing trend to use VR-based learning in education. Nevertheless, research findings are mixed regarding the learning effectiveness of VR-based learning. Positive research outcomes have been reported with VR-based learning such as better performance in business knowledge application (Cheng and Wang, 2011), improved spatial thinking (Cohen and Hegarty, 2014; Hauptman, 2010; Tekeli et al., 2024), enhanced spatial abilities for sensing and kinaesthetic learning style learners (Hauptman and Cohen, 2011; Sekerci et al., 2024) and for low visual-spatial ability learners (Meijer and Van den Broek, 2010; Tekeli et al., 2024) and the ability to accommodate learners with different learning styles in cognitive outcomes and affective outcomes (Lee, 2022).

Virtual Reality in Architecture

Architectural students are required to master science and technology so that they can assess the impact and benefits of technological development on designs, architecture and users. Efforts to improve the graduate capabilities of students cannot be separated from the educational process.

Although testing and improving designs is a good practice, waiting for buildings to be built to improve on a design is unnecessary. In this fast-paced world, VR would allow architects to experience and visualise spatial quality before it was even built so that testing can be done on simulations, experienced virtually and improvements in design can be made instantaneously.

The concept of VR can be broadly defined as the ability of a user to perceive and interact with a real-world environment in a 3D simulation on the computer with technologies that the user wears on his body (Freina and Ott, 2015). Recently, educational research has shown an increased interest in VR technology because of its ability to simulate real-world conditions. VR technology is among the most promising up-to-date technologies in terms of potential for being effectively used in education and training activities. The advantages of using VR environments in education have been studied by many researchers (e.g., Chen, 2010; Merchant et al., 2014; Webster, 2016; Bhatnagar and Boruah, 2024).

Architectural education, for example through architectural graduates of Lembaga Arkitek Malaysia Part 1, lists collaborative education or work and the use of appropriate communication tools as characteristics and attributes (Lembaga Arkitek Malaysia, 2022). Mikropoulos and Natsis (2011) concluded in their study that VR not only assists collaboration and social negotiations but also among avatars. Role plays also enhance collaboration, teamwork and negotiation skills using VR in architectural education. For example, Architecture Design Studio from Year 1, Semester 1, uses higher-order thinking skills. Therefore, the teaching and learning for design and technical modules involves real and complex information processing for students (Kim and Ko, 2019) and uses instructional techniques (Merchant et al., 2014) which are done as studio practice or tutorials in its technical studies.

Freina and Ott (2015) in their study concluded that immersive VR could offer great advantages for learning as VR allows for a direct feeling of objects and events that are physically out of our reach. Learning in a virtual environment that reproduces the real one can minimise the problems related to learning transfer. Hence, VR supports training in a safe environment, avoids potential real dangers and increases learner involvement and motivation while widening the range of supported learning styles (Freina and Ott, 2015). However, prior studies found a need for an extensive study to verify whether the knowledge and skills transfer is easier in teaching and learning architecture to aid design thinking with an immersive VR approach compared to traditional ones is not yet available (Freina and Ott, 2015; Natephra et al., 2017). For example, Delgado et al. (2020) in their study on AR and VR use in architecture, engineering and construction (AEC) found literature reviews on SCOPUS and Google Scholar on AR, VR or in combination utilised six categories: (1) stakeholder engagement, client engagement, virtual tour and walkthrough, (2) design and design support, (3) design review and design sign-off, (4) construction, construction support, progress monitoring, assembly and safety, (5) operations, maintenance, facility management and inspections and (6) training and education. Under the training and education category, three challenges were identified, namely (1) a shortage of experts to produce AR and VR content, (2) a lack of systematised evaluation processes and (3) a lack of integration with existing qualification standards.

Ehlers and Schneckenberg (2010) mentioned that the practices in the fields of strategic innovation of universities, faculty development, assessment, evaluation and quality assurance have not changed sufficiently to fully accommodate the changes in technology and teaching. Thus, there is a need for practical guidance on concepts and methods for developing technology-related competencies, assuring quality and evaluating learning outcomes of the next generation of learning scenarios. At the same time, new approaches for strategic implementation, evaluation and assessment are emerging alongside new technologies and new learning landscapes.

Thus, this study studied VR-based learning to understand the advantages or disadvantages of using VR in architectural education. This study was expected to contribute to enhancing evaluation processes of VR use in AEC education through its four research questions. This study also hoped to contribute to architectural education by guiding the use of VR to analyse daylighting and spatial functions.

Daylight and Data Analytics

Lindh and Billger (2021) explain that the subjective impressions of space as related to emotions and visual aspects correspond to non-scalable and scalable properties of space. To study subjective impressions of scaled model rooms, the study was set up to experiment with the visual appearance of a space, according to a set of criteria, namely: contrast, complexity, spaciousness and experience of a space, depth and width, and brightness and shadow.

Mangkuto (2024) used model geometry, calculating depth and width, followed by validation using daylight factors and climate-based daylight modelling and simulation. Yıldırım et al. (2023) measurement methods were grouped under six headings: solar path analysis, massing studies, sunlight-shading calculation, computer simulation, high dynamic range (HDR) imaging technique and Heliodon analysis. Meanwhile, Lindh and Billger (2021) consciously examined the visual appearance of a space. While the current study utilised a similar methodology to Mangkuto (2024), four methods, namely: solar path analysis, massing studies, sunlight-shading calculation and computer simulation, that were described by Yıldırım et al. (2023) were used in this study. These factors allow qualitative assessment that is difficult to imagine by sketching on paper and pencil in the initial designing stage. According to Sugati (2022), designers use experience and imagination to solve design problems and not through data.

Architects and architectural designs should move towards data-based or analytic-based architecture to build sustainable buildings. The complexity of designing to include data and building performance can be achieved using digital technology at the initial designing stages. It needs a comprehensive understanding of daylight knowledge and visualising using images of case studies. Evaluating building performances, such as indoor daylight, has usually been based on numerical simulation and 2D image illustration (Zhao, Zhang and DeAngelis, 2019). It is a phenomenon of visualising invisible concepts, such as the inclusion of heat and wind while inducing daylight in buildings that should be spatially based and place-varying. Otherwise, there is no necessity to exhibit them in virtual environments aimed at improving spatial perception.

Appropriate selection of visualisation mode will be less confusing when facing complex data. Interpreting the simulation results with 3D spaces can aid comprehension of the overall condition in a room. Accordingly, another advantage of VR is the ability to identify performance variations in the time dimension, which is especially useful for instantaneous simulations. Thus, using VR to assess the qualitative data in a spatial configuration would be the perfect and simplest method to be used in teaching and learning daylighting in architecture.

RESEARCH METHODOLOGY

An experiment using VR was conducted during the Architecture and Environment module. The use of VR in this workshop enabled students to view a model of a building or a case study that they have modelled on their own as a group. The experiment was conducted as a workshop after the completion of the module to investigate the architectural students' reflections on using VR to achieve learning outcomes. In this workshop, 3D modelling produced using Autodesk Revit software was imported into Enscape, Iris VR and Sentio VR to be viewed in VR using Oculus headset. The students were to view the play of light and shadow and analyse the daylight use in the space of a building that they chose as a case study. Students' responses to the survey were recorded and analysed using descriptive analysis. Three open-ended questions were analysed using content analysis, themed and coded.

This study was conducted to find out the use of VR in teaching and learning content. This crucial information could help predict the transfer of knowledge and the impact of learning using VR. Learning outcomes alone do not determine whether knowledge is gained, but a positive attitude towards a learning process makes it more probable for successful knowledge transfer. Students' acceptance of the use of VR in teaching and learning and seeing personal relevance for their studies could indicate their high motivation to learn. The instructions for daylighting analysis were given during tutorials.

For the construction of data, this workshop was conducted. The workshop began by establishing macroclimate, microclimate and weather, with a lecture on these topics. Next, it covered the establishment of lighting standards in space, referencing MS1525, MS3860 or standards specific to the location of a chosen case study, which was also delivered through a lecture. Students then chose a case study featuring either top lighting or side lighting and delved into understanding the relevant parameters and issues, guided by another lecture. The course proceeded with the construction of massing in Autodesk Revit, emphasising openings and glass, supported by both a lecture and detailed instructions. Finally, students created simulations and images, validating these against actual images from their case study research and the corresponding climate.

In this workshop, the VR template was also constructed. Figure 1 describes the BIM to extended reality (XR) toolsets workflow used in this study. The steps included importing Autodesk Revit files to Enscape, Iris VR, or Sentio VR, utilising a VR head-mounted display and performing a walkthrough of the space by setting a specific date and time. Table 1 summarises the quantitative and qualitative research methods used for this study and the related analysis for each of the methodologies.

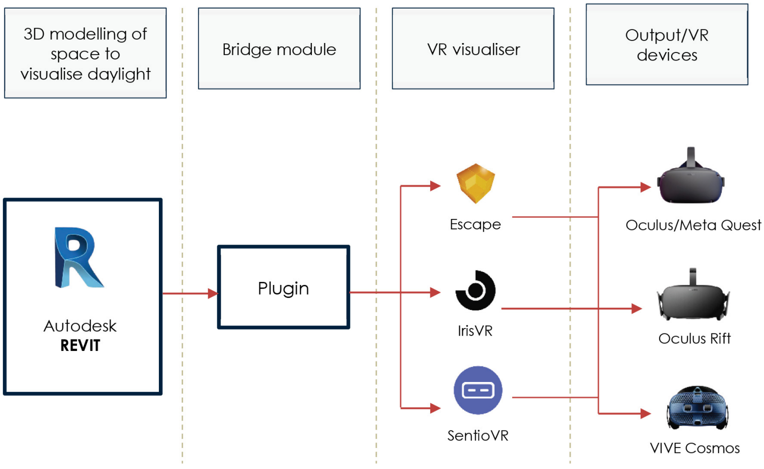

Figure 1. BIM to XR toolsets workflow

Table 1. Summary of methodology used and analysis methods

Research Questions	Methodology	Analysis
What is the learning process that the students go through to achieve the learning outcome for this project/ assignment?	Observation and brainstorming by researchers	Sketching/ diagramming
What is the student's acceptance level of using VR in learning daylighting in a case study?	Questionnaire (Sample: Students)	Descriptive analysis
Does VR support a better learning transfer than the traditional method?	Researcher's observation	Brainstorming
What are the improvements needed for using VR for teaching and learning in architecture?	Open-ended questionnaire (Sample: Students)	Content analysis, themed and coded

Workshop to Experience Virtual Reality

A four-hour workshop to experience VR was opened to 20 of 154 students who had completed the Architecture and Environment module. The workshop had five stations, each consisting of a laptop or personal computer and a VR headset. It was expected that a total of three students would share one station. Nonetheless, only 15 students were interested and available. They consisted of 47% male and 53% of female students from Semesters 2, 3 and 5. Table 2 describes the demographic of the 15 students who volunteered to attend this workshop. Some students had prior experience using VR for gaming, but this study did not require prior knowledge of VR use.

Table 2. Demographic data of respondents

Residents		N	%
Gender	Male	7	46.7
	Female	8	53.3
	Total	15	100
Age	20 years old	3	20.0
	21 years old	5	33.3
	22 years old	3	20.0
	23 years old	1	6.7
	24 years old	–	–
	25 years old	2	13.3
	26 years old and above	1	6.7
	Total	15	100.0
Semester	2	4	26.7
	3	6	40.0
	5	5	33.3
	Total	15	100.0

RESULTS AND DISCUSSION

Learning Process Model

Figure 2 outlines the learning process model of integrating VR in daylight study in the Architecture and Environment module. It visualises how a case study was chosen and modelled using the knowledge and technical details given in lectures and tutorials to be visualised in VR. A similar process was replicated for Architecture Design Studio to visualise daylight inclusion and spatial quality (i.e., contrast, complexity, spaciousness (esp., experience of space), depth and width, brightness and shadow) at the initial design stage (Abd-Alhamid et al., 2019).

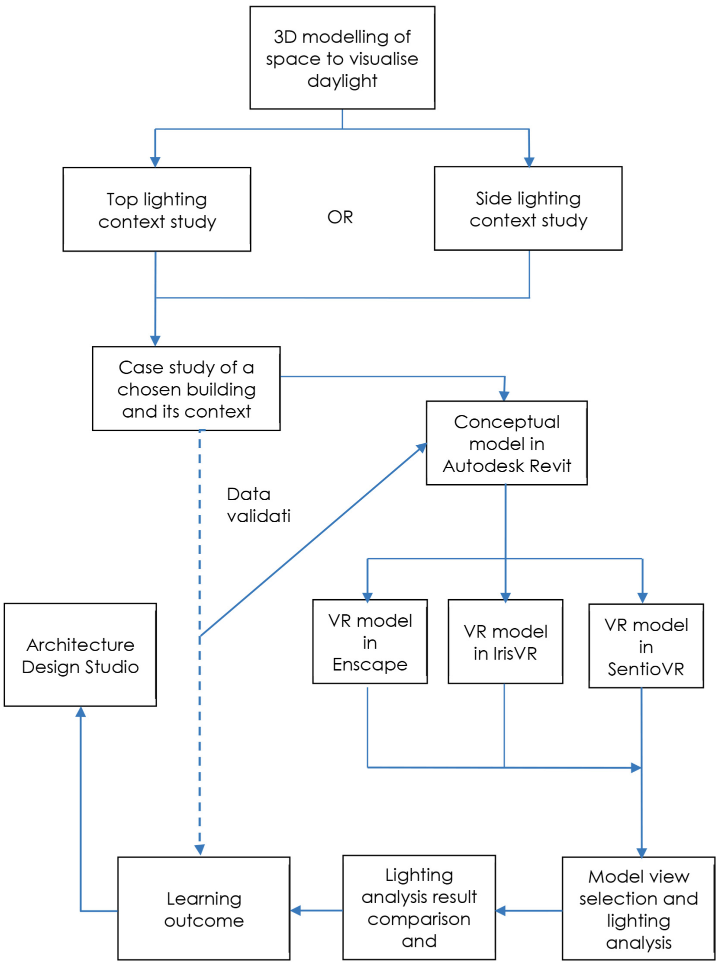

Figure 2. Learning process model integrating VR in daylight study in the Architecture and Environment module

Students' Acceptance of Virtual Reality in Learning

The statements posted to architecture students were according to the technology acceptance model to document their perception of the exploration of using VR applications to analyse daylighting and spatial functions in the Architecture and Environment module. The mean was calculated according to students' rating of the questions on a Likert scale, with 1 indicating "Strongly Disagree" and 5 indicating "Strongly Agree". The findings of this research in the mean score were divided into three categories: (1) "Low" (0.00–2.33), (2) "Medium" (2.34–3.66) and (3) "High" (3.67–5.00). Table 3 summarises the statements rated highly by students.

Table 3. Students' perceptions scores for exploring VR applications to analyse daylighting and spatial functions in architecture

	Items	**Mean**	**Standard Deviation**
	Perceived Usefulness (PU)	4.43	0.526
PU1	Using VR would improve my learning performance.	4.47	0.834
PU2	Using VR would enhance my academic effectiveness.	4.33	0.900
PU3	Using VR would increase my productivity.	4.20	0.941
PU4	Using VR can make teaching and learning easier.	4.40	0.828
PU5	Using VR can make teaching and learning fun.	4.73	0.458
	Perceived Ease of Use (PEU)	4.15	0.495
PEU1	I found importing 3d files to VR software to be easy.	3.87	0.990
PEU2	I found navigating around the VR screen to be easy.	4.20	0.862
PEU3	Distinguishing the appropriate icon for the application for the needed information is easy.	4.33	0.816
PEU4	The application is user-friendly.	4.20	0.862
PEU5	The VR would enable me to perform learning tasks more quickly.	4.13	0.915
	Student Performance (SP)	4.67	0.713
P1	Using VR is very useful in understanding daylight.	4.67	0.488
P2	Using VR, my learning skills are enhanced.	4.60	0.632
P3	Using VR, increased my understanding of daylight use in a space.	4.73	0.458
	Student Satisfaction (SS)	4.49	0.695
S1	Generally, I am satisfied with using VR for my learning in this module.	4.53	0.915
S2	I will use VR again for my learning.	4.33	0.976
S3	I will recommend this method to others.	4.60	0.828
	Behavioural Intention (BI)	4.56	0.699
B1	I intend to use VR to understand daylight.	4.60	0.507
B2	I plan to use VR in future as part of my studies.	4.40	0.828
B3	I will use VR for my Architecture Design Studio's daylight analysis in space.	4.67	0.617
	Student Motivation (SM)	4.51	0.694
M1	I believe that I can improve my skills by using the VR.	4.53	0.640
M2	I believe the use of VR has helped me to learn new things in architecture.	4.53	0.640
M3	I like to use VR to learn architecture as much as possible.	4.47	0.915

The responses expressed their positive responses towards the exploration of using VR applications to analyse daylighting and spatial functions in the Architecture and Environment module. Accordingly, the highest and the lowest-rated statements in Table 3 were discussed in the following paragraph.

"Using VR can make teaching and learning fun" for Perceived Usefulness and "Using VR increased my understanding of daylight use in a space" for Student Performances had the highest score of 4.73 (standard deviation = 0.458) each. The second highest scores were the statement "Using VR is very useful in understanding daylight" for Student Performance (mean = 4.67; standard deviation = 0.488) and "I will use VR for my Architecture Design Studio's daylight analysis in space" for Behavioural Intention (mean = 4.67, standard deviation = 0.617). According to Cohen and Hegarty (2014) and Kim and Ko (2019), VR is a good standard of training for real and complex situations. The third highest scores were "Using VR, my learning skills are enhanced" for Student Performance (mean = 4.60, standard deviation = 0.632), "I will recommend this method to others" for Student Satisfaction (mean = 4.60, standard deviation = 0.828) and "I intend to use VR to understand daylight" for Behavioural Intention (mean = 4.67, standard deviation = 0.507).

According to Table 3, the combined mean ranks for Student Performance scored the highest (mean = 4.67, standard deviation = 0.713). This indicated that the students believed that VR enabled them to do well in their studies as its use increased their understanding of knowledge and learning skills (Chen, Toh and Ismail, 2005; Lee, 2022). Behavioural Intention to use VR (mean = 4.56, standard deviation = 0.699) presented that students intended to use VR applications in Architecture Design Studio to analyse and understand daylight in space. Hauptman and Cohen (2011) perceived that VR-based learning increases spatial abilities. In addition, students were highly motivated by VR in their teaching and learning as they expressed their satisfaction with a high score for Student Motivation (mean = 4.51, standard deviation = 0.694), which has also been mentioned by Freina and Ott (2015). Students believed that using VR in class for learning can improve their existing skills as well as learn new skills (Martín-Gutiérrez et al., 2017) in architectural studies and that they would like to use VR to learn architecture. Students were satisfied with VR. Accordingly, they would use VR again for their learning and would recommend it to their peers. The combined mean score for Satisfaction using VR was high at 4.49 (standard deviation = 0.695).

Although Perceived Usefulness (mean = 4.43, standard deviation = 0.526) and Perceived Ease of Use (mean = 4.15, standard deviation = 0.495) were also high, these were ranked as the last two. Firstly, students agreed that VR made teaching and learning fun and easier (Freina and Ott, 2015). Students also agreed that VR would improve learning performance and enhance academic effectiveness by increasing productivity. As the use of VR was not taught and was run as a hands-on workshop, the students found it was not easy to import 3D files to VR software, but they found it had appropriate icons for the needed information, user-friendly and easy to navigate around the VR screen. They also believe that using VR would enable them to perform learning tasks more quickly.

Advantages of Using Virtual Reality

VR in the current study was not a substitute for the current learning method in the Architecture and Environment module. Instead, VR was included to understand the spatial configuration of the case study and to experience the aesthetic quality of light and shadow patterns in the space by simulating daylight inclusion throughout the day. The use of VR during the workshop was well-received by students. They were excited and wanted to learn more as there were many questions and discussions regarding VR, such as how to use it, what else could be done and why it has not been included in teaching and learning architecture. In addition, students found it easy to use and adapt to the VR hardware and applications, although some small glitches did happen during the workshop.

Improvements to Facilitate Virtual Reality Learning

The survey included three open-ended questions. The responses were analysed using content analysis, then themed and coded. The first question was "What are the setbacks of using VR in learning?". According to Figure 3, 64.64% of the students mentioned issues related to hardware/software. The issues included a long start-up time, difficulty in understanding and navigating, a lot of effort in making the model, poor quality of rendering and not owning a VR headset. The cost-related responses were 29.29%, with some students mentioning the high cost of a VR headset. A small percentage of students (7.7%) complained of motion sickness while using the VR headset.

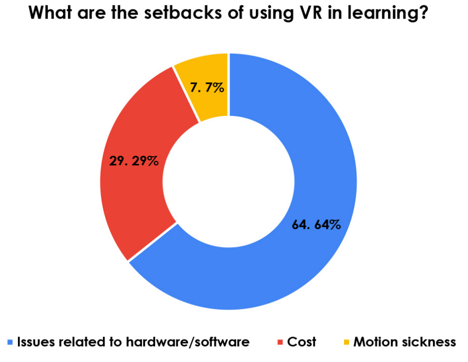

Figure 3. The setbacks of using VR in learning

Figure 4 displays data on an open-ended question "How learning using VR can be improved in future?" and 73.33% of students commented on the facilitating conditions. They described the need for a guide, bigger space, more VR stations, software availability and a voice guide. Meanwhile, 26.67% of students commented that VR improved and varied learning experiences using repetitive learning of various types, scales and context models in various architectural modules.

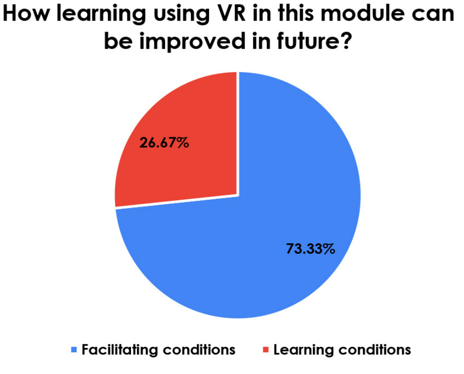

Figure 4. Improving learning using VR in architectural programmes

The open-ended question "How learning using VR in this module can be improved in future?" indicated that students were quick to identify the potential of using virtual learning in their architecture studies.

> Student 4: Instead of just daylight analysis, we can use VR to experience the user journey and analyse different aspects like sound as well.

> Student 13: Using models with different floor levels and site contexts like other buildings, vegetation and pedestrians will help us to envision a site at different hours virtually easily.

> Student 15: VR cannot only be used to study daylighting itself. Materiality, quality of spaces in terms of poetics experience and studying the practicality in views allow students to further develop their design after experiencing the preliminary conceptual models. VR can also be implemented in virtual site visits as some site visits can be too far to be visited frequently, as site visits are always encouraged to be done frequently in understanding the genius loci and getting a sense of place.

A total of 33.3% of the students could see the potential of using VR in learning while 26.67% commented that they enjoyed using VR for their learning, as also reported by Freina and Ott (2015). A few students, 6.67%, were positive and commented that they needed to adjust to the use of VR, while 33.3% had no opinions. The findings are summarised in Figure 5.

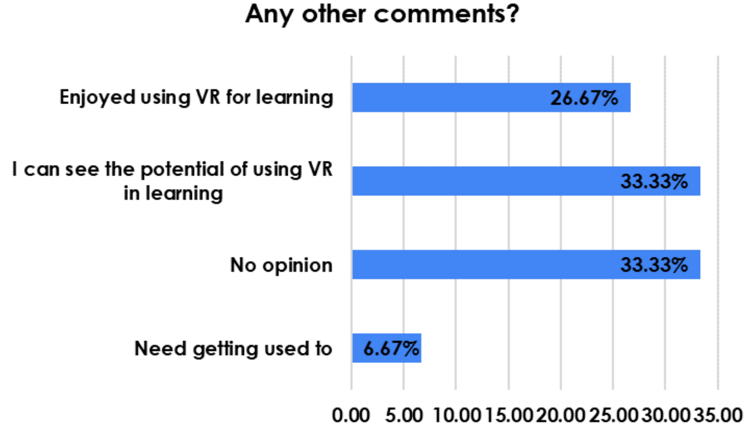

Figure 5. General comment on VR

In general, students also provided positive comments on the use of VR such as:

> Student 4: VR can be a bit time-consuming compared to regular research. But with VR, we can have a deeper understanding and a better learning experience. The analysis will be more detailed and will better reflect real-world applications.

Student 15: VR should be implemented in Architecture Studies/ Computer Applications modules to educate students further about technological advancement.

Student 6: I can see that using VR in studios or other modules would help students truly feel the space.

CONCLUSIONS

Learning Process Model

A learning process is complex. The process may affect class hours and extend the duration of tutoring. Nonetheless, the current study found that teaching and learning using VR was fun. In addition, VR made learning for students more enjoyable and futuristic. If the knowledge can be retained and rekindled in other modules, such as Architecture Design Studios, it will be more valuable to introduce VR in this study. Thus, VR would be a great visualising tool for an initial analysis of daylighting and spatial quality for a qualitative analysis such as contrast, complexity, spaciousness (especially, the experience of space), depth and width, brightness and shadow of an intangible attribute.

Students' Acceptance of Virtual Reality in Learning

The students' acceptance rate of using VR was very high. They believed that their performance was improved by using VR. They expected more exploration and the use of VR in other modules. They were highly motivated and satisfied with using VR and would use it again for their learning. In short, students found VR to be a useful tool and found it to be easy to use but with guidance.

Advantages of Using Virtual Reality

In this study, VR complemented existing learning activities. Students were very positive about using VR as a teaching and learning strategy in architectural modules. VR offered them a more profound comprehension, an improved educational encounter, intricate and authentic real-life involvement, technological progress and heightened spatial aptitude. In addition, VR can be further developed to include daylight analysis. It may be able to substitute some of the existing 2D analysis.

Improvements to Facilitate Virtual Reality Learning

VR for teaching and learning can be improved with a better guide or structured teaching and learning, a bigger space to facilitate human movements using VR, VR station availability (ideally 1 to 1 and not sharing), software availability and repetitive learning or continuous use of VR in architectural programmes.

Recommendations for Future Research

Future research should aim to replicate the workshop for the entire class and improve the conditions that facilitate learning. This will involve creating a guide that helps students engage in self-learning and reduce time spent in class. Additionally, the research should explore VR as a tool for initial design in Architecture Design Studio. The goal is to integrate daylight use in order to improve spatial quality and decrease reliance on artificial lighting.

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