Empirical Evaluation of Immersive and Non-Immersive Virtual Reality Systems in Interior Design Applications

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***Abstract*—This paper conducts a comprehensive review of existing literature to examine the transformative effects of virtual reality (VR) technologies on the field of interior design. The investigation emphasizes the diverse applications of VR, particularly in addressing the challenges inherent in traditional design methodologies. Key themes explored include the creation of immersive design experiences, enhancements in collaborative efforts, and improvements in overall efficiency. Previous studies provide significant insights, highlighting user-centric design approaches, economic considerations, cultural influences, and detailed comparisons with conventional design methods. Despite these contributions, a notable gap persists regarding the identification of the most suitable VR technologies specifically for interior design applications. Through a critical analysis of the reviewed literature, this paper aims to delineate the areas that future research should prioritize to advance the integration of VR in interior design.**

Keywords: Virtual Reality, Interior Design, Immersive Design Experiences, Design Technology, Design Innovation.

1. INTRODUCTION

In the dynamic realm of interior design, the integration of virtual reality (VR) technology has emerged as a transformative force, reshaping traditional design methodologies and addressing critical challenges. Cao (2021) conducted an analysis focused on China's housing market, demonstrating how VR mitigates traditional design problems by reducing misunderstandings between designers and clients. The study emphasizes VR's capacity to offer immersive experiences, aiding clients in visualizing designs before implementation. These findings underscore the multifaceted role of VR in revolutionizing interior design, from enhancing spatial perception and collaboration (Kaleja, 2017) to addressing longstanding design challenges. As we navigate this exploration, it becomes evident that VR technology is poised to redefine the future landscape of interior design practice. Given the importance of VR in interior design, it is necessary to determine which type of VR—among immersive VR, non-immersive VR, and augmented reality (AR)—and the associated software are most effective for optimal results in the field of interior design.

2. VIRTUAL REALITY AND INTERIOR DESIGN

Virtual Reality (VR) refers to a computer-generated simulation of an environment that can be interacted with in a seemingly real or physical manner by an individual. Kaleja and Kozlovská (2017) define VR as a modern Information and Communication Technology (ICT) tool that transcends traditional design environments by providing interactive imagery creation. They emphasize that VR, particularly in the form of dynamic real-time visualization (DRTV), offers a novel approach to interior design practices, introducing new ideas and perspectives in the application of VR tools for interior design. There are generally three types of virtual reality: immersive VR, non-immersive VR, and augmented reality (AR). Phan and Choo (2010) define Augmented Reality (AR) as a technology that involves the overlay of computer graphics on the real world, allowing users to see and interact with virtual objects in a real-world setting.

Kaleja and Kozlovská (2017) define interior design as the process of designing the interior spaces of

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buildings, encompassing the selection of furniture, color schemes, and other decorative elements. Interior design is the art and science of enhancing the interior spaces of buildings to create aesthetically pleasing and functional environments. It involves a holistic approach to designing interiors, considering elements such as color, furniture, lighting, texture, type of material, and spatial arrangements.

3. LITERATURE REVIEW

Kaleja and Kozlovská (2017) explore the innovative application of VR technology in interior design, particularly through the development of dynamic real-time visualization (DRTV) tools. The authors highlight the potential of information and communication technologies (ICT) in revolutionizing interior design practices, offering realistic perceptions of design proposals and enabling interactive virtual environments. The study emphasizes the use of game engine technology (Unity 3D) for creating interactive 3D models of interior spaces, allowing users to experience dynamic and immersive virtual environments. Furthermore, the research discusses the integration of cost control and budgeting within the virtual design process, showcasing the practical implications of VR technology in interior design (Figures 1-4). The authors present a specific case study demonstrating the benefits of DRTV in interior design, including intuitive design processes, real-time visualization, and cost control. Overall, their research provides valuable insights into the potential of VR technology as an innovative approach to interior design, supported by modern ICT tools and hardware technologies.

In the research conducted by Cao (2021), the application of virtual reality in interior design is thoroughly examined. The author identifies numerous challenges in the current interior design process, such as misunderstandings between designers and customers, gaps between customers' expectations and designers' designs, and design similarities. Cao emphasizes the potential of virtual reality to address these issues by providing customers with an immersive experience of interior designs, enabling them to visualize the outcome of renovations beforehand. The research also highlights the dimensions of customer satisfaction in interior design and discusses related products and research in the field, including the development of virtual reality applications by companies like IKEA and the use of 3D scanners to create models for old furniture (Figures 5-7). Furthermore, the author underscores the importance of considering factors such as customer participation experience, budget effectiveness, and designer reputation in achieving satisfactory interior design. Cao concludes by suggesting the need for further research and development of real products to validate the proposed virtual reality implementation in interior design. The research contributes to the understanding of how virtual reality can enhance the interior design process and identifies areas for future exploration, such as haptics simulation and temperature simulation within virtual scenes.

Rahmat et al. (2019) propose a collaborative virtual reality (VR) application for interior design, facilitating real-time collaboration between designers and customers. The study underscores the limitations of traditional 2D design presentations and advocates for a more immersive and interactive platform. The proposed application's framework, developed using Unity 3D and Unity Networking HLAPI (Figures 8, 9), outlines essential processes such as displaying descriptions, editing, and task completion. This framework guides the flow of these processes and details the elements involved. The application employs supportive input devices, including hand gesture recognition devices, enabling customers to view and edit designs in real-time. The authors compare their proposed application with related research in collaborative VR, highlighting its unique contributions to the field of interior design. Overall, the research provides a comprehensive exploration of the challenges in traditional interior design processes and the potential benefits of integrating collaborative VR technology to enhance design experiences and outcomes.

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Figure 1: From 2D Floor plan to DRTV of case study project

Figure 3: Selection of 3D interior objects from database and manipulating with it

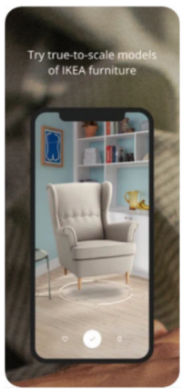


Figure 5. IKEA Place

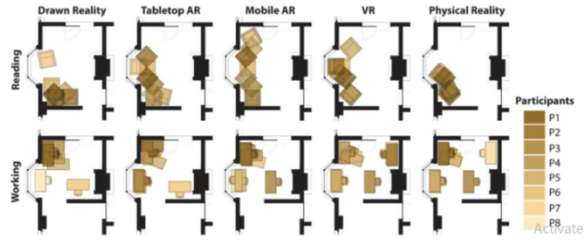
Figure 6. 3D Scanner

Figure 7. Picture Roomshift System

The detailed description of the proposed application's framework and architecture offers a clear understanding of the methodology employed to achieve these benefits. The application is positioned as a transformative tool with the potential to revolutionize the working style of interior designers, offering a more efficient and effective approach to design development and customer engagement.

Nguyen et al. (2022) investigate the use of simulated reality in the interior design process. The study recruited eight non-professional participants with no prior training in architectural design or exposure to simulated reality. Participants designed different interior layouts of an empty room using five simulated realities: Drawing Reality, Tabletop AR, Mobile AR, VR, and Physical Reality (Figure 10). The findings indicate that each simulated reality promotes or inhibits particular spatial qualities, leading to five design recommendations for more effective use of simulated reality in architectural design. The authors note that simulated reality can enhance spatial understanding, ease decision-making, and reduce misunderstandings. However, high-end technical requirements and the need for user training pose challenges to its practical adoption. The study highlights VR and AR for their realistic and interactive design experiences, with VR excelling in immersion and AR favored for cost-effectiveness. The research provides actionable insights for selecting the most appropriate simulated reality based on design goals and empowers non-professionals to actively participate in architectural design. Overall, the study contributes to the growing body of research on the use of simulated reality in architecture and design.

Figure 10
The five realities evaluated in this study. From left to right: P7 arranging the paper cut-out sofa in Drawing Reality; P2 viewing the scaled-down room in Tabletop AR; P8 observing his arrangement of the virtual desk next to the partition in Roomscale AR; P1 exploring the room in VR; and P3 arranging the lightweight chair and table in Physical Reality.



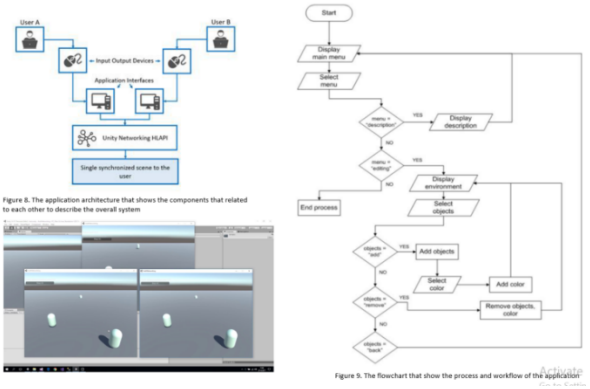


Figure 8. The application architecture that shows the components that related to each other to describe the overall system

Figure 9. The flowchart that show the process and workflow of the application

Xie and Chang (2021) explore the application of the assembling parts method based on virtual reality technology in interior design. The authors identify challenges arising from the intervention of virtual reality in the design process, particularly the contradiction between concrete perception and abstract order. To address this, the paper proposes the assembling parts method, citing its operability, repeatability, and strong logic as key advantages. The authors provide a detailed analysis of the characteristics of virtual reality technology, its application in interior design, and the reasons for the aforementioned contradiction. Two practical application cases demonstrate the feasibility and effectiveness of the assembling parts method in

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interior design. Overall, the research offers valuable insights into the use of virtual reality technology in interior design and provides a practical solution to the challenges encountered during implementation.

Phan and Choo (2010) explore the application of Augmented Reality (AR) technology for interior design, presenting a novel method for designing, educating, and presenting interior design projects. The study addresses the challenges of selecting furniture in interior design by proposing an AR system that allows users to visualize and interact with virtual furniture in a physical environment using a regular PC home system. This approach makes AR technology accessible to both professionals and amateurs. The methodology involves implementing an augmented reality system for interior design projects, using overlaid virtual furniture in a physical environment. Tracking markers define the scale and coordinate system of the room, enabling users to select and place virtual furniture in the design space. The system includes additional user interface functions and real-time interaction capabilities, allowing users to change the color, style, or covering of furniture in a real environment (Figures 11, 12). Overall, the article provides valuable insights into the application of AR technology in interior design, offering a dynamic and interactive platform for designing and visualizing interior spaces.

Figure 11. AR tracking& display process: the computer generated graphics are integrated into user's view.

Figure 12. Two-phase AR scene- user adjusts color of virtual furniture

participant completed design tasks in both VR and desktop environments (Figures 13, 14). The authors measured task completion time, design quality, and user satisfaction in both environments. The findings suggest that VR enhances the design experience by providing a more immersive and intuitive understanding of the dimension, size, and shape of the target object. However, the longer task completion time in VR poses a challenge for designers needing to work efficiently. The study's methodology, combining quantitative and qualitative data, provides insights into the participants' design experiences in both environments.

Janusz (2019) introduces Design3R, a revolutionary CAD system for interior design that seamlessly integrates augmented reality (AR) and virtual reality (VR). The paper emphasizes the use of HTC Vive and Google Tango, enabling real-time interaction with actual interior elements in their real size. The methodology employs Unity with C#, leveraging HTC Vive's quality and controllers for an advanced VR interface. The paper acknowledges hardware limitations and proposes solutions by adapting the interface for VR. Design3R's capabilities include recognizing and manipulating real interior spaces, changing material properties, and saving/loading projects. The forward-thinking approach includes transitioning to the ARCore platform, ensuring adaptability to evolving technologies. In summary, Janusz's paper provides valuable insights into the integration of AR and VR in interior design, showcasing the potential for widespread adoption and positioning Design3R as a significant advancement in shaping the future of interior architecture design.

Kim and Hyun (2022) explore the impact of virtual reality (VR) on the interior design process, addressing the challenges and benefits of using VR in design.

The studies collectively underscore the transformative potential of virtual reality (VR) and augmented reality (AR) in the field of interior design, aiming to address various challenges and enhance the overall design process. Common themes across the studies include the utilization of VR technologies to offer immersive and realistic design experiences, improve communication and collaboration among stakeholders, and increase overall efficiency in the design workflow.

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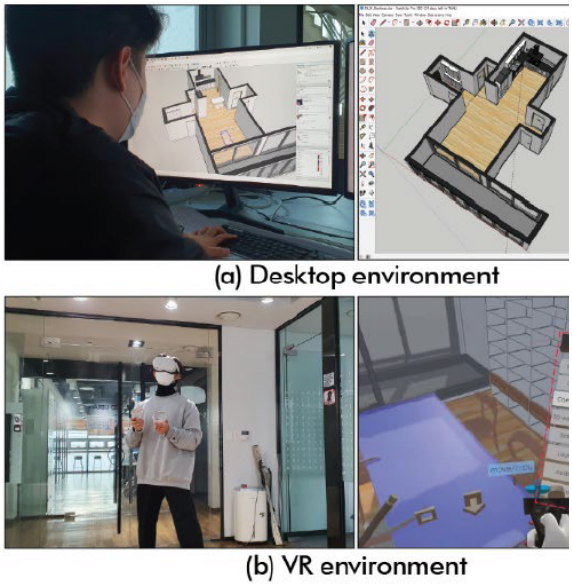

Figure 13. experimental settings

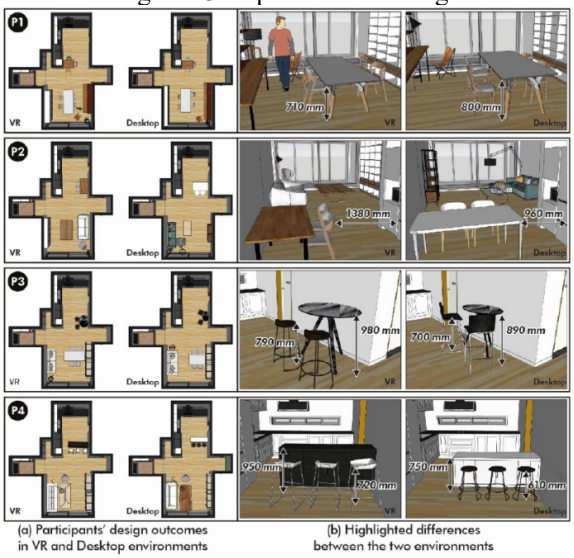

Figure 14. Design outcome from the experiment participants

Figure 15. Vive interface for furniture creation and manipulation

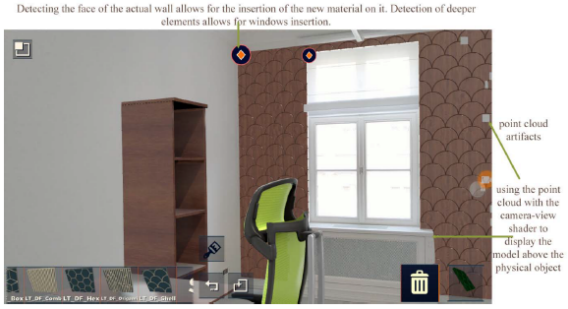

Figure 16. Change of the physical wall material and point clouds system for displaying real elements above virtual

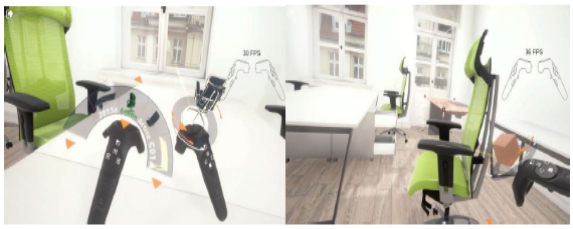

Figure 17. Design3R VR interface based on HTC Vive

4. RESULTS

However, a comparison of the selected studies reveals distinctive features and divergences across various criteria. Notably, studies such as Nguyen et al. (2022) and Rahmat et al. (2019) actively incorporate user involvement and gather feedback, showcasing a user-centric approach. In contrast, Xie and Chang (2021), while effectively addressing the contradiction between concrete perception and abstract order in VR-integrated interior design, may lack explicit user involvement. Cost considerations are thoroughly examined in Nguyen et al. (2022) and Kaleja and Kozlovská (2017), shedding light on the economic implications of their proposed solutions. Cultural considerations are explicitly addressed in studies like Cao (2021) and Rahmat et al. (2019), recognizing the impact of cultural factors on interior design practices and VR technology acceptance. Additionally, Kaleja and Kozlovská (2017) and Nguyen et al. (2022) stand out for their comprehensive comparison of VR tools with traditional methods, highlighting the advantages and limitations of virtual reality. One notable gap in the literature is the lack of comparison among different VR technologies. This area warrants further investigation to determine the most effective types of VR for specific applications in interior design.

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5. DISCUSSION

By conducting an analytical comparison of studies on virtual reality and augmented reality in interior design for previous studies, the following can be stated:

5.1. INNOVATIVE APPLICATION OF VR TECHNOLOGY

Kaleja and Kozlovská (2017) and Rahmat et al. (2019) both explore the innovative application of VR technology in interior design, highlighting the potential of information and communication technologies (ICT) to revolutionize design practices. Kaleja and Kozlovská focus on dynamic real-time visualization (DRTV) tools, emphasizing the use of game engine technology (Unity 3D) to create interactive 3D models of interior spaces. Their study integrates cost control and budgeting within the virtual design process, demonstrating practical implications and benefits such as intuitive design processes and real-time visualization. In contrast, Rahmat et al. propose a collaborative VR application that facilitates real-time collaboration between designers and customers. Their framework, developed using Unity 3D and Unity Networking HLAPI, outlines essential processes and employs supportive input devices like hand gesture recognition to enable real-time editing. Both studies underscore the limitations of traditional 2D design presentations and advocate for more immersive and interactive platforms.

5.2. USER INVOLVEMENT AND FEEDBACK

Nguyen et al. (2022) and Rahmat et al. (2019) actively incorporate user involvement and gather feedback, showcasing a user-centric approach. Nguyen et al. recruited non-professional participants to design interior layouts using various simulated realities, leading to design recommendations that enhance spatial understanding and decision-making. Rahmat et al.'s collaborative VR application allows customers to view and edit designs in real-time, highlighting the unique contributions of their work in the field of interior design. In contrast, Xie and Chang (2021), while effectively addressing the contradiction between concrete perception and abstract order in VR-integrated interior design, may lack explicit user involvement. Their study proposes the assembling parts method, focusing on operability, repeatability, and strong logic, but does not emphasize user feedback as prominently as the other studies.

5.3. COST AND CULTURAL CONSIDERATIONS

Cost considerations are thoroughly examined in Nguyen et al. (2022) and Kaleja and Kozlovská (2017), shedding light on the economic implications of their proposed solutions. Nguyen et al. highlight the cost-effectiveness of AR compared to VR, while Kaleja and Kozlovská integrate cost control and budgeting within the virtual design process. Cultural considerations are explicitly addressed in studies like Cao (2021) and Rahmat et al. (2019), recognizing the impact of cultural factors on interior design practices and VR technology acceptance. Cao's research identifies challenges in the current interior design process and emphasizes the potential of VR to address issues like misunderstandings between designers and customers. The study also discusses related products and research, including the development of VR applications by companies like IKEA and the use of 3D scanners.

5.4. COMPARISON WITH TRADITIONAL METHODS

Kaleja and Kozlovská (2017) and Nguyen et al. (2022) stand out for their comprehensive comparison of VR tools with traditional methods, highlighting the advantages and limitations of virtual reality. Kaleja and Kozlovská present a case study demonstrating the benefits of DRTV in interior design, while Nguyen et al. provide actionable insights for selecting the most appropriate simulated reality based on design goals. Both studies contribute valuable insights into the potential of VR technology as an innovative approach to interior design, supported by modern ICT tools and hardware technologies.

5.5. PRACTICAL ADOPTION AND FUTURE DIRECTIONS

Phan and Choo (2010) and Janusz (2019) explore the practical adoption and future directions of AR and VR in interior design. Phan and Choo present a novel method for designing, educating, and presenting interior design projects using AR technology. Their study addresses the challenges of selecting furniture

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by proposing an AR system that allows users to visualize and interact with virtual furniture in a physical environment. Janusz introduces Design3R, a revolutionary CAD system that integrates AR and VR, enabling real-time interaction with actual interior elements. The study acknowledges hardware limitations and proposes solutions by adapting the interface for VR, ensuring adaptability to evolving technologies. Kim and Hyun (2022) investigate the impact of VR on the interior design process, addressing the challenges and benefits of using VR in design. Their study recruited participants with experience in SketchUp and VR devices, measuring task completion time, design quality, and user satisfaction in both VR and desktop environments. The findings suggest that VR enhances the design experience but poses challenges in task completion time, providing insights into the participants' design experiences in both environments.

Thus, the analytical comparison of these studies highlights the transformative potential of VR and AR in interior design, addressing various challenges and enhancing the overall design process. Key findings include the utilization of VR technologies to offer immersive and realistic design experiences, improve communication and collaboration among stakeholders, and increase overall efficiency in the design workflow. Studies such as Nguyen et al. (2022) and Rahmat et al. (2019) emphasize user involvement and feedback, while Kaleja and Kozlovská (2017) and Cao (2021) address cost and cultural considerations. The lack of comparison among different VR technologies is a notable gap, warranting further investigation to determine the most effective types of VR for specific applications in interior design. Overall, these studies provide valuable insights into the integration of VR and AR in interior design, showcasing their potential to revolutionize the field and enhance design outcomes. See Table.1:

Table.1: An analytical comparison of previous studies on types of virtual reality in interior design

The studies	Technology Used	Technology Integration	Comparison with Traditional Methods	User-Centered Approach	Cultural Considerations	Cost Considerations
Kaleja and Kozlovská	Unity 3D					
Cao	IKEA place, 3D scanners					
Rahmat	Unity 3D, Unity HLAPI					
Nguyen	Mobile+ Tabletop AR & Immersive VR					
Xie and Chang	VR, software not specified					
Phan and Choo	ARtoolkit					
Kim and Hyun	Sketchup & VR					
Janusz	Design3R & HTC vive					

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6. CONCLUSIONS

The reviewed literature collectively underscores the underexplored potential of virtual reality (VR) in interior design, highlighting a range of applications and benefits. However, common research gaps persist, including the need for empirical evidence, comprehensive user experience evaluations, and comparative analyses with traditional design methods. Although the studies address the advantages of VR and compare it with conventional approaches, a direct comparison among different types of VR (immersive VR, non-immersive VR, and augmented reality (AR)) and their specific impacts on interior design is notably absent. Future research should focus on a systematic comparison of these VR types, evaluating metrics such as efficiency, cost, time requirements, ease of use, equipment availability, and accessibility to these technologies. Such a comparative analysis is essential to identify the most effective VR tool for achieving optimal results in interior design applications. Therefore, the primary focus of subsequent investigations should be to determine the most suitable VR method for enhancing interior design processes. The collective findings of these studies underscore the transformative potential of VR and AR in interior design, addressing various challenges and enhancing the overall design process. Key conclusions include the utilization of VR technologies to offer immersive and realistic design experiences, improve communication and collaboration among stakeholders, and increase overall efficiency in the design workflow. Studies such as Nguyen et al. (2022) and Rahmat et al. (2019) emphasize user involvement and feedback, while Kaleja and Kozlovská (2017) and Cao (2021) address cost and cultural considerations. The lack of comparison among different VR technologies is a notable gap, warranting further investigation to determine the most effective types of VR for specific applications in interior design. Overall, these studies provide valuable insights into the integration of VR and AR in interior design, showcasing their potential to revolutionize the field and enhance design outcomes.

REFERENCES

1. Nguyen et al. (2022). "How Lay People Design Interior Architecture Layouts in Virtual, Augmented, Drawing and Physical Reality" Volume 1–Co-creating the Future–eCAADe 40
2. Rahmat et al. (2019). "Collaborative virtual reality application for interior design." Indonesian Journal of Electrical Engineering and Computer Science, 16(1), 500-507.
3. Kaleja & Kozlovská (2017). "Virtual Reality as Innovative Approach to the Interior Designing." SSP-JOURNAL OF CIVIL ENGINEERING, 12(1)
4. Cao, L. (2021). "Analyze the application of virtual reality in interior design." Proc. SPIE 12153, International Conference on Artificial Intelligence, Virtual Reality, and Visualization (AIVRV 2021), 121530X.
5. Xie, & Chang (2021). "Research on Application of Assembling Parts Method Based on Virtual Reality Technology in Interior Design." AICS, Journal of Physics: Conference Series.Top of Form
6. Phan & Choo (2010)."Interior Design in Augmented Reality Environment." International Journal of Computer Applications (0975 – 8887)Volume 5– No.5.
7. Kim and Hyun(2022) ""Understanding Design Experience in Virtual Reality for Interior Design Process" 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA)
8. Janusz (2019). "Toward the new mixed reality environment for interior Design" IOP Conference Series: Materials Science and Engineering471 102065.

DOI: http://doi.org/10.24086/icace2025/paper.1649