CHAPTER 24

Augmented Reality and Virtual Reality Applications for Enhanced Visualization and Decision-Making

Nikhil Thute[1], Shubhankar Pandey[1], Himanshu Khairnar[1] and Raghavendra Kumar[2]

ABSTRACT

This study is built upon address construction project management with Augmented Reality (AR) and Virtual Reality (VR) technologies. Such promises come along with the work of enabling better visualization by decision-makers and collaboration among all stakeholders. These immersive virtual environments allow stakeholders to simulate the real-life scenarios of construction processes, predict problems, and optimize them before actual construction. A questionnaire survey was conducted to determine how the AR/VR tools are improving spatial understanding, enhancing planning accuracy, and boosting on-site performance. According to the findings, AR/VR technology to reduce mistakes, encourage green behaviors, and speed up decision-making are most valuable for the construction sector. The study further acknowledges limitations around small sample sizes, very short-term evaluations, and context-based designs, thus leading to restrictions on ascertainments. Therefore, it aligns technological innovations with real needs in the industry, which further contributes to developing better strategies for implementing AR/VR in construction workflows, such that project management would be more efficient, collaborative, and sustainable.

Keywords: Augmented reality; Virtual reality; Construction on management; Stakeholder engagement; Decision-making.

1.0 Introduction

Virtual Reality (VR) and Augmented Reality (AR) are new technologies in which people experience digital worlds in an entirely different way through first-class views and a first-class action in real time. People may practically work on hard data in these tools and make better decisions in space or on engineering works. Building, engineering, and business analysis are fields that benefit immensely from AR and VR because they enable teams to collaborate in real time, assess risks, and ultimately improve processes. Yet they have been largely unused to date, because of their high costs and complexity of learning them. Solving these issues could really help make better decisions in many areas.[Noghabaei, 2020] [Asadi, 2018]

[1]School of Construction, NICMAR University, Pune, Maharashtra, India
[2]Corresponding author, School of Construction, NICMAR University, Pune, Maharashtra, India
(E-mail: raghavendra.kumar@pune.nicmar.ac.in)

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*

1.1 Background and context

AR and VR show data in three dimensions, which is better than old methods like CAD models. They are widely used in gaming and health care, but not much in building and city planning. Regardless of the useful application of AR and VR, there is a dismaying lack of evidence to suggest that they are better at decision-making. They can be very expensive and quite demanding of training, plus there are holes when it comes to understanding how to balance risk and work with others. This study looks at their effects using detailed checks and statistical tests.

2.0 Research Backgroud

Though one of the biggest and most complex industries in the world, the construction sector has, in fact, suffered from age-old problems, with common issues such as cost overruns, delays, or rework. Inadequate visualization, poor decision-making, or inefficient collaboration between stakeholders (Noghabaei, 2020) normally account for these issues. Quite a few other project management practices, like 2D drawings, and even 3D Building Information Modeling (BIM), are limited in providing a broad comprehension of complex construction projects, especially for non-technical stakeholders (Asadi, 2018). Augmented Reality and Virtual Reality technologies have garnered the attention of many in this type of construction as transformation tools in the last few years. AR and VR technologies enable immersive virtual environments, allowing different stakeholders to visualize construction scenarios in order to identify possible issues as early as possible in the life cycle stage to improve the flows of work-from decision-making to collaboration (Du, 2018). The literature review that follows concentrates on the ways in which AR and VR are used in the management of construction projects and in enhancing visualization, decision-making, and stakeholder engagement.

2.1 AR/VR in construction visualization

Visualization is a core element of construction project management since it helps stakeholders understand design elements and identify their potential issues for further decisions. Conventional visualization methods like 2D drawings and 3D BIM models do not always capture the interest of stakeholders, especially when these latter are unfamiliar with technical drawings. AR and VR technologies help bridge that other between stakeholders and construction processes, since they provide interactive and immersive virtual environments to engage in real-time with 3D models. Among the major advantages of augmented and virtual realities in construction visualization are the simulation that they are capable of doing on real construction sites. In this context, [Balali *et al.*, 2018] developed a cloud\-based virtual reality platform called CoVR to allow multiple users to collaborate on BIM models in a shared virtual space. This platform takes a big step in improving communication among remote stakeholders by providing a common space for visualizing and commenting on project data. In the same stream of work,

DOI: 10.17492/JPI/NICMAR/2507024 ISBN: 978-93-49790-54-4

[Sacks *et al.*, 2013] created a Mobile Augmented Reality (MAR) application to overlay BIM models on real\-world environments. With such an application, construction technicians will be able to visualize and refine their designs right there on site, thus eliminating errors and rework. Further, AR and VR technologies allow for virtual site walkthroughs, whereby those concerned are able to literally walk through the site before any construction begins. Such a method is beneficial in making design clashes or conflicts more evident before actual construction starts, improving spatial comprehension and make construction planning more precise.

2.2 AR/VR in decision-making

The decisions made in any construction project will be one of the most important aspects for the success of that project. Traditional methods by which decisions are made are mostly based on incomplete or inaccurate information, which ultimately leads to suboptimal decisions. AR and VR types of technologies enhance decision-making capabilities with the ability to visualize and simulate aspects of a project so that stakeholders can make better-informed decisions. A critical application of AR and VR in decision-making is cost estimation. Balali *et al.* (2018) developed a VR-based cost estimation system that enables stakeholders to assess the financial impact of design modifications in real time. This method improves cost estimation accuracy and supports better decision-making in both design and construction phases. Also, with the aid of VR simulations, different construction sequences can be modeled, which allows project managers to check and eliminate all anticipated issues beforehand. Sacks *et al.* (2013) highlighted VR-based simulations as perceptive tools available for project managers to visualize construction processes and predict problems before they occur, thus preventing delays and extra costs from occurring. Equally critical is the risk management that can be accomplished using AR and VR. By simulating the risks and their repercussions, these technologies allow project managers to lay preemptive plans for the mitigation of such risks. Jeelani *et al.* (2017) designed a VR-based safety training program in which workers are placed in realistic construction accident scenarios that allow them to practice dealing with dangerous situations and do so without exposure to actual danger. This increases awareness of hazards and perception of risks, reducing accidents on the site.

2.3 AR/VR in stakeholder engagement

AR VR probably is one of the biggest leaps in stakeholder collaboration by allowing them to conduct virtual design meetings and reviews. Some other systems that have been mentioned in relation to digitized communication platforms are W. T. Du and coworkers' [Balali *et al.*, 2018] CoVR system for letting remote stakeholders into virtual meetings. The embedded AR VR spaces allow stakeholders to review project information without physical proximity. This is extremely critical especially for vast projects with geographically dispersed stakeholders [Wei *et al.*, 2015]. It also allows AR VR to further coordinate between architects, engineers, and construction workers. Williams and coworkers [Sacks *et al.*, 2013] built a mobile

DOI: 10.17492/JPI/NICMAR/2507024 ISBN: 978-93-49790-54-4

AR assistant for performing BIM on-the-job in case of overlays onto a real-world setting so that the field technicians could visualize and correct their work on the fly. Errors would be reduced, and rework will eventually improve the efficiency of the project.

2.4 Limitations and challenges

While various advantages exist for the introduction of AR and VR technologies in the construction industry, their widespread acceptance has been rather sluggish mostly due to several obstacles. One major wall would be the high cost of implementation, including hardware, software, and personnel training [Goulding *et al.*, 2012]. Besides, the lack of awareness and knowledge about the advantages associated with AR and VR among construction professionals, especially at the management level [Ergan *et al.*, 2019], leads to resistance to adopting these new technologies. One more important problem is integration of AR and VR into existing construction activities. Numerous firms have been employing BIM and other digital devices, while the combined application of AR and VR with such systems can become both furthermore complex and time-consuming [li, 2018]. Also, the power of AR and VR management depends on the information and modes upon which it is developed. Suboptimal, incomplete BIM models will likely obscure accurate visualization further rendering a decision-making process inefficient [Pelargos *et al.*, 2017].

2.5 Research gap

Even though the short-term advantages of AR and VR in building are notable, their long-term advantages still require an evaluation. Present literature focuses largely on real-time visualization and decision-making enhancements of AR and VR applications, however, little has been done to understand their impacts on more chronic success indicators, such as cost savings, schedule adherence, or final project quality [Danylec *et al.*, 2022] [Zheng *et al.*, 2021]. Another gap in research relates to the technical skills needed to implement AR and VR. Many construction companies lack construction decision-making expertise or technical skill within their organizations to integrate these new technologies among their workflows. Thus, they partly rely on consultants [Beh *et al.*, 2022]. Nevertheless, with recent developments in AR and VR platforming, implementation is anticipated to be made easier and will have fewer barriers financially, thus having these technologies become user-friendly in the construction industry [Aguilar *et al.*, 2024].

3.0 Research Methodology

This study adopts a quantitative research approach to analyse the trends and adoption of AR/VR technologies in the construction industry. The research is based on survey responses collected from professionals in the construction sector to understand their familiarity with AR/VR, adoption barriers, and the impact of these technologies on decision-making and project efficiency. The Flowchart of the methodology is depicted in Figure 1.

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*

Figure 1: Research Methodology Flow Chart

3.1 Questionnaire survey

A structured survey was carried out to assess awareness, use, and attitude towards Augmented Reality (AR) and Virtual Reality (VR) technologies in construction. The aim was to determine challenges, advantages, and how AR/VR can be incorporated into construction processes. A structured survey is conducted amongst the constructional professionals focusing mainly on AR\VR users.

The survey focused on:

- Industry Experience & Technology Adoption.
- Usage & Understanding of AR/VR.
- Benefits & Challenges.
- Future Adoption & Suggestions.

Data Collection process: Online survey with Construction professionals.

3.2 T tests analysis

A t test is a statistical test that is used to compare the means of two groups. This method will be helpful for assessing different factors that will be affecting adoption of AR\VR in the

DOI: 10.17492/JPI/NICMAR/2507024 ISBN: 978-93-49790-54-4

construction industry. The t test is a parametric test of difference, meaning that it makes the same assumptions about the available data as other parametric tests. The t test assumes our data:

1. are independent
2. are (approximately) normally distributed
3. have a similar amount of variance within each group being compared (a.k.a. homogeneity of variance)

4.0 Data Collection

Data was collected using an online questionnaire survey. At first, a sampling method was used, and a specific formula was utilized to calculate the sample size. The sampling process was conducted, and data was collected through Google Forms. The respondents primarily consisted of professionals from the construction industry, including architects, civil engineers, project managers, and construction site supervisors. The responses were then processed and analysed with the help of Microsoft Excel after data collection. We applied statistical methods such as t test analysis to find whether their differences are statistically significant or not. t-test was appropriate in the study as it statistically confirms participants are utilizing AR/VR applications. Significant results allow further study on the aspect of AR/VR enhancing visualization and efficiency of decision-making. The use of statistics helps to derive conclusions from accurate data, hence its importance in maximizing AR/VR systems and user experience.

4.1 Questionnaire survey

In this study, data collection was conducted using online as well as offline methods including a structured questionnaire in excel sent using Google Forms. Since the minimum sample size for calculating t test is not universally defined, most researchers recommend collecting a sample of at least 30 responses to make it statistically significant for analysis. A pilot study with 30 responses was first conducted to determine the appropriate sample size. Thus, a formal sampling nature was employed, obtaining a total of 40 responses from the construction professionals.

4.2 Data analysis

Comparing the graphs clearly illustrates trends in the adoption of AR/VR, users' experience, and challenges. Analysing usage patterns, user characteristics, motivations for the adoption of AR/VR technology, and adoption challenges can provide valuable information on how the industry is evolving. It reflects the rising perception of its use in more detailed visualization and decision-making within sectors. Better project productivity enhanced spatial perception, and training in immersion are the main impulses of AR/VR use, justifying enhanced utility of the technology in the modern working scenario.

The Analysis from the online questionnaire are as follows.

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*

Figure 2: Classification According to Experience

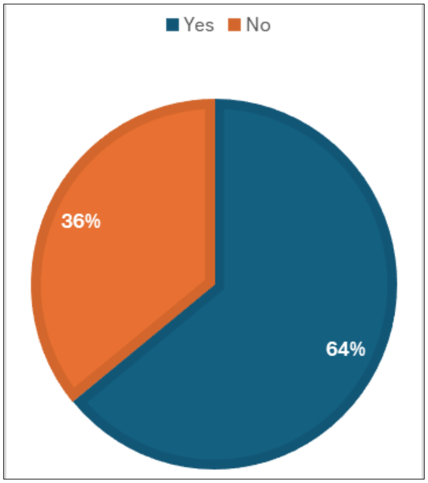
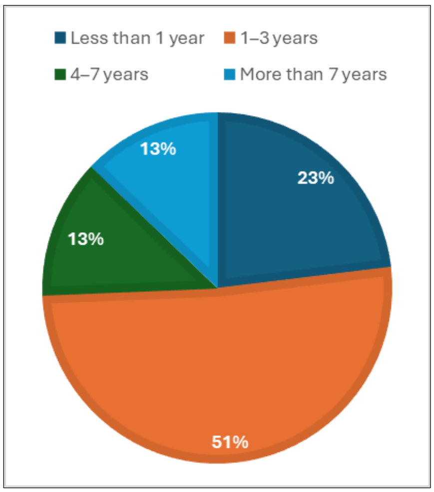


Figure 3: Classification According to Usage



4.3 t test result

Table 1: t Test Result

Variable	t-value	df	p-value
Experience	14.417	38	<.001
Usage	19.923	38	<.001

DOI: 10.17492/JPI/NICMAR/2507024 ISBN: 978-93-49790-54-4

5.0 Results and Discussions

- Since $p < 0.001$ for experience and usage, the mean of these variables significantly differs from zero.
- Higher t-values (14.417 and 19.923) indicate greater deviation from zero and verifies participants are well versed and use AR/VR applications.
- Degrees of freedom ($df = 38$) indicate that 39 participants were analysed.

As per current Study:

- Verifies that AR/VR applications are used actively for visualization and decision-making.
- Is equipped with statistical evidence supporting participants having meaningful interaction with AR/VR.
- Justifies continuing research in understanding how AR/VR affects cognitive processes and decision efficiency.

Figure 4: t Test Result

One Sample T-Test

	t	df	p
Experience	14.417	38	< .001
Usage	19.923	38	< .001

Note. For the Student t-test, the alternative hypothesis specifies that the mean is different from 0.

Note. Student's t-test.

5.1 Q-Q plots interpretation (normality check)

Q-Q plots are used to determine if residuals (errors) are normally distributed. Points should align along the red diagonal line.

5.1.1 Experience Q-Q plot

- There is a general tendency of most of the residuals to follow the red line apart from in extreme regions (outliers). Q-Q plots are used to determine if residuals (errors) are normally distributed. Points should align along the red diagonal line.
- It points towards moderate normality, but some deviations exist.

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*

Figure 5: Q-Q Plots of Experience

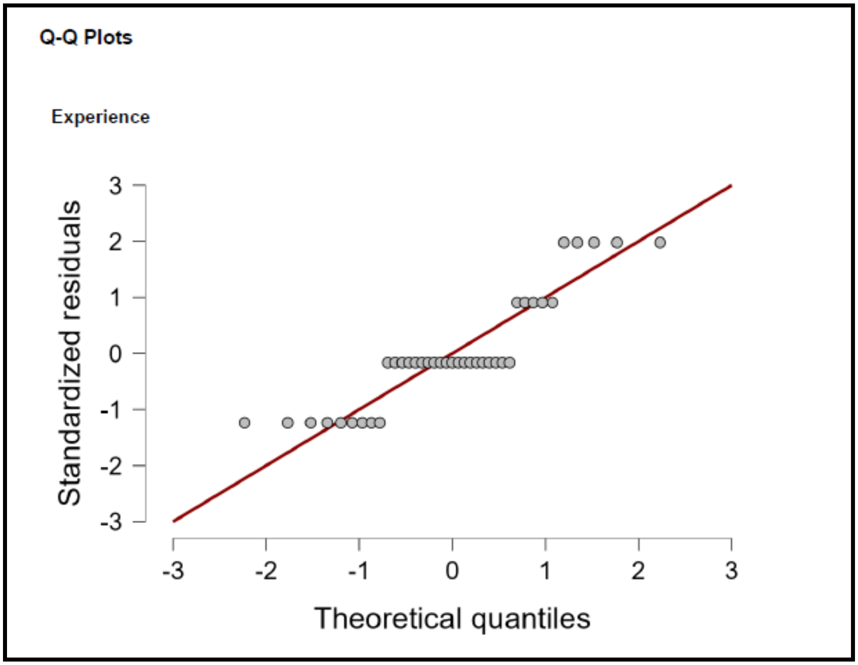
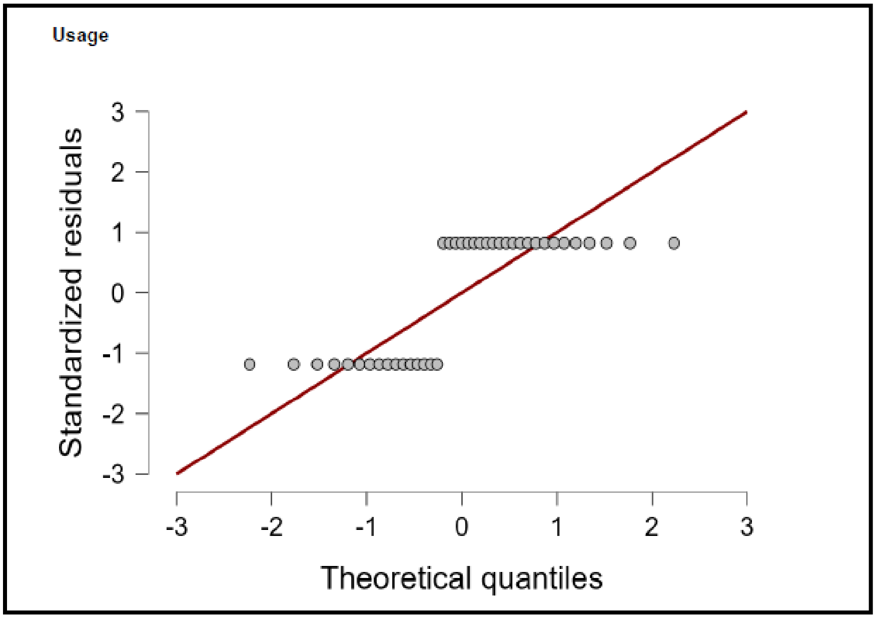


Figure 6: Q-Q Plots of Usage



DOI: 10.17492/JPI/NICMAR/2507024 ISBN: 978-93-49790-54-4

5.1.2 Usage Q-Q plot

- Same pattern—data clings to the line but with variation at extremes.
- Suggesting almost normal distribution, though it is slightly skewed.

5.2 Relevance to our current study

- Since normality is approximately met, parametric tests (ANOVA, regression) are applicable for examining AR/VR effect.
- The slight deviations suggest that a few users of outstandingly high or low experience exist, and they might be investigated in a qualitative follow-up study.
- This supports the use of predictive modelling to examine the effect of AR/VR use on decision-making.

5.3 Result

The research tested the effect of Augmented Reality (AR) and Virtual Reality (VR) apps on improved visualization and decision-making. One-sample t-test was used to check if participants' experience and use of AR/VR apps were significantly different from zero. The findings were as below:

- Experience: $t\ (38) = 14.417$, $p<0.001$
- Usage: $t\ (38) = 19.923$, $p<0.001$

Both p-values were extremely significant, which shows that participants do use and have experience with AR/VR applications. The high t-values suggest high levels of evidence that AR/VR applications are widely used and provide high levels of engagement for users. In addition, Q-Q plots were examined to assess residual normality. It was noted that points were mostly consistent with the normality line but slightly diverged at extremes, reflecting little skewness but generally moderate normality. This opens a door for additional parametric testing, e.g., regression or ANOVA, to ascertain how AR/VR apps enhance cognitive ability and decision-making.

6.0 Conclusion

The findings validate that AR/VR applications are utilized for visualization and decision-making in active forms. The high t-test values support the hypothesis that AR/VR technologies play a crucial role in enabling users' ability to dissect intricate information and make sound decisions. Although usage and experience levels are high, more research is required to identify how particular AR/VR features (e.g., interaction level, 3D visualization, real-time data integration) help to achieve better decision-making outcomes. Additionally, the minimal departures from normality in Q-Q plots indicate that although AR/VR applications are, in general, advantageous, user experience is variable based on familiarity, training, or application type. Future research must investigate the variations to maximize AR/VR use in decision-making contexts.

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*

References

Aguilar, K. N., Smith, M. L., Payne, S. C., Zhao, H., & Benden, M. (2024). Digital human ergonomics training for remote office workers: Comparing a novel method to a traditional online format. *Applied Ergonomics, 117*, 104239.

Akcayir, M., & Akcayir, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20*, 1–11.

Asadi, K., Han, K., Lobaton, E., & Wu, T. (2018). Vision-based integrated mobile robotic system for real-time applications in construction. *Automation in Construction, 96*, 470–482.

Balali, V., Noghabaei, M., Heydarian, A., & Han, K. (2018). Improved stakeholder communication and visualizations: Real-time interaction and cost estimation within immersive virtual environments. In *Construction Research Congress 2018* (pp. 217–226).

Beh, H. J., Rashidi, A., Talei, A., & Lee, Y. S. (2022). Developing engineering students' capabilities through game-based virtual reality technology for building utility inspection. *Engineering, Construction and Architectural Management, 29*(7), 2854–2877.

Danylec, A., Shahabadkar, K., Dia, H., & Kulkarni, A. (2022). Cognitive implementation of metaverse embedded learning and training framework for drivers in rolling stock. *Machines, 10*(10), 926.

Dascal, J., Reid, M., IsHak, W. W., Spiegel, B., Recacho, J., Rosen, B., & Danovitch, I. (2017). Virtual reality and medical inpatients: A systematic review of randomized, controlled trials. *Innovations in Clinical Neuroscience, 14*(1–2), 14–21.

Du, J., Shi, Y., Zou, Z., & Zhao, D. (2018). CoVR: Cloud-based multiuser virtual reality headset system for project communication of remote users. *Journal of Construction Engineering and Management, 144*(4).

Eiris, R., Gheisari, M., & Esmaeili, B. (2018). PARS: Using augmented 360-degree panoramas of reality for construction safety training. *International Journal of Environmental Research and Public Health, 15*(11), 2452.

Ergan, S., Radwan, A., Zou, Z., Tseng, H., & Han, X. (2019). Quantifying human experience in architectural spaces with integrated virtual reality and body sensor networks. *Journal of Computing in Civil Engineering, 33*(3), 04019013.

Goulding, J., Nadim, W., Petridis, P., & Alshawi, M. (2012). Construction industry offsite production: A virtual reality interactive training environment prototype. *Advanced Engineering Informatics, 26*(1), 103–116.

Jeelani, I., Han, K., & Albert, A. (2017). Development of immersive personalized training environment for construction workers. In *Proceedings of the ASCE International Workshop on Computing in Civil Engineering* (pp. 398–405).

Le, Q. T., Pedro, A., & Park, C. S. (2015). A social virtual reality-based construction safety education system for experiential learning. *Journal of Intelligent & Robotic Systems, 79*(3–4), 487–506.

Li, R. Y. M. (2018). Virtual reality and construction safety. In *An economic analysis on automated construction safety* (pp. 117–136). Springer.

Mosadeghi, S., Reid, M. W., Martinez, B., Rosen, B. T., & Spiegel, B. M. R. (2016). Feasibility of an immersive virtual reality intervention for hospitalized patients: An observational cohort study. *JMIR Mental Health, 3*(2), e28.

Nikolic, D., Jaruhar, S., & Messner, J. I. (2009). An educational simulation in construction: The virtual construction simulator. *Journal of Computing in Civil Engineering, 25*(6), 633–642.

Noghabaei, M., Heydarian, A., Balali, V., & Han, K. (2020). Trend analysis on adoption of virtual and augmented reality in the architecture, engineering, and construction industry. *Data, 5*(1), 26.

Pelargos, P. E., Nagasawa, D. T., Lagman, C., Tenn, S., Demos, J. V., Lee, S. J., Bui, T. T., Barnette, N. E., Bhatt, N. S., & Ung, N. (2017). Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery. *Journal of Clinical Neuroscience, 35*, 1–4.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrovic, V. M., & Jovanovic, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education, 95*, 309–327.

Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics, 31*(9), 1005–1017.

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*

Tashjian, V. C., Mosadeghi, S., Howard, A. R., Lopez, M., Dupuy, T., Reid, M., Martinez, B., Ahmed, S., Dailey, F., Robbins, K., & Spiegel, B. (2017). Virtual reality for management of pain in hospitalized patients: Results of a controlled trial. *JMIR Mental Health, 4*(1), e9.

Wei, X., Weng, D., Liu, Y., & Wang, Y. (2015). Teaching based on augmented reality for a technical creative design course. *Computers & Education, 81*, 221–234.

Williams, G., Gheisari, M., Chen, P.-J., & Irizarry, J. (2015). BIM2MAR: An efficient BIM translation to mobile augmented reality applications. *Journal of Management in Engineering, 31*(6).

Zheng, Z., Ma, A., Zhang, L., & Zhong, Y. (2021). Deep multisensor learning for missing-modality all-weather mapping. *ISPRS Journal of Photogrammetry and Remote Sensing, 174*, 254–264.

DOI: 10.17492/JPI/NICMAR/2507024 *ISBN: 978-93-49790-54-4*