THE PROCESS OF APPLYING AR/VR/MR IN DESIGN IMPLEMENTATION IN CONSTRUCTION PROJECTS

Nam Phuong Nguyen[1], Tuan Sy Ho[1], Sy Tien Do[2,3]

1) Engineer, Portcoast Consultant Corporation, Ho Chi Minh City, Vietnam. Master's Student in Hanoi University of Civil Engineering. Email: nam.np@portcoast.com.vn; tuan.hs@portcoast.com.vn
2) PhD, Assoc. Prof., Department of Construction Engineering and Management, Faculty of Civil Engineering, Ho Chi Minh City University of Technology (HCMUT), Ho Chi Minh City, Vietnam. Email: sy.dotien@hcmut.edu.vn
3) Vietnam National University Ho Chi Minh City, Ho Chi Minh City, Vietnam

Abstract: Despite the prospective advantages of using virtual reality (VR), augmented reality (AR), and mixed reality (MR) in the construction industry, there are still obstacles that must be overcome, including high initial investment costs, equipment and application synchronization, and staff training. The purpose of this research was to establish a method for utilizing VR/AR/MR in the implementation of design in construction projects. This study employs design software and VR/AR/MR applications to generate 3D models, identify and resolve errors and problems, generate a virtual tour, and optimize 3D models. The primary outcome is a procedure for applying VR/AR/MR to design implementation that specifies personnel requirements and construction project implementation processes. This research will contribute to the development of best practices for implementing VR/AR/MR in the construction industry, thereby enhancing construction processes and project management.

Keywords: AR (Augmented Reality), VR (Virtual Reality), MR (Mixed Reality), Design phase, Interaction, Feasibility evaluation.

1. INTRODUCTION

The accelerated development of Virtual Reality, Augmented Reality, and Mixed Reality (VR/AR/MR) technologies is transforming the construction industry. They are revolutionizing the conceptualization, presentation, and execution of designs, thereby augmenting the efficiency and effectiveness of project management and construction processes.

One of the key advantages of VR/AR/MR is that it allows architects, engineers, and builders to visualize and test their designs in a virtual environment. This enables them to identify and correct design defects and construction issues early on, reducing the need for costly and time-consuming modifications later on. It also enables stakeholders to experience the design in a more immersive and interactive manner, thereby enhancing communication and collaboration.

Despite the prospective benefits, utilizing VR/AR/MR in the construction industry still presents obstacles. The cost of apparatus and software which can be substantial, is one of the primary obstacles (Gu el at 2021). In addition, high-quality 3D models are required, and synchronization between devices and applications can be difficult (Wang et al., 2020). Furthermore, training and skill development are required for effective use of this technology (Cao et al., 2020).

To surmount these obstacles, construction companies must invest in research and development, as well as their employees' training and education. By doing so, they can realize the full potential of VR/AR/MR and obtain an industry advantage.

Figure 1. Applying technology in construction (Portcoast Consultant Corporation)

In conclusion, VR/AR/MR technologies are revolutionizing the construction industry, offering significant benefits. By utilizing these technologies to enhance design, communication, safety, and training, construction companies can boost efficiency, cut costs, and deliver improved client service (Figure 1). To stay competitive, it is crucial for the industry to stay informed about new advancements and embrace them. This article aims to investigate and assess the potential and effectiveness of AR/VR/MR technologies in construction project design and implementation. The study will specifically examine the applications of AR/VR/MR in streamlining the design process, minimizing errors, improving efficiency, and reducing costs in project management and construction operations.

2. LITERATURE REVIEW

BIM and AR/VR/MR technologies are promising trends in the construction industry, offering significant benefits in design improvement and collaboration among stakeholders. BIM enables the creation of detailed virtual models, enhancing design quality, reducing errors, and improving communication (Huang et al., 2019). AR/VR/MR applications in construction enhance collaboration, communication, safety, and training, though challenges like cost and skill shortages exist (Shen et al., 2021; Gu et al., 2021).

Despite the challenges, the benefits of using BIM and AR/VR/MR technologies in the construction industry are significant, and they have the potential to transform the industry's processes and outcomes. As such, it is crucial for industry stakeholders to continue exploring and adopting these technologies to improve the construction industry's overall performance.

Table 1. Research around the world using Bim in the design and application AR/ VR /MR technology

No.	Title	References	Problem Statement	Objectives	Research Methodology	Results
1	Augmented Reality for Maintenance and Inspection in Civil Engineering: A Systematic Review [1]	Liu el at.,2022	The limited understanding of the potential applications and benefits of AR in maintenance and inspection tasks in civil engineering	To identify the potential applications of AR in maintenance and inspection tasks in civil engineering and to evaluate the benefits of AR in improving these tasks	Systematic literature review	AR can improve the accuracy and efficiency of maintenance and inspection tasks, reduce downtime and maintenance costs, and provide a more intuitive and interactive user interface for inspection software
2	Mixed Reality for Building Information Modeling: A Review [2]	Park el at.,2021	The lack of research on the application of MR in building information modeling (BIM)	To identify the potential applications of MR in BIM and to evaluate the benefits of MR in improving BIM processes	Systematic literature review	MR can improve the visualization and interaction of BIM models, increase collaboration and coordination among stakeholders, and provide a more intuitive user interface for BIM software
3	Virtual Reality Training for Construction Safety: A Review of the Literature [3]	Huang el at.,2021	The need for more effective and engaging training methods for construction safety	To evaluate the effectiveness of VR training for construction safety and to identify the factors that contribute to the success of VR training programs	Systematic literature review	VR training can improve the engagement and retention of safety training, increase worker awareness and preparedness for hazardous situations, and reduce the risk of on-site accidents and injuries
4	Augmented reality, virtual reality, and mixed reality in construction: A systematic review [4]	Shen el at.,2021	To assess the use of AR, VR, and MR in construction	To identify the benefits, challenges, and future directions of AR, VR, and MR in construction	Systematic literature review	Identified the benefits, challenges, and future directions of AR, VR, and MR in construction

No.	Title	References	Problem Statement	Objectives	Research Methodology	Results
5	The Application of Virtual Reality in the Construction Industry [5]	Gu el at.,2021	To assess the use of VR in the construction industry	To identify the applications, benefits, and challenges of VR in the construction industry	Literature review	Identified the applications, benefits, and challenges of VR in the construction industry
6	BIM-based sustainability analysis in building design: A systematic literature review [6]	Wang el at.,2020	The lack of systematic literature review of BIM-based sustainability analysis in building design	To conduct a systematic literature review of BIM-based sustainability analysis in building design	Systematic literature review	Identified the current state of BIM-based sustainability analysis in building design and highlighted the gaps in the existing research
7	Design and Implementation of VR/AR/MR-Based Education System [7]	Cao el at.,2020	To design and implement a VR/AR/MR-based education system	- To design a VR/AR/MR-based education system - To implement the education system using Unity 3D and Vuforia SDK - To evaluate the usability and effectiveness of the education system	Design and implementation study	- The VR/AR/MR-based education system was successfully designed and implemented - The education system can provide immersive and interactive learning experiences - The education system can improve students' learning motivation and performance
8	Application of augmented reality for simulating 3D model from point cloud and photogrammetry – A study case of construction site inspection[8]	Thu el at.,2020	The limitations of traditional methods in construction site inspection	To evaluate the effectiveness of AR in simulating 3D models for construction site inspection	Case study	AR was found to be an effective tool for simulating 3D models and improving efficiency in construction site inspection
9	Integrating point cloud from 3D Laser scanning and Unmanned Aerial Vehicle (UAV) equipment in order to collect construction [9]	Sy el at.,2019	The need for improved efficiency and accuracy in data collection in construction	To integrate point cloud from 3D Laser scanning and UAV equipment for improved data collection in construction	Case study	The integration of point cloud from 3D Laser scanning and UAV equipment was found to improve efficiency and accuracy in data collection in construction
10	A systematic review of building information modeling (BIM) in the construction industry: Current status, challenges, and future directions[10]	Huang el at.,2019	To assess the current status, challenges, and future directions of BIM in the construction industry	To identify the current status, challenges, and future directions of BIM in the construction industry	Systematic literature review	Identified the current status, challenges, and future directions of BIM in the construction industry

In conclusion, using BIM in the design and VR/AR/MR applications in construction design provides significant benefits in enhancing collaboration, reducing errors, improving safety, and minimizing environmental impact. While there may be initial investment costs and technical requirements, the long-term benefits make it a valuable tool for construction companies looking to improve their processes and stay competitive in the industry.

3. RESEARCH METHODOLOGY

The application of 3D modeling and AR/VR/MR technology in construction projects has revolutionized the industry by providing enhanced visualization and interactivity, streamlining communication and decision-making processes, and minimizing errors and costs. With 3D models, stakeholders can better understand the

project design and identify potential issues before construction begins. Moreover, AR/VR/MR technology allows for immersive experiences that enhance user engagement and understanding. This technology has the potential to greatly improve the efficiency and effectiveness of construction projects, ultimately leading to better outcomes for all parties involved.

Application implementation process

The process to deploy this application, stakeholders will follow several steps (Figure 2) such as:

Step 1: Collecting information about the project, including architectural, structural, and MEP (Mechanical, Electrical, and Plumbing)

Step 2: Using design software and AR/VR/MR technologies to create a 3D model of the project

Step 3: Checking and evaluating the 3D model to detect and address errors and issues

Step 4: Enhancing user interaction with the 3D model by creating diverse interactive experiences, such as creating a virtual tour of the construction space.

Step 5: Optimization and tuning the 3D model on various AR/VR/MR devices

Step 6: Using the 3D model to make decisions and solve problems during the construction process

4. RESULTS AND DISCUSSION

4.1 Results

In recent years, the adoption of AR/VR/MR technologies in the design phase of construction projects has brought significant benefits to the industry. By leveraging the power of virtual environments, architects, engineers, and builders are able to visualize and test their designs in a more intuitive and immersive manner, leading to improved work efficiency. As a result, potential design defects and construction issues can be identified and addressed early on, saving both time and costs that would have otherwise been spent on modifications during the construction phase.

Furthermore, the collaborative nature of these technologies enables project stakeholders to communicate and make decisions more effectively, leading to faster project progress. For example, by using virtual reality (VR) technology, stakeholders can experience a 3D model of a building before it's constructed and make informed decisions based on their virtual experience. The use of augmented reality (AR) can also help workers on construction sites visualize where to place components or identify potential hazards, improving safety and reducing the risk of errors.

These benefits are exemplified in Figure 2 and Figure 8, which shows a virtual model of a construction project being viewed and modified by architects, engineers, and builders. Through the use of AR/VR/MR technologies, the team is able to collaborate more effectively, address design issues early on, and ultimately deliver a higher quality project.

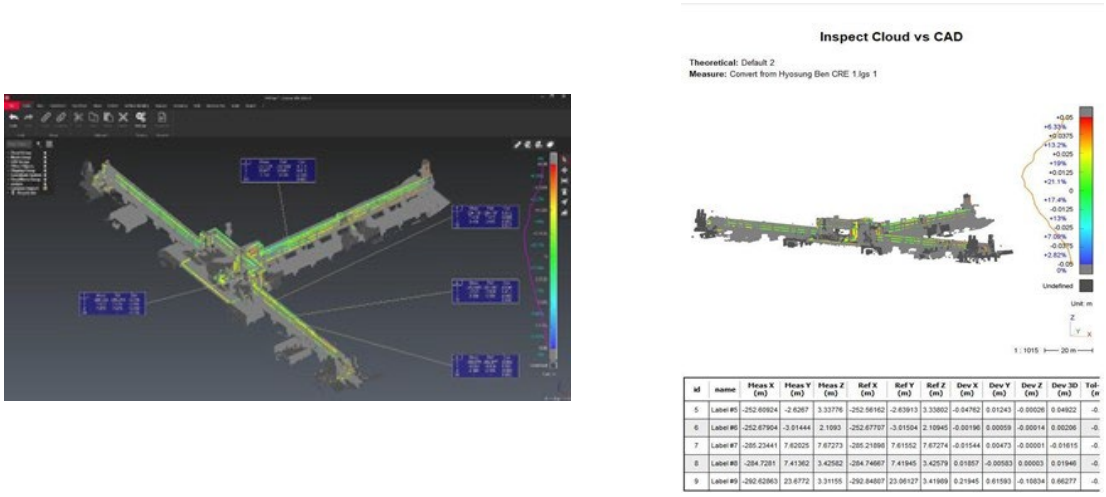

Figure 2. Checking and evaluating the 3D model

The adoption of AR/VR/MR technologies in the construction industry has enabled the creation of virtual tours that offer a more immersive and interactive experience than traditional 2D renderings or physical models. As a result, stakeholders are able to better visualize and understand the project design, leading to more informed decision-making.

One notable example of the benefits of virtual tours can be seen in Figure 3, where a virtual tour of a building design is being conducted. Through the use of AR/VR/MR technologies, the tour provides a realistic and engaging experience for users, allowing them to explore the building design in detail and gain a deeper understanding of its layout and features.

In addition to being engaging, user feedback from virtual tours has been overwhelmingly positive. Many individuals have reported that the immersive experience provided by AR/VR/MR technologies is not only enjoyable but also informative. This feedback highlights the potential of virtual tours to improve communication and collaboration among project stakeholders, ultimately leading to higher quality construction projects that better meet the needs of users.

Figure 3. The owner's experience when visiting their construction site through VR.

The adoption of AR/VR/MR technologies in the construction industry requires an investment in both equipment and skills, but the long-term benefits are significant. Figure 4 illustrates the use of laser scanning equipment, which can create 3D models of a construction site. This technology can help to identify potential issues in the early stages of the project, allowing for prompt and cost-effective resolution.

In addition to cost savings, the use of AR/VR/MR technologies can also lead to faster decision-making and project progress, thanks to improved communication and collaboration between stakeholders. By leveraging these technologies, project teams can work together more effectively, regardless of their physical location.

While the initial investment in AR/VR/MR technologies may be substantial, the decreasing cost of equipment and software is expected to make it more accessible and cost-effective for construction companies in the future. In fact, training employees to use laser scanning equipment and other AR/VR/MR tools is becoming increasingly common, reflecting the growing recognition of the benefits of these technologies.

Figure 4. Training employees to use laser scanning equipment

4.2 Discussion

The application of 3D and AR/VR/MR technology in construction design and project management brings many benefits to contractors, investors, and other stakeholders. By using interactive 3D models, users can experience a more realistic and comprehensive understanding of the project design and details, which helps to minimize errors during the construction process. Moreover, AR/VR/MR applications allow users to interact with 3D models and view details that are difficult to discern in reality. In addition, the use of this technology improves work efficiency and reduces costs for all parties involved in the design and construction processes. The application of 3D and AR/VR/MR technology in construction projects is an unstoppable trend and will continue to be developed in the future.

This application also has the potential to reduce costs and time in the design and construction process, while minimizing errors and risks during implementation.

To effectively employ this technology, however, designers and project managers will require investments in in equipment and skills. Additionally, the accuracy and reliability of the 3D model must be ensured in order to make the correct design and construction decisions.

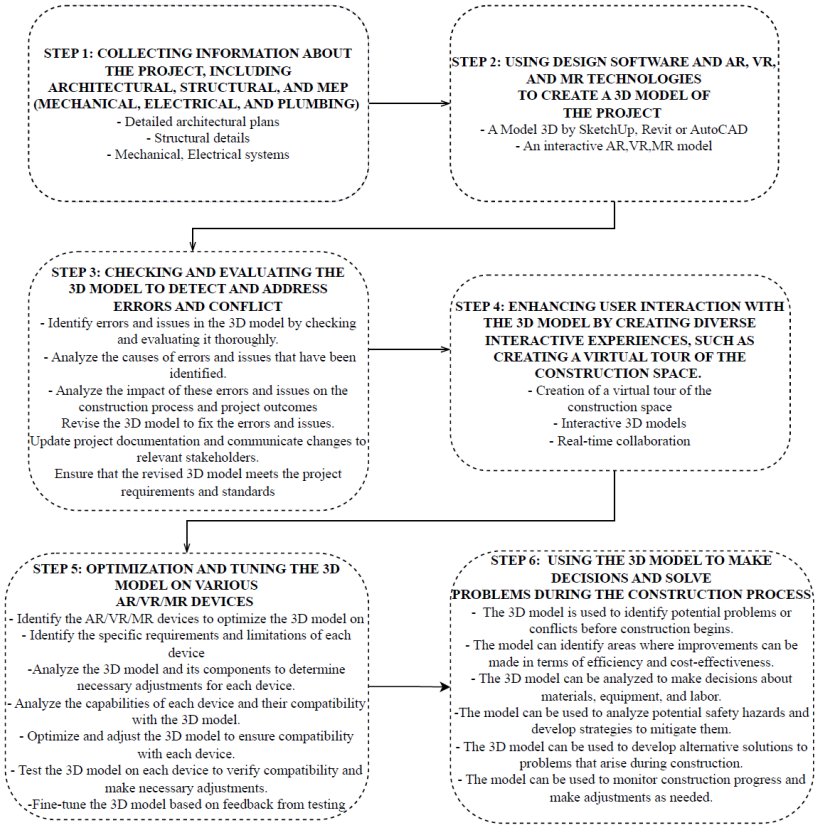

Figure 5. Research process for applying AR/VR/MR in desing implementation

The following is a detailed step-by-step im plementation to apply in the design phase.

Step 1: Collecting information about the project, including architecture, structural, and MEP (Mechanical, Electrical, and Plumbing) (Figure 6)

In the first step of the process, the researchers gathered information about the construction project, including its purpose, area, architecture, and structure. This involved collecting data and documents related to the project, such as drawings, blueprints, specifications, and site plans. The goal was to obtain a comprehensive understanding of the project's requirements, constraints, and objectives, and to identify any potential issues or challenges that might arise during the construction process.

To collect this information, the researchers employed various research methods, such as surveys, interviews, or site visits. They may have also used computer-aided design (CAD) software to analyze and visualize the project's architectural and structural features. This step was crucial in laying the foundation for the subsequent stages of the process, as it provided the necessary input data for creating the 3D model and evaluating its performance.

Unmanned Aerial Vehicle (UAV)

3D Laser Scanning equipments

Figure 6. Collecting the basis information for construction design

Step 2: Using design software and AR/VR/MR technologies to create a 3D model of the project (Figure 7)

After gathering sufficient project information, the next crucial step in implementing AR/VR/MR in the construction industry is creating a 3D model of the construction project. This comprehensive model incorporates various elements such as architecture, structure, electrical and water systems, and landscape. However, creating a detailed 3D model can be challenging, considering factors like precision, time, cost, and designer expertise. Fortunately, AR/VR/MR technology has simplified this process. Modern design tools like SketchUp, Revit, and AutoCAD enable engineers and designers to rapidly create accurate and comprehensive 3D models.

Once the 3D model is ready, it serves multiple purposes in construction. Virtual walk-throughs provide immersive and interactive experiences for stakeholders. It also facilitates problem identification and modifications before construction commences, minimizing errors and delays. Additionally, the 3D model enhances communication and collaboration by providing a clear, shareable depiction of the project.

Figure 7. Creating 3D Model

Step 3: Checking and evaluating the 3D model to detect and address errors and conflict (Figure 2)

Once the 3D model has been created and visualized using AR/VR/MR technology, the next critical step is to conduct a thorough inspection and evaluation to identify any errors or issues. This stage is vital in ensuring the accuracy and compliance of the final product.

Various tools and methods are available for examining and evaluating the 3D model. Commonly, software is used to analyze the model, identifying errors related to size, shape, structural integrity, and other factors that may impact functionality or safety.

During the review and evaluation process, it is crucial to ensure that the 3D model can be effectively utilized as intended. For instance, if it is designed for architectural purposes, it must accurately depict the building's construction and be compatible with the software commonly used by architects and engineers. Similarly, if it is intended for virtual or augmented reality applications, optimization for the appropriate hardware and software platforms is essential.

Overall, the review and evaluation of the 3D model are critical stages in the AR/VR/MR construction design process. By ensuring accuracy, error-free representation, and compatibility with its intended use, high-quality designs can be created that meet project requirements and serve as valuable resources for architects, engineers, and other construction professionals.

Step 4: Enhancing user interaction with the 3D model by creating diverse interactive experiences, such as creating a virtual tour of the construction space (Figure 8)

After creating and refining the 3D model, the next step is to incorporate interactive features to enhance the user's experience. One way to achieve this is by creating a virtual tour of the construction site, using virtual reality (VR) technology to enable users to explore the virtual space and interact with various aspects of the construction design.

For example, in a commercial building project, users can take a virtual tour of the foyer and examine the various design elements such as layout, furniture, and decor. They can also interact with virtual elements like doors, elevators, and lighting to see how they function in the space.

Another method to improve the user experience is by creating interactive simulations. In a residential construction project, for instance, users can interact with a kitchen simulation to visualize how various appliances and materials will appear and function in the space. They can experiment with different layouts and designs to find the optimal solution for their needs.

By providing these interactive experiences, users can better understand and interact with the building's design, enabling them to make better decisions and achieve a better outcome.

Figure 8. Interacting with the model in real space

Step 5: Optimizing and Fine-tuning the 3D Model for Different AR/VR/MR Devices (Figure 9)

After creating and enhancing the 3D model with interactive features, it is crucial to optimize and fine-tune it for various AR/VR/MR devices. This involves adjusting the resolution, frame rate, and other settings to ensure the model runs smoothly and looks good on different devices.

As different AR/VR/MR devices have varying technical specifications and capabilities, it is important to optimize the 3D model for each device to ensure the best user experience. A 3D model that looks fantastic on a high-end VR headset may not perform well on a lower-end AR app for a smartphone.

Optimizing the 3D model may also involve modifying the user interface and interactions to ensure they are intuitive and easy to use on each device.

Overall, optimizing and fine-tuning the 3D model for various AR/VR/MR devices is a crucial stage in ensuring the success of the project as it can significantly impact the user experience and engagement.

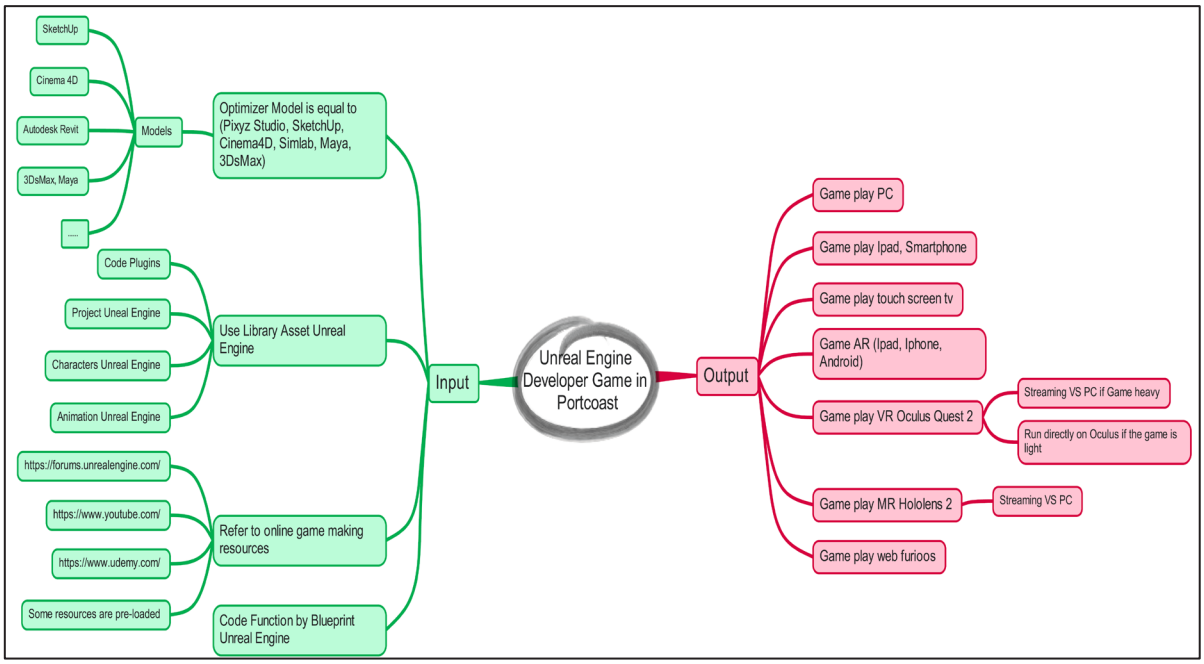

Figure 9. Optimizing process on AR, VR,MR devices projects

Step 6: Using the 3D model to make decisions and solve problems during the construction process (Figure 10)

The 3D model created through AR/VR/MR technology serves as a valuable asset throughout the construction process, aiding decision-making and problem-solving.

Before construction begins, the 3D model enables early detection and resolution of potential issues. By visualizing the project in 3D, conflicts or discrepancies between different building components can be easily identified, thus preventing costly construction errors.

During construction, the 3D model facilitates coordination among teams and subcontractors. For instance, the electrical team can visualize the installation of electrical components and ensure accurate placement. Similarly, the plumbing team can examine the interconnections of plumbing components and ensure proper installation.

Furthermore, the 3D model allows for real-time monitoring of construction progress. By overlaying the model onto the construction site, areas falling behind schedule can be pinpointed, and the overall progress can be assessed.

Figure 10. Illustration of applying virtual reality technology in desgin

Using the 3D model during construction can ultimately speed up the process and reduce the likelihood of errors. It can help ensure that the project is completed on time, within budget, and to everyone's satisfaction.

5. CONCLUSIONS

The use of 3D technology and AR/VR/MR in the design and management of construction projects offers numerous benefits to contractors, developers, and other stakeholders. By utilizing an interactive 3D model, users can gain a more authentic and comprehensive understanding of the project's design and details, which can help to minimize errors during the construction process. Moreover, the use of AR/VR/MR technology allows users to interact with the 3D model and view difficult-to-see details in the real-world environment. In addition, this technology can increase work efficiency and save costs for all parties involved in the design and construction process. In summary, the application of 3D and AR/VR/MR technology in construction projects is an unstoppable trend that will continue to be developed in the future.

The popularity of using AR/VR/MR technology in the construction industry is increasing rapidly, enhancing the interactivity and visuality of the 3D model while improving the ability to evaluate and manage construction projects. This application also has the potential to reduce costs and time in the design and construction process while minimizing errors and risks during implementation.

However, to effectively apply this technology, it is necessary to invest in equipment and training for designers and project managers. Additionally, ensuring the accuracy and reliability of the 3D model is essential to make the right decisions during the design and construction process.

ACKNOWLEDGEMENTS

We would like to acknowledge Portcoast Consultant Corporation for their support and for providing the data used in this study.

We acknowledge Hanoi University of Civil Engineering (HUCE) for supporting this study.

We acknowledge Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for supporting this study.

REFERENCES

Cao, D., Yang, J., Zhang, Y., & Ding, Y. (2020). Design and Implementation of VR/AR/MR-Based Education System. *In Advances in Computer Science and Education Applications.*

Gu, H., Guo, Y., & Zhou, Y. (2021). The Application of Virtual Reality in the Construction Industry. *In 3rd International Conference on Communication and Information Processing*.

Huang, Y., Gu, N., & Wu, D. (2021). *Virtual Reality Training for Construction Safety: A Review of the Literature. Automation in Construction.*

Huang, T., Ren, Z., Shi, Y., Liu, S., & Wang, X. (2019). *A systematic review of building information modeling (BIM) in the construction industry: Current status, challenges, and future directions. Sustainability*.

Liu, Y., Huang, Y., Zhang, H., & Qiu, Z. (2022). Augmented Reality for Maintenance and Inspection in Civil Engineering: A Systematic Review. *Automation in Construction.*

Park, K., & Lee, G. (2021). Mixed Reality for Building Information Modeling: A Review. *Automation in Construction.*

Shen, W., Liu, Y., Zheng, X., & Qiu, H. (2021). Augmented reality, virtual reality, and mixed reality in construction: A systematic review. *Automation in Construction*.

Sy, T. D., Thu, A. N., Hiep, H., Loan, T. V., Phuoc, N. T. L., Truong, V. V., Vi, N. T. N., Quang, M. D., An, T. T. P. (2019). Integrating point cloud from 3D Laser scanning and Unmanned Aerial Vehicle (UAV) equipments in order to collect construction project information modeling. *Vietnam Journal of Construction.*

Thu, A. N., Sy, T. D., Hiep, H., Khanh, D. T. N., Dai, H. N., Dat, H. Q. C., Hai, P. H. *(2020).* Application of augmented reality for simulating 3D model from point cloud and photogrammetry – A study case of construction site inspection. *Vietnam Journal of Construction.*

Wang, C., Li, Y., Li, Y., & Li, Y. (2020). The application of virtual reality technology in architecture and construction industry. *In International Conference on Civil, Architecture and Sustainable Development*.