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Exploring the Effectiveness of Immersive Virtual Reality for Project Scheduling in Construction Education

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Abstract: The emergence of immersive technologies, such as virtual reality (VR) headsets, has revolutionized the way we experience the physical world by creating a virtual, interactive environment. In the field of education, this technology has immense potential to provide students with a safe and controlled environment in which to experience real-world scenarios that may be otherwise unfeasible or unsafe. However, limited research exists on the effectiveness of integrating immersive technologies into technical education delivery. This research investigated the potential use of immersive virtual reality (IVR) in university-level construction management courses, with a focus on integrating IVR technology into traditional education for construction project planning and control. The experiment involved comparing the students' learning and understanding of the subject matter using a set of two-dimensional construction drawings and a critical path method (CPM)-based construction schedule, with and without the use of an immersive environment. The findings suggested that the use of immersive technology significantly improved the students' ability to understand technical concepts and identify any errors in the construction sequence when compared to traditional teaching methods. This paper presents the details of the experiment and a comparative analysis of both approaches in terms of students' learning and understanding of project planning, sequencing, and scheduling.

Keywords: immersive technologies; virtual reality; technical education; construction project planning; construction sequencing; construction scheduling; comparative analysis

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1. Introduction

Engineering education amalgamates related research and technical education to foster technological and educational innovation, thereby enhancing problem-solving abilities and creativity among recent graduates entering the technical workforce. The 2019 Degree Survey by the Ministry of Education (MoE) in the United Arab Emirates (UAE) identified engineering as the most sought-after degree program. According to the Knowledge and Human Development Authority (KHDA)—MoE, over 9000 engineering students are currently enrolled in various institutions across the UAE, and this number is anticipated to significantly escalate [1]. These statistics underscore the criticality of a technically skilled workforce and the indispensability of quality engineering education in the UAE.

Conventional approaches to engineering instruction are limited in their ability to provide students with exposure to practical applications of their field-specific knowledge, as they are typically conducted in a classroom setting with minimal opportunities for hands-on learning [2]. This poses a challenge for students in understanding real-world situations, particularly in harsh weather conditions such as those experienced in the UAE [3]. Moreover, conventional engineering courses rely heavily on non-intuitive documentation, which can be problematic for students lacking industry experience, such as those in construction management programs. Such documentation, including two-dimensional drawings and project-related materials for activities such as project planning, activity sequencing, scheduling, safety planning, and cost estimates, can be difficult to comprehend and prone to error.

The emergence of building information modeling (BIM) has brought about numerous opportunities for both industry and academia to transition from traditional document-oriented practices to data-driven, 3D model-enabled engineering processes and workflows [4]. Additionally, the advent of immersive and reality-based technologies has given rise to highly effective tools such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). The construction sector has increasingly used applications of BIM and VR to enhance construction sequencing and planning, such as 4D BIM and virtual construction. VR technology offers users the ability to completely immerse themselves in a virtual environment through computer-generated simulations [5], providing a symbolic representation that helps them better visualize and understand the project [6]. As a result, decision-makers can use VR simulation to visualize, evaluate, and mitigate any errors that might obstruct the project's execution. The integration of BIM and immersive technologies has been studied, and various studies have used these integrations to enhance the construction management process [7–9]. This advanced visual communication can significantly improve students' ability to understand and learn by reviewing designs for constructability and planning the construction of building and infrastructure projects. Moreover, the utilization of advanced visualization techniques can promote active learning among students. However, limited studies have investigated the potential of these technologies in enhancing engineering education.

The purpose of this research was to investigate the potential application of immersive virtual reality (IVR) in construction management courses at the university level. Specifically, this study aimed to examine the integration of IVR technology into traditional construction management education, particularly in courses related to construction project planning and control. To achieve this objective, the effectiveness of IVR in enhancing students' understanding of project sequencing and planning was tested with architectural engineering students at the UAE University and compared with the use of traditional 2D project data. The research methodology comprised four main steps: (1) development of a simplified Gantt chart and 3D Revit model for IVR application, (2) experimentation with construction management students, (3) assessment of the students' experiences through a post-experiment survey, and (4) analysis of the survey outcomes. The findings of this study are expected to contribute to the existing knowledge on the integration of advanced technologies in construction education and encourage course instructors to consider IVR as a teaching tool in their courses.

2. Literature Review

2.1. Immersive Virtual Reality (IVR)

IVR refers to a computer-generated environment that simulates an interactive experience and fully engages the user's senses, typically including sight, sound, and touch. IVR involves the use of wearable displays, such as head-mounted displays (HMDs), to track the movements of users and present virtual information based on their positions. This enables users to experience the virtual environment in 360 degrees, resulting in a fully immersive experience. It is this sense of immersion that is often associated with VR technology and is one of its most marketable features [10]. The history of IVR can be traced back to the 1960s when Ivan Sutherland introduced the first head-mounted display system. However, the technology was not advanced enough to garner widespread attention until the 1990s, when the reality-based system became a research field of its own [11]. Moreover, the idea of IVR began to gain traction with the advent of consumer-grade hardware such as virtuality headwear and Nintendo's Virtual Boy, which helped introduce the concept to the general public [12]. With advancements in computer processing and graphics technology, the CAVE (cave automatic virtual environment) was conceived by a team of scholars at the University of Illinois at Chicago in 1991 as a tool to advance scientific visualization. The CAVE system elicited a sense of immersion by enclosing the user within a physical space surrounded by projection screens that displayed images in a stereo format. The projected images were rear-projected onto the walls and down-projected onto the floor. To fully experience the stereoscopic visualization, the user required specialized three-dimensional shutter glasses [13]. In the 2000s, with the rise of the internet and advent of online gaming, IVR continued to evolve with the development of more sophisticated hardware such as HMDs and haptic feedback devices that allowed for greater sensory immersion [14]. IVR represents a significant advance in our ability to simulate and interact with the digital environment, opening up new possibilities for entertainment, education, and scientific research.

IVR technology has experienced significant advancements that have opened up various possibilities for exploring new dimensions in different fields, such as education, healthcare, gaming, entertainment, engineering, and beyond [10]. A literature review recently explored the impact of IVR on various fields, highlighting its current and potential applications along with the limitations of the technology. The study noted the potential of IVR in industrial applications such as driving simulation, as it allows the creation of realistic situations without risk to the driver or learner [15]. Additionally, IVR can be used in product design and prototyping by creating virtual design alternatives, thus saving significant time, money, and effort by reducing material wastage [16]. The study also identified the potential of IVR in education, specifically in fields such as medicine, engineering, and military training [17]. IVR technology can keep students more attentive and enable teachers to have one-on-one interactions with students, thereby enhancing the learning experience [18,19]. In addition, IVR-based medical training can be utilized to train surgeons to operate and practice in a virtual environment, reducing the chances of mistakes, while students can practice and experience real-life scenarios with virtual patients [20,21]. Moreover, IVR has great potential in public health and wellness. For instance, exergaming, fitness, and sports opportunities can be provided that improve the overall fitness of users, which contrasts with traditional sedentary techniques of gaming [22]. IVR technology is also utilized in therapy and meditation to provide immersive environments for overcoming traumas and other stress-related illnesses [23]. Furthermore, social interactions are one of the latest additions to the category, where IVR provides a realistic setting to interact, improving the social abilities of people with disabilities or allowing individuals to interact in various situations such as education, business, work, and community gatherings [23,24].

In recent years, IVR technology has made significant progress, thanks to continued technological advancements in both hardware and software [25]. These innovations have contributed to the enhancement of the VR experience, resulting in increased levels of immersion and interactivity for users. The integration of high-quality displays, wireless headsets, hand and body tracking, haptic feedback, and artificial intelligence (AI) works together to create a more realistic and engaging virtual environment [26,27]. High-quality headsets equipped with advanced features such as high resolution, high refresh rate, wide field of view, and precise tracking accuracy have greatly enhanced the IVR experience [28]. These features contribute to a more realistic and detailed visual representation of the virtual environment, providing users with a truly immersive experience. Furthermore, the introduction of wireless VR headsets has significantly improved the IVR experience by freeing users from the physical constraints of being tethered to a computer or console [29]. The integration of hand and body tracking in virtual reality technology has improved the overall immersive experience by enabling more natural and intuitive interactions with the virtual environment [30]. In addition, haptic feedback improves the immersive virtual reality experience by providing tactile sensations that simulate the feeling of touch and enhance the realism of interactions with virtual objects [31]. Artificial intelligence has also been used to create better virtual reality experiences by developing new techniques for improving 3D displays for virtual and augmented reality technologies. AI can also be used to interpret user input in a more natural way, allowing for more realistic and responsive interactions with virtual characters and environments [32]. These advancements have the potential to revolutionize the way we interact with virtual reality. Overall, the progress in IVR technology has the potential to disrupt almost every field imaginable in the near future and remarkably enhance the users' learning experiences across all domains.

2.2. IVR in Construction Education

The emergence of IVR has transformed the way students learn in many fields, including education. This technology provides an opportunity to engage learners in a highly interactive and immersive learning environment [33]. IVR has been shown to enhance the learning experience by providing a highly realistic and interactive setting where learners can visualize and experience complex concepts, ideas, and procedures [34]. The use of IVR in education offers several benefits, including increased engagement, better knowledge retention, and enhanced learning outcomes [35]. Furthermore, it offers the potential to overcome traditional classroom limitations by enabling students to learn at their own pace and in a way that best suits their learning style [36]. One of the key benefits of IVR in education is that it provides a safe and controlled environment for learners to experiment and practice without the risk of harm or damage to equipment [37]. For example, engineering students can simulate and explore different design solutions while construction management students can simulate and practice project management scenarios, leading to better decision-making and critical thinking [38]. Additionally, the use of IVR in education has the potential to address the challenge of providing practical experiences for students in fields such as medicine and healthcare, where the risks associated with real-world procedures are high [39]. By using IVR to simulate real-world scenarios, students can develop their skills and improve their confidence in a controlled and safe environment. Despite the many potential benefits of IVR in education, some limitations exist, such as the high cost of implementation, technological limitations, and the need for specialized training for both educators and learners [33,40]. Moreover, there is a lack of standardization in the field, making it difficult to evaluate the effectiveness of IVR in education [41]. Nonetheless, the potential of IVR in education is enormous, and with continued development and refinement, it could revolutionize the way students learn in the future.

The use of IVR technology has been implemented in various studies focused on construction management education, with positive results. A study reviewed the recent applications of VR in architecture, the construction industry, as well as in education and evaluated its potential to improve student learning. It found that using VR could enhance creativity, improve visualization of complex designs, and aid in understanding course concepts but may face obstacles related to cost and rapidly changing technology [42]. Another study developed and tested an augmented reality-based assessment tool for evaluating hazard recognition skills of construction management students, finding that it outperformed traditional paper and computer-based assessments in terms of effectiveness and student preference. The study highlighted the potential of immersive technologies to bridge the gap between classroom and real-world construction environments for improved safety training [43]. Furthermore, Whisker et al. [5] explored the use of 4D CAD modeling and immersive virtual reality in construction engineering education and found that these advanced visualization tools could improve students' understanding of construction projects and plans. The study suggested that using virtual reality could supplement actual construction site visits and allow students to experiment with different construction sequences, temporary facility locations, trade coordination, safety issue identification, and design improvements for constructability. In a similar realm, a recent study investigated the use of immersive videos (360, 180 3D, and flat) as an educational tool in construction management and found that students had a positive perception towards using this technology, with HMDs being their preferred delivery method. The study suggested that incorporating immersive videos could enhance construction management education, although further research with larger and more diverse samples was needed [44]. A class experiment found that the implementation of a 4D BIM schedule, along with virtual reality technology, could enhance the fabrication and assembly performance of modules. Most of the participants who experienced a 4D BIM schedule along with immersive virtual reality (4D/IVR) strongly agreed that it was an easy and straightforward way to visualize the project, understand the schedule, and find any errors. Moreover, almost all of them successfully sequenced the assembly with 4D/IVR, compared to only 42% with conventional 2D drawings and schedules [45]. In an effort towards implementation of VR-based techniques, a recent research study proposed a methodology for implementing VR-BIM technology in the construction management undergraduate curriculum to enhance students' understanding of building principles. The methodology included integrating VR-BIM into the existing courses and providing a new computer lab classroom, while overcoming challenges such as faculty training and availability of technology [46]. These studies have reported that the implementation of IVR-based techniques can enhance creativity, improve visualization of complex designs, aid in understanding course concepts, and supplement actual construction site visits. However, obstacles such as cost, limited exposure of both students and faculty to VR, lack of infrastructure, rigidity of traditional course content, and policies may impede the implementation of IVR in construction management education [47,48].

3. Research Methodology

Initially, a case study project was selected and essential documentation, including 2D construction drawings and a construction schedule, was acquired. Then, a modified construction baseline schedule was prepared that presented only execution-related activities in the Gantt chart. The Gantt chart was created using Microsoft® Project™, a project management software used for developing and managing construction schedules. Simplification of the baseline schedule was necessary to avoid overwhelming students who had little or no knowledge of construction sequencing. Additionally, the 2D drawings were transformed into a detailed 3D structural model using the licensed version of Autodesk® Revit™ 2022. The 3D Revit model was divided into several pre-arranged phases as per the activities present in the simplified construction baseline schedule. After the 3D Revit model was developed, it was transformed into the IVR environment using the Enscape™ plug-in. The Oculus™ Rift S headset was utilized as the IVR gear, allowing users to experience the 3D constructability of the case study building and evaluate its correctness.

Subsequently, the experiment was conducted by randomly dividing students in the undergraduate course "ARCH 450—Construction Project Planning and Control" and the graduate course "MEME 635—Project Management for Engineers" into two groups: the control and test groups. Both groups consisted of 45 students each, and all users were tested and evaluated independently. The sample size was much larger than that of Wang and Dunston's [49], who experimented with 16 students, and an experimental study [50] that included 20 participants for similar experiments. The control group comprised students who were tested using the 2D set of drawings and baseline schedule (Gantt Chart). Each user in the control group was briefed on the research objective and provided with a comprehensive description of the expected task. A laptop was provided to all users to review the documents and a sheet of paper was given to record their observations during the experiment. On the other hand, all users in the test group were briefed on the experiment and a ten-minute session was arranged to train them on how to use the Oculus™ Rift S headset gear and navigate through the IVR environment on a sample 3D model. After the necessary training, all users in the test group were exposed to the IVR model and their feedback was recorded. The IVR simulation included phases from laying out the foundation, framing each floor, to completion of the frame structure of the case study building.

Thirdly, to capture the users' experiences, a survey questionnaire was developed with three distinct sections. The first section aimed to gather demographic information and prior knowledge of the users and consisted of six questions. The second section, comprising six questions, aimed to assess the users' overall experiences throughout the experiment, including both the control and test groups, through selection- and statement-type responses. Lastly, the third section of the survey consisted of three statement-type questions aimed at evaluating the quality of interaction experienced by the users throughout the experiment. The complete survey questionnaire can be found in Table 1. This structured approach to data collection was crucial for accurately analyzing and understanding the users' experiences.

Table 1. Questionnaire.

Subjective Measures	Questions
Characterization of Users	Question 1: Year of your Undergraduate study (Tick One) *First Year* *Second Year* *Third Year* *Final Year* Question 2: Did you take any construction management courses in your degree so far? (Selection Response) *Yes* *No* Question 3: Did you have any construction-related internships so far? (Selection Response) *Yes* *No* Question 4: Did you review the Gantt Chart/2D or experience virtual reality? (Tick One) *Gantt Chart/2D* *Virtual Reality* Question 5: How familiar are you with the Gantt Chart/virtual reality technique? (Selection Response) *Very Familiar* *Somewhat Familiar* *Not Familiar* Question 6: How familiar are you with construction planning/sequencing? (Selection Response) *Very Familiar* *Somewhat Familiar* *Not Familiar*
The Extent of Experience Felt	Question 7: How difficult was this experience for you? (Selection Response) *Very Difficult* *Somewhat Difficult* *Not Difficult* Question 8: Did you entirely complete the given task? (Selection Response) *Yes* *No* Could not review through this method Question 9: Do you think that you have found all errors/ irregularities in the construction sequence? (Selection Response) *Yes* *No* *Not Sure* Question 10: Did you think that you had understood the given task properly before starting this experiment? (Selection Response) *Yes* *No* *Not Sure* Question 11: Do you think enough time was given to review the construction schedule in this experiment? (Selection Response) *Yes* *No* *Not Sure*

Table 1. *Cont.*

Subjective Measures	Questions
	Question 12: Please respond to the following aspects of the tool/technique/method you have experienced (Selection Response): i. Information was clear with this method *Strongly Agree* *Agree* *Neutral* *Disagree* *Strongly Disagree* ii. Information was easily understood with this method *Strongly Agree* *Agree* *Neutral* *Disagree* *Strongly Disagree* iii. Did not need to consult with the professor for clarifications *Strongly Agree* *Agree* *Neutral* *Disagree* *Strongly Disagree* iv. The method was effective in presenting the construction sequencing information *Strongly Agree* *Agree* *Neutral* *Disagree* *Strongly Disagree* v. Sequencing errors/irregularities were easier to locate *Strongly Agree* *Agree* *Neutral* *Disagree* *Strongly Disagree*
User Opinion of the Quality of the Interaction	Question 13: What aspects were difficult for you to complete this task? (Statement Response) Question 14: What do you think could be done to make it easier for you to perform this task? (Statement Response) Question 15: Please specify all construction sequencing errors/irregularities found. (Statement Response)

Finally, the users' feedback collected through the paper-based survey questionnaire was entered into a Microsoft® Excel™ spreadsheet for further analysis. Descriptive analysis was conducted on the data to gain valuable insight into the effectiveness of the techniques employed and to evaluate the effectiveness of the advanced IVR environment in enhancing the delivery of construction management education. The complete methodology is depicted in Figure 1.

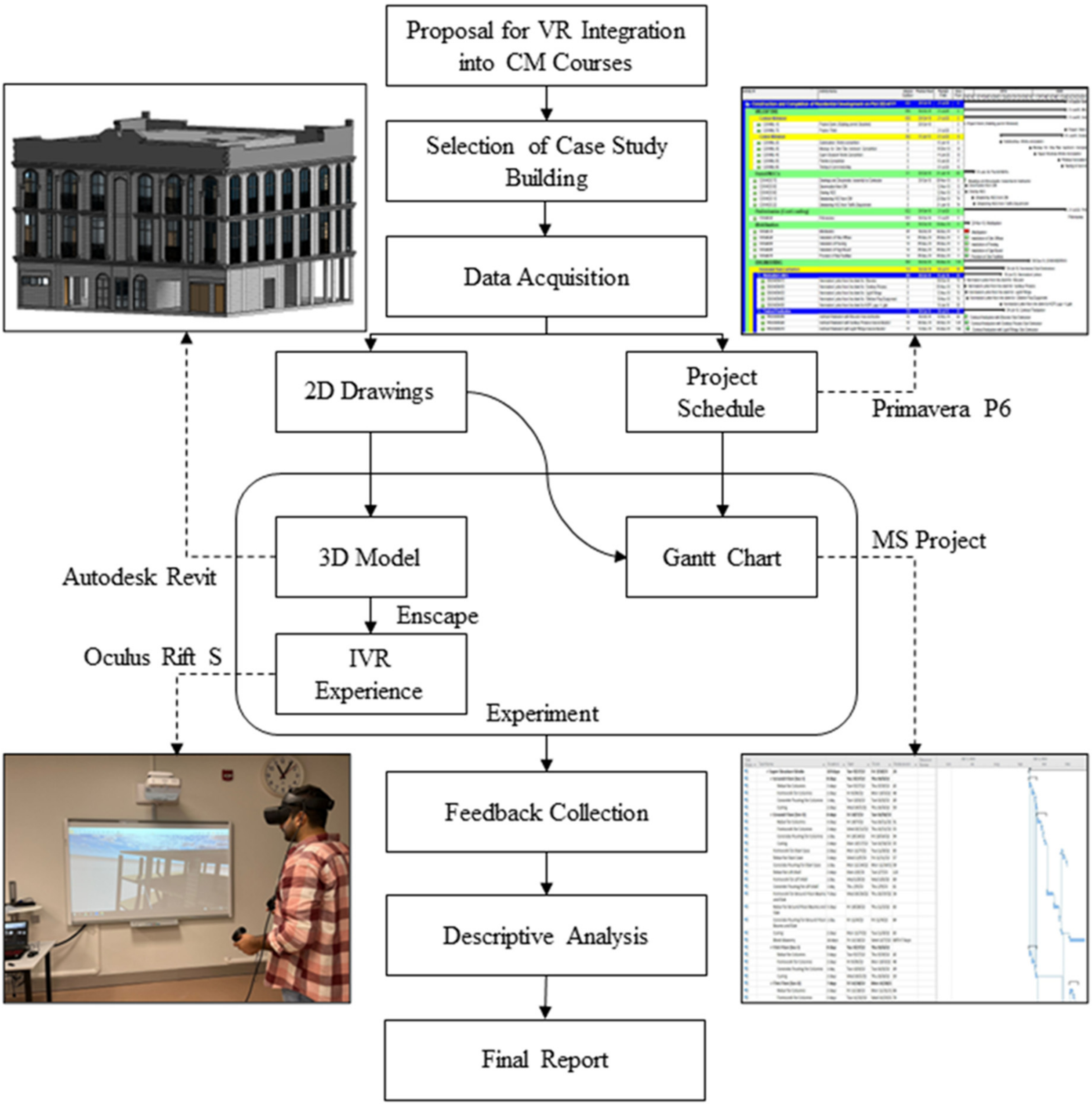

Figure 1. Representation of research methodology.

4. Results and Discussion

4.1. Participant Characterization, Experience, and Quality of Interaction

To conduct this comparative study testing the effectiveness of IVR in teaching construction sequencing and planning as compared to traditional 2D teaching techniques, a total of 90 users participated and completed the survey questionnaire after the test. For users' educational year, more than 70% of the users were enrolled full-time in their fourth and final year of study in the Department of Architectural Engineering. There were four users currently enrolled full-time in the second year of their undergraduate study program and nine users were enrolled full-time in the first year of their master's study program. For users' construction management-related education, all of the users were either enrolled in the construction management-related course/s or had already taken one of these courses in previous semesters. The Department of Architectural Engineering offers three construction management-related courses in its Bachelor of Architectural Engineering Degree Program i.e., ARCH 326—Building Construction Methods and Equipment, ARCH 440—Construction

Project Management, and ARCH 450—Construction Project Planning and Control. Moreover, the users from the Master of Engineering Management program were enrolled in MEME 635—Project Management for Engineers. For users' construction-related exposure either through full-time jobs or internships, nearly 31% of the users had actual construction experience through summer internships, which was a similar figure among the control and test groups.

Both the control and test groups each comprised 45 users. For users' familiarity with the method tested, 56% of the users were '*somewhat familiar*' with the tested method, 17% of users were '*not familiar*' with the technique they were using, and 27% of users stated a high level of familiarity with the method in the test group. For the control group, 60% of the users stated that they were '*somewhat familiar*' with the method of identifying the construction sequence using a 2D set of drawings and a Gantt chart, 20% of users mentioned a high level of familiarity with the method, and the rest were unfamiliar with the method altogether. Furthermore, for their familiarity with construction scheduling and sequencing, 51% and 60% of the users in the test and control groups, respectively, were '*somewhat familiar*' with construction scheduling and sequencing. A summary of the responses on users' characterization is presented in Table 2.

Table 2. Summary of participants' characterization.

Characterization Questions	**Qualitative Responses (Out of 45 for VR and 45 for 2D)**	
	VR	**2D**
Educational Year		
First Year	9	8
Second Year	4	4
Third Year	-	-
Final Year	32	33
Construction Courses		
Yes	45	45
No	-	-
Internships		
Yes	14	15
No	31	30
Method Used	45	45
Familiarity with Method		
Very Familiar	12	9
Somewhat Familiar	25	27
Not Familiar	8	9
Familiarity with Sequencing		
Very Familiar	18	7
Somewhat Familiar	23	32
Not Familiar	4	6

Moreover, to gauge the quality of the users' interactions, the survey presented five selection-type response questions on the level of difficulty of the task, the extent of its completion, the opinions of the users on whether they had found all the errors, their understanding of the task beforehand, and their opinion on whether they were given enough time to complete the given task. For the level of difficulty of the task, 62% of the users in the test group reported the task as '*not difficult*' while the rest of them classified the task as '*somewhat difficult*'. In contrast, 93% of the users in the control group found this task as '*somewhat difficult*' and '*very difficult*'. Regarding their opinion about completion of the given task, 98% of all of the users in the test group agreed that they successfully finished the given task except for one user. However, there was an equal difference of opinion about the completion of the given task in the control group, as 18% of the users stated that the given task was not finished to its entirety and two users stated that it was not possible to review through this method. Regarding the identification of all the errors in the given task, 63% of the users in the test group were confident about finding all the errors and irregularities in the construction sequence and only 28% said the same in the control group. Most of the users in the test group agreed that they clearly understood the task before starting the experiment and enough time was given to complete the test. However, in the control group, only 82% stated that they had understood the task beforehand and a similar percentage agreed on having enough time to finish the task at hand.

The users were also asked to provide their feedback on the following five aspects of the method used: (1) information clarity, (2) information understanding, (3) need for professor assistance, (4) effectiveness of the method, and (5) locating errors. The responses are discussed briefly as follows and also summarized in Table 3.

Information clarity: The users were asked whether the scheduling and sequencing information provided through the method being tested was clear enough. For the test group, 67% of users '*strongly agreed*' that the information was clear enough and the rest of the users in the group '*agreed*'. The results were not surprising, as one of the primary advantages of VR technology is its ability to provide clear and immersive information. This has contributed to its growing popularity in various fields, including construction management, where it can be used to improve construction quality, monitor progress, and enhance safety [7,51]. However, only 75% of the users in the control group either '*strongly agreed*' or '*agreed*' that the information was clear enough and 22% remained '*neutral*'. The results of the research aligned with previously published studies indicating that both students and field experts experience difficulties in interpreting information presented through 2D drawings in construction management practices [5,52]. Additionally, studies have highlighted the need to supplement traditional 2D practices with more information-rich three-dimensional models, such as BIM [4].

Information understanding: The users in both the test and control groups were asked to state whether the information provided was easily understood. For the test group, 91% of the users '*strongly agreed*' or '*agreed*' with the statement, and only 4 users remained '*neutral*'. The research findings were consistent with research conducted on exploring the effectiveness of immersive interfaces for learning, as these studies indicated that immersive virtual reality experiences offered a more engaging and effective way to perceive and understand complex information compared to information presented in 2D or even simple 3D models by providing a more interactive, emotional, and multi-sensory experience [53,54]. In contrast, only 40% '*agreed*' with the statement while 33% and 9% of the users in the control group remained '*neutral*' and '*disagreed*', respectively. The overwhelming disagreement with the effectiveness of understanding the information through 2D drawings was reasonable as it has been well-documented in previous research. Drawings can limit the effectiveness of construction education due to their provision of limited spatial awareness, incomplete information, lack of interactivity, difficulty in visualization, and limited engagement [50,55].

Need for professor assistance: The users were permitted to consult their professor for any necessary clarifications during the experiments, and they were also asked about this in the survey questionnaire. For the test group, 49% of participants either '*strongly agreed*' or '*agreed*' with the fact that they did not feel the need to consult their professor during the experiment and only 18% remained '*neutral*'. While the effectiveness of IVR in providing information clearly and improving understanding was evident from the predictable responses, it is worth noting that most participants lacked formal construction experience, such as through jobs or internships. Therefore, the tendency to consult the professor for concept or process clarification was not due to a lack of information clarity or understanding provided by IVR, but rather a lack of user experience related to the information [55]. On the contrary, 94% of the users in the control group either '*disagreed*' or '*strongly disagreed*' with this statement. These findings aligned with the broader trend, as students encountered difficulty in comprehending the information due to the cluttered and disconnected nature of 2D drawings and the Gantt chart. Consequently, they were compelled to consult the professor more frequently, indicating the limitations of this approach in delivering construction project planning and control course content and impeding participants' comprehension.

Table 3. Summary of participants' experience.

Experience Questions	Qualitative Responses (Out of 45 for VR and 45 for 2D)	
	VR	**2D**
Level of Difficulty		
Very Difficult	-	3
Somewhat Difficult	17	25
Not Difficult	28	17
Completion of the Task		
Yes	44	35
No	1	8
Could not Review	-	2
Finding all Errors		
Yes	28	8
No	2	13
Not Sure	15	24
Understanding of the Task		
Yes	40	37
No	1	1
Not Sure	4	7
Enough Time Given		
Yes	42	38
No	1	5
Not Sure	2	2
Aspects of the Method Used		
i. Information Clarity		
Strongly Agree	30	11
Agree	13	23
Neutral	2	10
Disagree	-	1
Strongly Disagree	-	-
ii. Information Understanding		
Strongly Agree	28	8
Agree	13	18
Neutral	4	15
Disagree	-	4
Strongly Disagree	-	-
iii. Need Professor Assistance		
Strongly Agree	13	-
Agree	9	-
Neutral	8	3
Disagree	14	29
Strongly Disagree	1	13
iv. Effectiveness of Method		
Strongly Agree	28	9
Agree	15	20
Neutral	2	10
Disagree	-	6
Strongly Disagree	-	-
v. Locating Errors		
Strongly Agree	29	6
Agree	13	10
Neutral	2	15
Disagree	-	8
Strongly Disagree	1	6

Effectiveness of the method: The users were also asked whether or not they thought that the given method was effective in presenting the construction sequencing information. In the test group, 96% of the users either '*strongly agreed*' or '*agreed*' with the statement, which showed the effectiveness of IVR in presenting the construction sequencing information to the users. Similar results were reported on the effectiveness of IVR-based classroom learning by a recent review analyzing 17 studies published between 2015 and 2019, which suggested that virtual classroom environments are increasingly being used alongside traditional teaching with reported significant improvements in cognitive and skill-based learning outcomes [56]. However, only 44% of the users '*agreed*' and 22% remained '*neutral*' in the control group. This finding aligned with the existing literature, which highlighted the insufficient emphasis placed on developing students' spatial skills through the utilization of 2D representations of 3D objects in the current engineering curriculum. Traditional approaches, such as analyzing pictorial and orthogonal views, are insufficient for enabling students to appropriately interact with and observe objects in 3D [57].

Locating errors: At the end of this section of the survey questionnaire, the users were asked to provide their opinion on their ease of finding errors and irregularities using the given method. For the test group, 65% of the users '*strongly agreed*' and 29% 'agreed' with the fact that errors and irregularities were easier to locate using IVR. A recent study investigating the efficacy of combining 4D BIM and IVR to determine accurate assembly sequences in modular construction projects reported comparable findings [45]. However, 33% of the users in the control group remained '*neutral*' and a similar percentage of the users either '*disagreed*' or '*strongly disagreed*' with the statement. This result indicated that many students struggle to connect the two-dimensional plan of a building with the corresponding section also presented in a 2D format. This difficulty in visualizing and predicting the constructability of a construction project based on 2D documents is a significant limitation in identifying potential logical errors solely from 2D drawings and Gantt charts. According to a research study, professional construction estimators who relied on 2D drawings and specifications took longer to complete the task and produced less accurate outcomes compared to those who utilized reality-based tools [50].

For users' opinion on the quality of interaction, the users were directed to provide statement-type responses to two questions. For aspects that posed difficulty in the completion of the task, 55% of the users in the test group mentioned motion sickness and dizziness during their interaction. However, 60% of the users in the control group reported that the major hurdle in completing tasks was the lack of sufficient knowledge regarding construction sequencing or the overall construction process. Construction management students often lack experience with the complexity of construction processes, which limits their understanding of spatial and temporal constraints on construction sites and makes them ill-prepared for such intricacies regarding actual construction processes [58]. In their opinion on improving similar experiences, 51% of the users in the test group mentioned adequate training and practice in the VR environment beforehand. However, 82% of the users in the control group stated that prior adequate construction planning and sequencing knowledge was the key factor for an improved experience. Further detail on the users' opinions on the quality of interaction as thematic responses is summarized in Table 4.

Table 4. Users' opinions on the quality of interaction.

Users' Opinions on the Quality of Interaction	Thematic Responses	
	VR	2D
What aspects were difficult to complete this task?	Motion sickness and dizziness (25/45)	Not enough knowledge of construction sequencing (23/45)
	Lack of VR training (14/45)	Locating information from 2D documents (21/45)
	Error identification without enough knowledge of construction sequences (09/45)	The number of activities was high (07/45)
What could be done to improve the experience?	Adequate VR training and practice (23/45)	Prior construction planning and sequencing knowledge (37/45)
	Adequate knowledge of construction sequencing (11/45),	Site visits or actual construction experience (22/45)
	better resolution, and quieter environment (07/45)	Easier/clearer schedule (14/45)

4.2. Error/Irregularity Identification

While preparing the simplified construction baseline schedule and IVR simulation, five logical sequencing errors were intentionally introduced. The primary reason for intentionally introducing these errors was to evaluate the effectiveness of the proposed method, i.e., IVR, in improving students' ability to identify these errors as compared to traditional 2D techniques. By introducing these errors, the effectiveness of the IVR technique in improving students' level of understanding could be measured. An overview of the sequencing errors is as follows: (1) the height of the ground floor columns was extended to the first floor ceiling slab, (2) the first floor stairs were built before the first floor ceiling slab, (3) the second floor ceiling slab was built before its beams, (4) the lift well was built from the ground up after the roof slab was poured and the structure was finished, (5) the second floor walls were built before its columns. The representation of errors in IVR and the Gantt chart can be seen in Figure 2.

All of the users were expected to locate these intentional logical sequencing errors during the experiment. For error 1, 73% of the users in the test group successfully identified the error as compared to only 11% in the control group. For error 3, 78% of the users in the test group successfully identified the logical error and 2 of the 45 users in the control group could do the same. Similarly, the users in the test group were able to identify the errors with a certain percentage of success; however, this statement was not true for the control group. This comparison presented the effectiveness of IVR in identifying sequencing errors and irregularities as compared to a complicated construction baseline schedule. Figure 3 presents an overview of the task completion status of both groups.

Despite the overwhelming positive response from the participants using IVR regarding information clarity and understanding, the overall success rate of task completion remained low, even when using IVR. The unanimous agreement among participants regarding information clarity may be inflated, potentially resulting from overconfidence due to improved visualization. This heightened confidence may lead participants to believe that they have correctly identified the errors in the provided task, when in reality they have not. Similar outcomes may also be observed in 2D tasks where poor responses or significant disagreement could indicate a lack of confidence among participants, potentially arising from cluttered information and perceived difficulty in error identification. However, with adequate time provided for participants to familiarize themselves with the task, working memory may be enabled that leads to improved performance, as suggested by ref. [59].

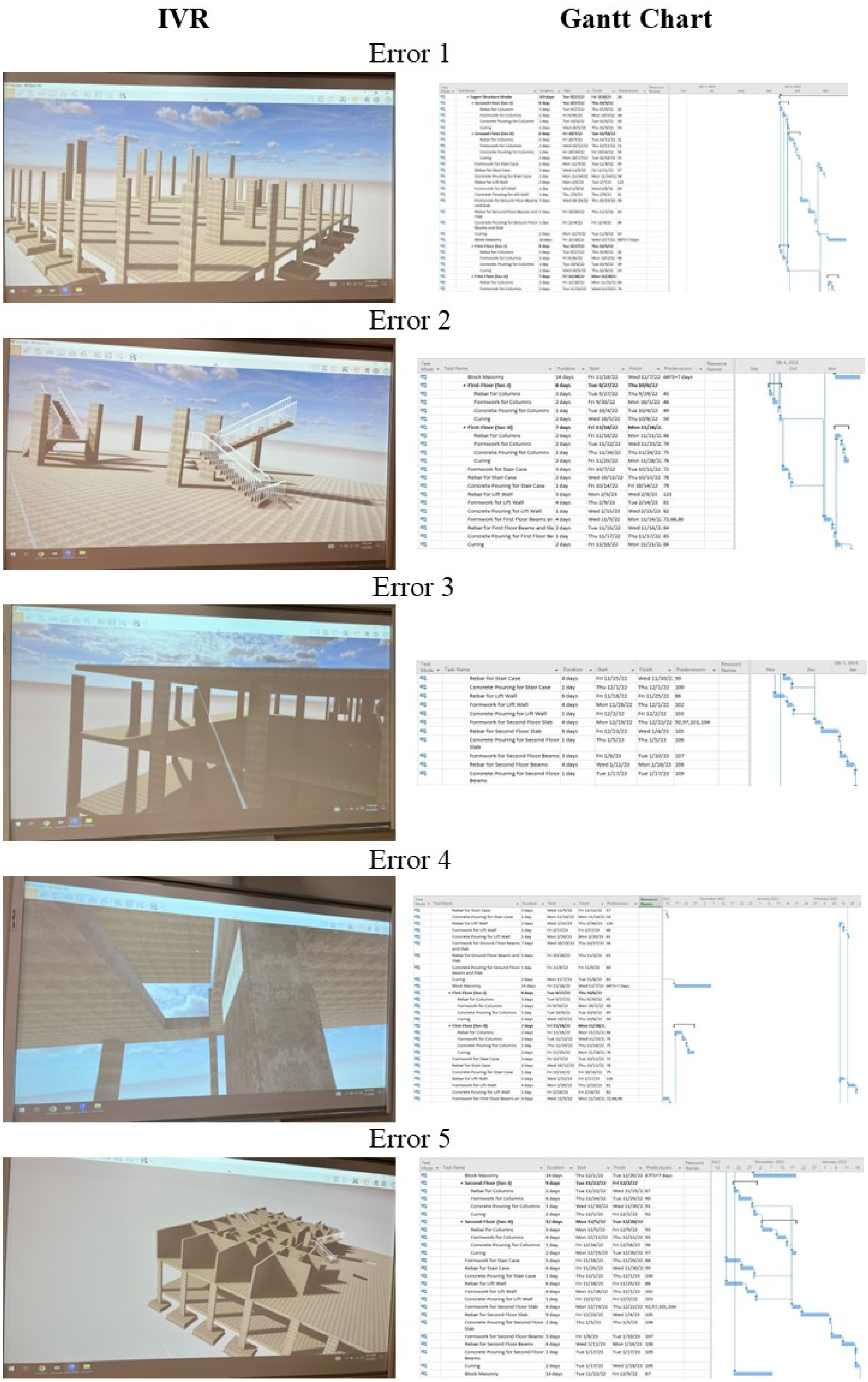

Figure 2. Representation of errors in IVR and Gantt chart.

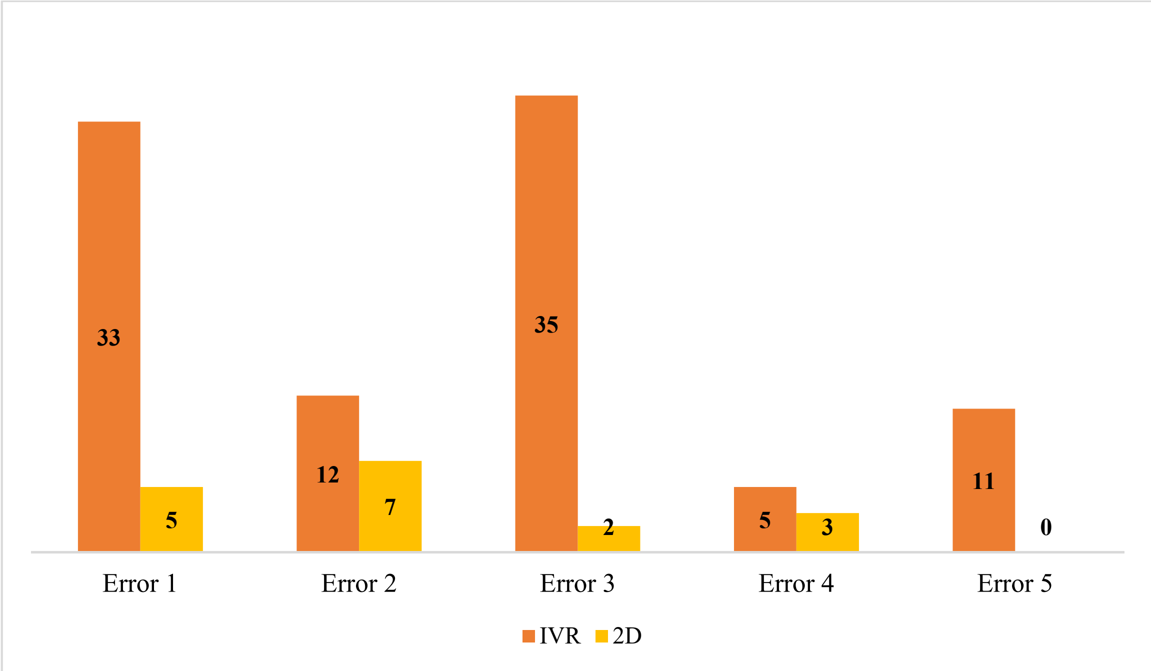

Figure 3. Task completion status (IVR vs. 2D).

5. Conclusions

IVR technology has been the subject of numerous studies examining its effectiveness across various domains, including education. This study aimed to address a gap in the existing literature by incorporating IVR technology into the delivery of construction sequencing and planning content. To compare the efficacy of IVR-based construction sequence simulation with traditional 2D documentation, an experiment was conducted in an undergraduate construction project planning and control course. The students were randomly assigned to a control group (2D) or test group (IVR), and both groups were tasked with identifying intentional logical errors in the construction baseline schedule of a low-rise apartment building. The results indicated that IVR simulation was significantly more effective than traditional 2D documentation in helping users identify errors and irregularities in construction schedules. Additionally, the survey questionnaire responses indicated that the IVR presentation was clearer, easier to understand, more effective at presenting sequencing information, and facilitated the identification of logical sequencing errors without requiring assistance from the professor. Notably, users appeared more confident in their ability to address various aspects after IVR simulation, in contrast to using the 2D method, which caused confusion.

Despite evidence supporting the effectiveness of IVR technology in delivering construction planning course content to students, significant concerns remain that limit the capabilities of this method. One major hurdle was the users' lack of familiarity with construction sequences. Additionally, this study's limited sample size and failure to consider demographic factors, such as the number of construction management courses completed, exposure to real construction environments through internships, and the extent of learning during those internships, limit the generalizability of the findings. Furthermore, issues such as dizziness, motion sickness, and eye soreness were major factors that affected users' ability during the experiment. However, these are common and well-established issues associated with experiencing IVR simulations. One potential solution to mitigate these issues is to expose users to the IVR environment for a more extended period, allowing them to become accustomed to the technology through semester-long training.

Future research will employ experiments that involve a more diverse demographic by carefully selecting users who possess at least some level of field experience and a foundational understanding of construction planning and sequencing. Typically, graduate-level students in the department are working professionals who have already been exposed to the real construction environment through part-time or full-time employment. Furthermore, it is recommended that field personnel with first-hand experience in construction planning, monitoring, and control be included in future experiments to gain a deeper understanding of the effectiveness of the proposed system. Such experimentation will provide valuable insight for improving the experience of undergraduate students.

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