Integrating Mixed Reality Technologies in Design Education

A cognitive evaluation proposal

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While virtual and augmented reality technologies have been widely studied in design processes, research on mixed reality (MR) remains limited. MR offers unique opportunities by enabling real-time interaction between physical and digital environments, presenting transformative potential in design education. This study presents a comparative experimental analysis of MR's pedagogical integration into design workflows. Using a design protocol methodology, the research investigates factors influencing MR use, including design tools and environments, target users, effectiveness, advantages, challenges, MR content types, and infrastructure requirements. The study compares the design processes of participants using MR tools with those who do not, focusing on ideation, problem-solving, and decision-making. Findings from the first phase of protocol analysis reveal that MR enhances creative problem-solving and supports pedagogical benefits such as increased user engagement, immersive experiences, interaction with design environments, peer learning, and a stronger sense of place. Technical challenges, including hardware limitations and usability issues, are also identified. Although only preliminary results are presented due to time constraints, the study lays the groundwork for future phases of cognitive analysis. Strategic recommendations are offered to support the effective integration of MR in design education, contributing to future research and application in academic and professional contexts.

Keywords: *Mixed Reality, Design Tool/Environment, Design Cognition, Design Process, Protocol Analysis*.

INTRODUCTION

The development of digital technologies transforms design processes and differentiates the tools/environments that designers can use in design processes. As an important technological development, MR (Mixed Reality) offers a richer and more interactive experience in design processes by combining both physical and virtual components (Milgram and Kishino, 1994). This technology allows users to explore and manipulate spatial forms, especially in architectural design processes. MR technologies create an interactive and intuitive design environment by enabling simultaneous use of the physical environment and the virtual information to be used. In design education, MR provides students with a more interactive learning environment, allowing them to visualize complex structures, iterate on their designs in real time, and collaborate with peers in virtual spaces (Dünser et al., 2012). Research on how the use of MR in design education transforms the process and how it affects problem solving and decision making skills is limited. This study aims to reveal the transformative role of MR technology in design process.

In this context, the study is based on the following research questions:

- What is the role of MR in the design process and how does it differ from traditional methods?
- How do MR technologies influence design students' problem solving and decision making?
- What are the pedagogical advantages and challenges of MR?

In the study, first of all, a literature review was conducted and previous research in the field was examined. The role of MR in design processes, the advantages and limitations of MR use, and protocol studies in design education in the context of the methodology used are discussed, followed by the experimental study proposal and its findings.

LITERATURE REVIEW

Although there is an extensive literature on the use of virtual and augmented reality technologies in design processes, studies addressing the role of mixed reality (MR) technologies in design are limited. MR offers new opportunities by enabling real-time interaction between physical and digital environments in design workflows. Recent research has focused on questions such as how MR technologies can be integrated into learning and design processes, what advantages they provide, what challenges they bring, and in which areas of design they are most effective.

Mixed Reality (MR) is often mentioned together with Augmented Reality (AR), but these two technologies differ significantly in terms of interaction and level of immersion. AR displays digital content on top of the physical world through a screen or transparent device and offers limited interaction. In contrast, MR places digital objects into the real environment and allows users to interact with them in real time. In MR environments, users can move and manipulate virtual objects as if they were physically present, and the system responds to environmental inputs such as spatial position, hand gestures, and object overlap. This two-way interaction sets MR apart from AR and makes it especially suitable for design processes in educational settings (Milgram and Kishino, 1994; Brigham, 2017).

MR opens up new possibilities in terms of creating conceptual models, developing spatial perception and producing prototypes in the design process (Dorta et al., 2014). The use of MR in design education provides students with the opportunity to view and experience their abstract thoughts concretely, develop creative thinking skills and interact with the design product (Wang et al., 2020; Gero and Kannengiesser, 2014). On the other hand, it improves spatial perception and creates the opportunity to experience space in multiple dimensions (Schubert et al., 2001). The immersive structure of the MR environment increases the user's active participation in the process (Benko et al., 2008) and supports the learning experience. It encourages peer learning through collaborative workspaces and the creation of these environments develops critical thinking and problem-solving skills in the design discipline (Cobb et al., 1999; Schubert et al., 2001).

The role of MR in design processes

Mixed Reality (MR) combines physical and digital environments, allowing users to experience both worlds simultaneously. MR technologies are used to increase collaboration in design processes, improve visualization capabilities and optimize creative processes. Artificial Intelligence (AI)-assisted mixed reality systems enable the creation of dynamic and realistic virtual environments, increasing the efficiency of users in design processes (Xu et al., 2024).

Immersive virtual environments increase participation in the design process and support creative thinking. MR technologies are emerging as effective tools to enhance sensory engagement in cultural exhibitions and education. The AI-powered ecological virtual reality simulations developed by Li and Cao (2024) provided a more immersive presentation of cultural content and revealed that the simulations created a stronger emotional connection with users and facilitated learning processes (Li and Cao, 2024).

MR is increasingly recognized as a transformative tool in architectural design, especially in education and visualization. By integrating MR technologies, architectural design processes can become more interactive and immersive, enhancing both learning and client engagement. Milgram and Kishino (1994) explained how MR technologies transform user interactions along the reality-virtuality continuum. By combining both physical and virtual components, MR offers a richer and more interactive experience in design processes (Milgram and Kishino, 1994). This technology allows users to explore and manipulate spatial forms, especially in architectural design processes. However, experimental studies in the field of digital game design are limited in the existing literature.

MR technologies facilitate experiential learning by encouraging students to visualize and manipulate designs in real time (Kıdık and Asıliskender, 2024). Participatory Action Research (PAR) frameworks have shown that integrating MR into design processes significantly increases student engagement and learning outcomes (Crolla et al., 2024). The use of devices such as HoloLens 2 has been found to be particularly effective for mapping interior space, providing accurate and reliable data for designers (Phuc et al., 2024).

Moralıoglu (2018) developed a MR-based spatial interface for individuals with autism spectrum disorder to help them manage sensory processing disorders. The interface, designed using the HoloLens device, enabled individuals to control environmental stimuli and relax, and the stress-reducing effect of visual supports was confirmed. The findings suggest that MR technologies are effective in supporting individual differences and have the potential to improve the quality of daily life. In the future, it is recommended to improve device ergonomics and accessibility (Moralıoğlu, 2018). In addition, Microsoft HoloLens, used as a MR goggle, offers interactive and real-time solutions to facilitate the daily lives of individuals with sensory processing disorders (Brigham, 2017).

In a study examining the effect of mixed reality technologies on the design thinking processes of first-year architecture students, the physical environment and Microsoft HoloLens-based MR environment were compared. The two-stage protocol research conducted in the study showed that creative and productive approaches in design processes were more prominent in the MR environment. The findings reveal that this technology can be a potential tool in architectural basic design education (Cindioğlu, 2019).

In their study, Gül et al. (2023) aimed to increase visitor awareness in cultural heritage sites by combining MR technologies and gamification elements. The experience route designed in Yedikule Fortress enabled users to better understand historical events and strengthened their spatial awareness through spatial analysis and game elements. The study reveals the potential of MR technologies in creating interactive and instructive experiences in historical contexts (Gül et al., 2023). This study emphasizes the importance of developing tools that support spatial cognitive differences in design processes.

Advantages and limitations of MR use

The main advantages offered by MR technologies can be listed as direct interaction, experiential learning, and advantages in decision-making processes. Unlike traditional interfaces such as mouse and keyboard, MR technologies offer direct interaction methods such as gesture tracking, voice commands and hand gestures, during chat with the LLM (Large Language Models). MR in education provides an interactive and immersive environment to better understand complex concepts. Kıdık and Asılıskender (2024) show that the integration of MR into design education processes increases student engagement. It accelerates design processes by allowing users to experience architectural spaces in real time. Phuc et al. (2024) emphasize that HoloLens 2 devices enable designers to make more accurate decisions by optimizing the interior mapping process.

In addition to the advantages offered by MR, there are some technical and pedagogical challenges that limit its use and prevent its widespread use. Factors such as technical hardware requirements, system and software solutions can limit the use of MR applications in educational settings (Billinghurst and Duenser, 2012; Cipresso et al., 2018). In addition, infrastructure inadequacies and access costs are barriers (Freina and Ott, 2015). On the other hand, it may be necessary to support students with additional training to facilitate their adaptation (Makransky and Lilleholt, 2018). In order to integrate MR into education, curricula need to be adapted as a result of pedagogical research and educators need to adapt to the system. Interactive learning practices and pedagogical strategies should be designed effectively (Bower et al., 2014).

Challenges related to the implementation of MR include cognitive load, accessibility and cost, user experience and ergonomics. MR environments can increase users' perceptual and cognitive load, which can lead to difficulties in long-term use. One of the biggest barriers to the widespread adoption of MR devices is the high cost and technical infrastructure requirements. The ergonomic design of MR systems should be developed to minimize problems such as eye strain and motion sickness. In conclusion, in order to effectively integrate these technologies into education, more research and regulation is needed from a technical and pedagogical point of view to overcome the challenges, taking into account the advantages and potentials that MR technologies offer to education.

MR and protocol studies in design education

Various methods are used to measure the perception of presence in mixed reality. One of them is the Immersive Tendencies Questionnaire (ITQ), a survey instrument that assesses presence perception on a seven-point scale. The ITQ measures participants' tendencies by focusing on factors such as Interest, Focus, Games and Emotions. The System Usability Scale (SUS) (Brooke, 1996) is a scale used to assess the usability of a system. SUS scores range from 0 to 100. It was applied for the use of Microsoft HoloLens MR glasses. Flow Scale State (FSS) is a five-point scale used to assess a person's experience of flow (Gironacci et al., 2018).

The research field of design cognition aims to understand how designers design, not what they do. In order to realize understanding in this field, the most widely used method in which design processes are examined in detail is protocol studies (Özbaki, 2016). Bilda and Demirkan (2003), in their study titled “An Insight on Designers' Sketching Activities in Traditional versus Digital Media”, examined the effects of using different media in the conceptual design development process. In this study, protocol studies were conducted to understand the effects of traditional and digital media in the early stages of design and the two media were compared.

(2005) “Comparing Freshman and Senior Engineering Design Processes: An In-Depth Follow-Up Study” examined how expert engineering students and beginners tackled a design problem and analyzed the differences in processes and actions between the two groups. The study evaluated the quality of solutions, the time spent on problem solving, the variety of alternatives generated, and the transitions between design steps in the design processes carried out by students at different levels of expertise. For this analysis, protocol studies were conducted with a total of 93 engineering students from different levels of expertise. Segmented protocols were coded according to the design steps (Atman et al., 2005).

Kruger and Cross' (2006) study titled “Solution-Driven Versus Problem-Driven Design: Strategies and Outcomes” examines how cognitive strategies used in design processes affect design quality and creativity. For this purpose, the researchers identified the design activities that the designers performed during the process. These actions Gather data, Assess value and validity of data, Identify constraints and requirements, Model behaviour and environment, Define problems and possibilities, Generate partial solutions, Evaluate solutions, Assemble a coherent solution (Kruger and Cross, 2006).

METHODOLOGY

This study aims to address gaps in the literature by proposing an experimental study investigating the pedagogical and cognitive effects of MR technologies on design processes. Using a design protocol methodology, this research aims to comparatively analyze how MR affects design cognition and creative problem-solving processes. The integration of MR into pedagogical design processes reveals transformative potential for educational environments. To unlock these potentials, this study focuses on various factors influencing the use of MR in design processes, including “design tools/environment”, “target audience”, “effectiveness of MR in design processes”, “advantages of MR use”, “challenges encountered in MR applications”, “types and content of MR used”, and “required software and hardware infrastructure”.

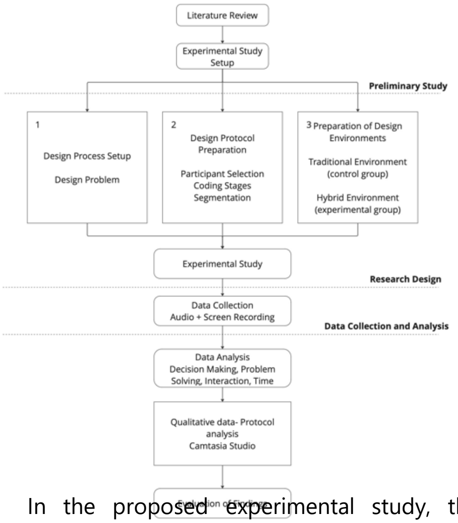

Figure 1
Research Design

In the proposed experimental study, the design processes of participants with and without MR tools are compared through protocol analysis. This cognitive approach focuses on the impact and potentials of MR on the design workflow, emphasizing the differences in idea generation, problem solving and decision making between the two groups (Figure 1).

Research Question

This study aims to understand the impact of MR technologies on the design process of digital game design students when designing game spaces. In this context, the behaviors and performances of two groups of students with and without MR are compared in the design process. The research examines how MR technology affects design decisions, creative thinking and problem-solving skills.

How does MR technology make a difference in the digital game design process? What is the difference between the creative thinking, problem solving and decision-making skills of students who use MR and those who do not?

Participant Selection

Students: The experiment is conducted with 2nd-year Digital Game Design students.
Groups: Each group consisted of 3 students. Students should have a basic knowledge of designing/modeling game spaces using game engines.

Design Problem

Students design a maze game space based on their physical space. The group using MR can extend the physical space with virtual elements, adding interactive doors, moving walls and holographic clues, while the traditional group designs a digital version of the space and develops navigation mechanics. The game aims for players to navigate their way through the maze, reach specific goals and complete tasks by following clues.

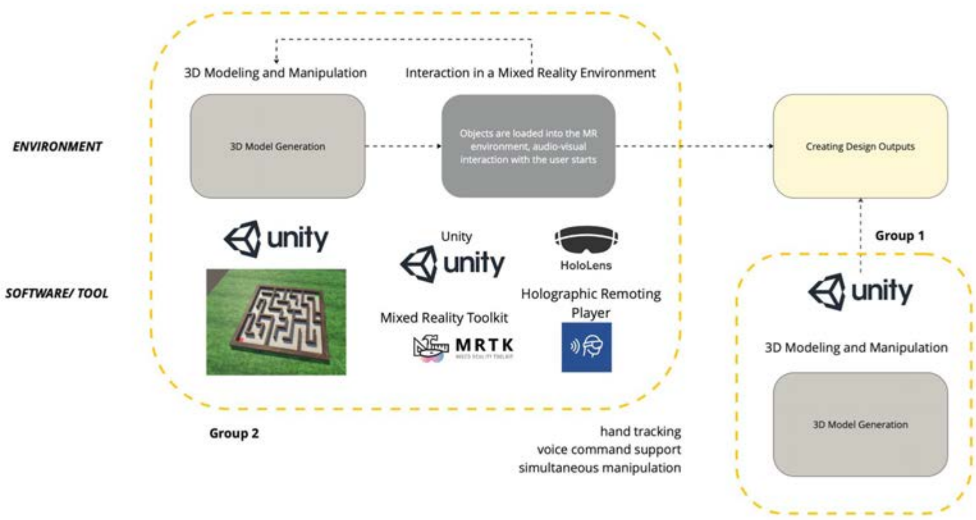

Figure 2
Experimental Groups, Environments, Tools

The experiment takes place in two different environments (Figure 2):

Firstly, participants using MR use game engines (Unity) and MR-supported tools (MRTK-Mixed Reality Toolkit) to design game spaces. Microsoft HoloLens 2 is used as MR glasses. The connection between Unity and MR is made with IP via Holographic Remoting Player. By modeling in the game engine, they experience their models with mixed reality glasses in the physical space they are in. In this environment, users can design game spaces interactively with the physical space and develop new creative solutions by blending real-world objects and virtual elements with MR platforms.

For instance, in one of the experimental setups, students used the real-world layout of their classroom walls, desks, and doors as a foundational structure, and overlaid it with virtual extensions such as holographic gates, moving walls, and floating navigation clues. By anchoring these digital components onto physical objects, participants could test how virtual cues guided user movement in space, observe spatial transitions in real-time, and adapt their game mechanics accordingly. This fusion of real and virtual allowed them to evaluate interaction dynamics in situ, providing insights that are difficult to achieve with screen-based design alone.

With MR technologies, participants can interactively manipulate virtual objects using physical movements and hand gestures. This process can enable designs to be created in a more flexible and creative way. The process is analyzed to evaluate interaction and decision-making strategies in the MR environment (Figure 3).

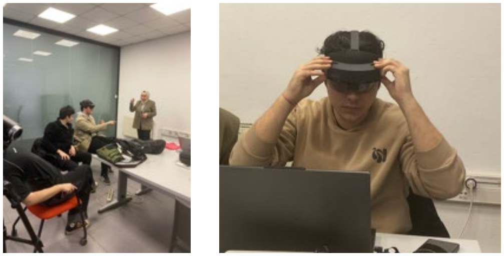

Figure 3
Experimental Group Design Process

Secondly, those who do not use MR make their designs on the game engine Unity. Participants create a 3D model of the game space. They design on the screen and do not interact with the physical environment. The process is evaluated on how decision-making and creative thinking strategies work in screen-based applications.

Protocol Analysis (Data Collection)

Since the experimental session is still ongoing, this article presents preliminary findings based on the second phase of the cognitive protocol framework, while data collection will be conducted in Stage 3. Participants' thinking processes are intended to be observed through segmentations (decision making, problem solving, creative thinking). The study is designed to identify which steps take longer, what decisions are made, and how problem-solving strategies differ between the MR and traditional groups. A timeline will be followed for both groups, and each student's design process will be recorded step by step using screen capture and audio recordings. In the subsequent phase, qualitative data such as think-aloud protocols will be coded into categories like 'decision-making' and 'creative thinking,' and the frequency of these codes will be quantitatively analyzed to reveal cognitive differences between MR and traditional workflows.

Evaluation Criteria

- Creativity: The extent to which new ideas and originality come to the fore in the design is evaluated.
- Problem Solving and Decision Making: The ability to cope with design challenges and develop creative solutions to these problems is evaluated.
- Interaction: How the design interacts with the player is evaluated.
- Time Management: Each group's time management is evaluated in terms of productivity.

FINDINGS

As the experimental sessions are currently being conducted, this paper presents no finalized empirical results but focuses on outlining the expected outcomes based on the research design and early-stage observations. Also, it outlines the anticipated outcomes based on the research design and theoretical framework. The study is expected to reveal pedagogical implications of integrating MR into design practice, such as enhanced interaction with design tools and environments, increased user engagement, opportunities for peer learning, and immersive experience.

Predicted Outcomes

The predicted findings of this study are expected to reveal the contribution/impact of MR technology to the game space design process and the differences between it and traditional design methods. It can be observed that students using MR can extend the physical space with virtual elements to provide a more dynamic and interactive experience. Through elements such as virtual obstacles, holographic clues and interactive objects, it is predicted that designers can directly engage players with the space, act intuitively in the navigation process and test their designs in real time. In addition, students using MR are expected to iterate faster to improve their designs and use the physical environment as an experimental space.

It is predicted that the group that does not use MR conducts user experience tests in a simulation environment rather than in a real space since they create their designs with screen-based tools. This situation may eliminate the advantage of virtual interaction with the real space offered by MR technology, making the design process longer and requiring detailed planning. As a result, it can be concluded that MR technology provides advantages in areas such as rapid prototyping, intuitive exploration and spatial awareness in game space design, while traditional methods offer a more controlled and predetermined design process.

CONCLUSIONS

This study explores the cognitive and pedagogical potentials of integrating Mixed Reality (MR) into the design education process, particularly in spatial design tasks for digital game students. Although the experimental process is ongoing, the predicted results point toward both procedural and qualitative advantages of MR over traditional screen-based methods.

Beyond accelerating the design process, MR appears to improve design quality by fostering intuitive and embodied exploration. Students working in MR environments are anticipated to engage more dynamically with spatial problems, benefit from real-time feedback, and iterate with greater fluency. These features contribute to more user-centered and interactive design outcomes compared to conventional methods that rely on pre-planned, abstract modeling. In contrast, traditional approaches offer more structured but less flexible workflows. While they support detailed planning, they may fall short in enabling immersive testing and adaptive problem-solving during the design process. This distinction highlights the qualitative shift MR introduces not only in terms of speed, but in transforming how students perceive and interact with design space. However, the study is currently limited by the early phase of data collection. Full protocol analysis and quantitative evaluation will be necessary to validate these insights. Future research should expand the participant pool, include longitudinal observation, and investigate how different cognitive styles respond to MR-enhanced design environments.

The findings are expected to contribute to the growing body of literature on immersive learning technologies and offer actionable strategies for educators seeking to implement MR in design curricula. In particular, protocol analysis methods can uncover how MR influences idea generation, decision making, and creative strategies—critical processes in design education. Strategic recommendations for curriculum integration, infrastructure development, and instructor training are also suggested to support long-term adoption of MR in academic and professional design contexts.

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