Designing the Future: Real-Time Digital Design in a Mixed Reality Landscape

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Abstract: Graphic design is mostly concerned with static images, such as posters or packaging, but digital design involves the creation of dynamic experiences that incorporate navigation and user interaction. Real-time digital design represents the most innovative and challenging area in such design. The article attempts to comprehend the role of mixed reality (MR) in the modern world from the standpoint of convergence of technological and societal aspects and implications of the development of relevant tools and environments. Based on structural and functional approach, the directions, prospects, and advantages of using MR tools in real-time digital design are considered. It is shown that interdisciplinarity represents one of the fundamental characteristics of design and is associated with the multidimensionality and complexity of design. Much attention is paid to the phenomenon of participatory design, the development of which today is largely based on MR and creates evident societal implications, ecologies of social and technological transformation

Keywords: digital design; mixed reality; participatory design; co-creation; community.

Introduction

With the development of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) technologies, the barrier between the actual and virtual worlds is dissolving. VR has given the virtual world an immersive sense, while AR has already generated attention by incorporating virtual elements into the actual world. However, it is time to move beyond AR and VR and create lifelike sounds, visuals, and feelings so that we can experience and engage with the virtual world in real life. By merging the real and virtual worlds, mixed reality solutions create new simulated landscapes and images where digital and physical items may interact in real time. It blends the ideas of virtual reality with augmented reality. Users may use their hands and motions to engage with Mixed Reality. This gives consumers the opportunity to engage with the virtual items in addition to experiencing them in the actual world.

Product design and review processes are now subject to numerous restrictions and specifications. The influence that design decisions have on end users and the usability of solutions are two of the most important needs. As a result, anticipating human factors issues in the early stages of the product development process is becoming increasingly important. Additionally, they must be able to see consumers as they engage with the product in real time since human variables have a huge impact on decision-making and effect users unconsciously. According to this paradigm, the platform that users and human factors experts utilize has a significant impact on the assessments and evaluations of human factors. Recent advancements in extended reality have made it possible to construct new simulation platforms that enable professionals to thoroughly examine items in real time through interactive and collaborative settings prior to the actual product mockup. A Mixed Reality tool for airplane interior design is described by Santhosh and De Crescenzio (2022) to show how it may be used as a co-creative platform to keep human factor specialists informed as the project is being completed. The authors have created an MR multi-user, co-located, collaborative, and interactive environment of an airplane galley in which a flight crew member and an HF specialist may work together to see the galley's true size model and complete an operational job. Such a co-creative tool is anticipated to fulfill user needs while cutting down on time and expenses associated with the product development cycle by conducting usability testing during the design review phase. A design review scenario serves as the foundation for the application research. The 3D interactive model of a newly designed aircraft galley populates the MR environment. The primary user assumes the role of a flight attendant or crew member, while the secondary user observes as a human factors specialist. The visible elements, such as reachability of the surfaces and contact with the items, are associated with ergonomics and usability. To assess tasks and usability in the environment, the human factors specialist should look at these functions. A human factors specialist may watch and assess the situation as the user, posing as a crew member, completes a job in front of the galley using the software program. As a result, two people wearing mixed reality head-mounted displays can collaborate and co-locate to share the scene. Table 1 provides an explanation of the work description.

Table 1. Task description of the aircraft galley application in MR environment

Cabin item	*Aircraft galley*
User 1	Crew member
User 2	Human Factors expert
Scenario Description	The same galley in the same setting is visualized by the crew member and HF specialist. The crew member is tasked with retrieving the water jar from the galley's upper shelf and setting it on the platform.
Measurable metrics	Task analysis (Usability, Reachability), and visual comfort
Target	Optimize overall performances, co-create

Source: Santhosh and De Crescenzio (2022)

To improve the performance of the Mixed Reality application, parameters such Pulse Shader Spatial Mesh Prefab, Target Scale (Room scale), Display Option (Occlusion), and Spatial Awareness have been changed. The desired scenario has been examined in order to identify the qualities that must be present in the environment in order to create shared experiences for both users. As a result, a 3D environment with one-to-one sharing experiences has been established based on the airline galley scenario utilizing a Microsoft HoloLens2 MR device. The physical settings were comparable, and the cooperation took place in real time (Fig. 1).

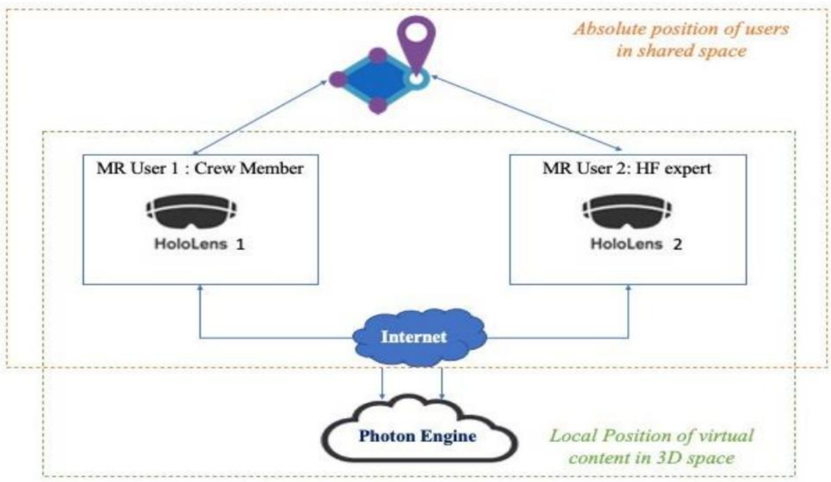

Figure 1: Multi-User Framework for real-time designing the aircraft galley scene in MR landscape

Source: Santhosh and De Crescenzio (2022)

This example is bright demonstration of contemporary principles of real-time design within MR environment. The tools provided by MR revolutionize the field of design, creating new opportunities not only of technical/technological/artistic planes, but also of societal nature, allowing smooth convergence of cultural and emotional patterns and the latest solutions.

2. Methodological framework

In conducting the study, the authors were guided by the following principles:

• A comprehensive interpretation of the methodology as a system of principles, categories, and laws that examines the scientific, technical, and social components of the development of society and the principles of its comprehension. Such an understanding indicates the universal objective nature of the relationship and mutual determination of social and scientific-technical phenomena, reveals the patterns of development of these social phenomena;

• The structural and functional principle of mixed reality analysis, which allows conceptualizing this phenomenon as a holistic formation deployed in a dynamic process with both external and internal development resources;

• The principle of determination of the technical form of development by the value intentions of society and the associated principle of emergence.

This study is grounded in a theoretical–methodological research design aimed at systematizing the role of mixed reality (MR) technologies within contemporary digital spatial design practices. The research does not involve empirical experimentation; instead, it focuses on the conceptual structuring of interdisciplinary knowledge, technological workflows, and design paradigms associated with MR environments.

The methodological foundation integrates principles from architectural theory, digital design, human–computer interaction, and spatial visualization. The research adopts a conceptual synthesis approach, enabling the integration of technological, spatial, and socio-cultural dimensions into a coherent analytical structure. This approach allows the study to move beyond descriptive narratives toward structured methodological generalization.

The conceptual framework is based on the premise that mixed reality technologies function not only as visualization tools but also as mediators of design cognition, facilitating interaction between digital models, designers, and stakeholders. Accordingly, the research focuses on identifying structural relationships between digital modeling environments, immersive interfaces, and collaborative design processes.

A key methodological component of this study is conceptual analysis, applied to clarify the terminological and functional distinctions among extended reality (XR) technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR). Given the increasing overlap of these technological domains, terminological ambiguity remains a critical issue in contemporary research and professional discourse.

The research further employs interdisciplinary synthesis, integrating knowledge from architecture, digital media design, computer graphics, and immersive technologies. This synthesis supports the identification of technological dependencies and workflow relationships that structure contemporary MR-based design environments.

A central methodological contribution of this research is the conceptual modeling of mixed reality design workflows. Unlike empirical modeling, this approach focuses on the logical structuring of design stages and technological interactions rather than quantitative simulation. The workflow model is developed through abstraction and synthesis of recurring patterns identified across digital design environments and case studies. The modeling process identifies sequential and iterative relationships among key stages of MR-integrated spatial design. The conceptual workflow includes the following generalized stages:

1. Conceptual Spatial Ideation: Formation of initial spatial concepts and narrative structures.

2. Digital Geometric Modeling: Creation of parametric and geometric models using digital design tools.

3. Mixed Reality Integration: Transfer of digital models into immersive environments for spatial alignment and visualization.

4. Interactive Visualization and Collaboration: Real-time interaction with digital models by designers and stakeholders.

5. Feedback and Iterative Refinement: Integration of feedback into subsequent design iterations.

This conceptual model functions as a methodological framework, enabling systematic interpretation of MR-based design practices across different project types.

3. Digital surroundings: Mixed realities spectrum potentials

Digital and real-world realities are presented linearly on the Mixed realities spectrum. Depending on the kind of solution and its intended use, it maps itself anywhere along the scale between the virtual and physical worlds. Everything in the digital world is computer-generated and shown electronically, whereas everything in the physical world is presented as real. By fusing the two, mixed reality produces an immersive experience that incorporates both artificial things and motion.

In order to create new settings and representations where real-time interactions between digital and actual items occur, MR combines VR and AR. Instead of either occurring in the real or virtual world, MR is a hybrid that uses immersive technology to combine AR with augmented virtuality (Mountain and Liarokapis 2007). MR, also known as augmented virtuality, merged reality, or hybrid reality, has been applied in a number of fields, such as medical training (Albrechta et al., 2013), enhancing museum and historic building visits, and rebuilding heritage restoration projects (Huang et al., 2009).

The nineteenth century saw the invention of the panoramic picture (360-degree murals or panoramic paintings) and its reproduction in spatial installations, which sparked the desire to immerse oneself in a parallel, immersive identity. The earliest visual mass media in Europe were despised by panoramic paintings. Morton Heilig's Sensorama Machine, developed in 1950, made VR technology possible because to the quick advancements in computer and electromechanics. Ivan Sutherland and Bob Sproull's 1968 presentation of their first VR/AR head-mounted display, HMD (Sword of Damocles), at MIT's Lincoln Laboratory undoubtedly marks a turning point when it comes to the technology's applicability to architecture. "You should not think of a computer screen as a way to display information, but rather as a window into a virtual world that could eventually look real, sound real, move real, interact real, and feel real", Ivan Sutherland emphasized in 1965 at a computer conference, outlining his vision for the future of virtual reality. Significant advancements in immersive and responsive technology were made during this period (Sutherland, 1968).

The primary market outlet for this technology during the past three decades has been the gaming sector. Chauhan et al. (2024) The first VR eyewear prototype, the Oculus Rift, was created by Palmer Luckey in 2010 and released as a test model in 2014. In the field of HMD and VR goggles (mobile VR viewers), more than 200 comparable items have since been created (Fricker, 2018). These new technologies enable a wide range of applications, particularly in the domains of architecture and landscape architecture, and come with room-scale tracking and gesture input devices.

Digital surroundings may be accessed with remarkable ease due to modern interfaces for virtual, augmented, and mixed reality. According to Fricker (2018), a transdisciplinary research hub developed a set of tools and workflows that integrate site-specific environmental datasets, like rainfall, wind, or ambient noise data, with highly detailed geometrical data of a site with 3D models and point clouds of a future design (see Fig. 2).

Figure 2: Immersive storytelling with high-resolution pointcloud data model. Student project Courtesy of Aalto University. Series of atmospheric screenshots, modelled with Rhino, Cinema 4D and Unreal Engine. By superimposing environmental data sources in an artistic manner that improves the impression of space, the students in VR concentrated on expressing the atmospheric tale of their creation.

Source: Fricker (2018)

In order to preserve people's living conditions, architecture, engineering, and building projects must be promoted in balance with the environment. In order to minimize ambiguity while conducting environmental impact assessments, stakeholders and decision-makers discuss and evaluate landscape photos taken during and after construction throughout the planning and design phase. In the realm of landscape design, mixed reality which superimposes virtual material over a real scene - has gained attention due to the absence of a standard visualization technique for future landscapes that do not yet exist. Occlusion, which happens when virtual objects block out real items that need to be presented in the front, is one problem in MR. Existing occlusion management techniques may encounter challenges in MR-based landscape visualization due to the potential for wide variations in the distance between the MR camera and actual things in front of the virtual objects. An evidence-based approach has grown in importance during the landscape design process. Semantic segmentation via deep learning, which can identify the surrounding environment, has been extensively researched for landscape evaluation in order to estimate landscape indexes. In order to facilitate dynamic occlusion handling and landscape index calculation for both existing and created landscape evaluation, Kido et al. (2021) incorporated deep learning-based semantic segmentation into an MR system. By linking to real-time semantic segmentation on a powerful personal computer, this technology may be used on a mobile device with internet-based video communication. Through case studies and accuracy testing, the created system's usefulness is illustrated.

Fig. 3 displays an example of a virtual area set up in the Kido et al. (2021) system. The camera location and a 3D model of the new design goal are established in the virtual environment. The live picture in real space is overlaid on a 3D model of the new building created by a virtual camera (henceforth referred to as a "MR image"). This solution uses OpenCV for Unity to create a frame-by-frame mask picture of an occlusion target region from semantic segmentation images. A mask picture for occlusion may be created based on the RGB values of the detection categories thanks to semantic segmentation, which defines RGB values for each category of landscape features, such as sky and vegetation. When creating a mask picture in our system, the user pre-specifies the types of real objects to mask for dynamic occlusion. This makes it possible to automatically create a mask picture that obscures actual things in every frame. Dynamic occlusion is then achieved by combining the produced mask image with the MR picture and making the combined mask region of the MR image invisible. The dynamics of the occlusion process are depicted in Fig. 4. According to reports, blurring the mask image to be synthesized can improve the optical consistency of the boundary between the 3D model and the actual object (Kido et al., 2021).

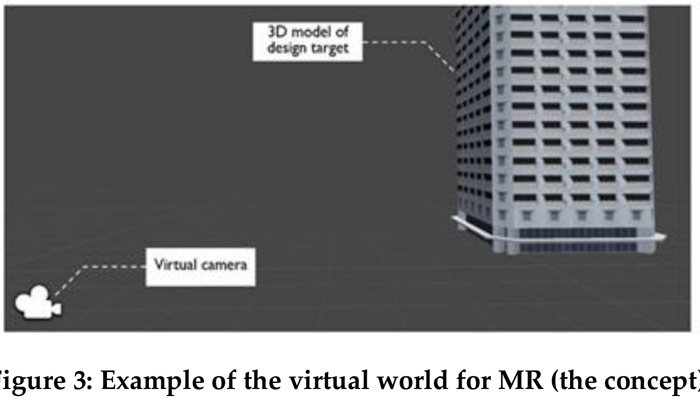

Figure 3: Example of the virtual world for MR (the concept)

Source: Kido et al. (2021)

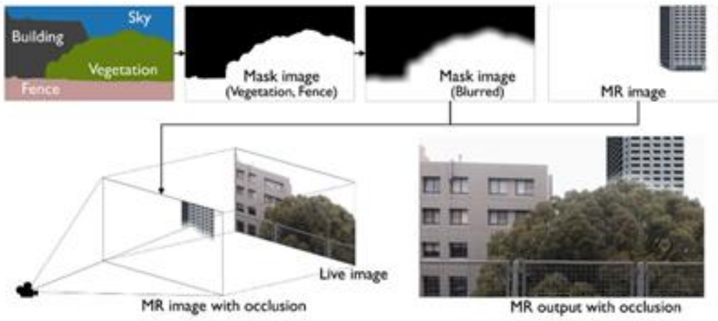

Figure 4: MR with occlusion handling using semantic segmentation

Source: Kido et al. (2021)

MR in architecture has enormous business possibilities. A recent market analysis predicts that the worldwide mixed reality industry will expand dramatically because to its use in a number of industries, such as building and architecture. This expansion demonstrates how MR can revolutionize various sectors (Chandran, 2024).

According to Carrasco and Chen (2021) and Carbonari et al. (2022), Mixed Reality in architecture has numerous and significant advantages that are changing the field of design and construction in a number of crucial ways:

1. Improved Visualization:

•Contextual Understanding: MR enables clients and architects to see the finished product in its intended setting as well as a stand-alone model. By evaluating the design's harmony with its surroundings, this contextual visualization makes sure that the finished structure not only satisfies aesthetic criteria but also blends in with its surroundings.

•Dynamic Interaction: MR offers a dynamic platform that allows real-time manipulation of design components, in contrast to static representations. Making educated selections regarding materials and textures, comprehending the interaction of light and space, and seeing intricate structural details are all made possible by this tool.

•Proportion and size: MR allows viewers to see the design's proportions and size in a real-world setting. To ensure that the finished building speaks to human scale and comfort, this immersive experience is essential to understanding how space is used and perceived.

2. Enhanced Collaboration:

•Real-time Iteration and input: Stakeholders may engage with the design in real-time via MR, giving prompt input. Without the need for expensive physical models or drawn-out rendering procedures, this collaborative method expedites the design process and enables quick iterations and modifications.

•Remote Collaboration: By removing geographical restrictions, MR makes it possible for stakeholders from all over the world to work together as though they were in the same space. In addition to incorporating a variety of viewpoints into the design process, this international cooperation drastically cuts down on travel expenses and time.

•Interdisciplinary Communication: The many disciplines participating in the construction process may communicate with each other more easily because to MR's universal language. MR helps architects, engineers, contractors, and customers communicate more clearly by visualizing complicated technical concepts, which guarantees that everyone is on the same page about the project's goals and vision.

3. Reduction of Errors:

•Pre-construction Visualization: Before construction starts, MR enables a thorough examination of the design in its intended setting by superimposing digital material onto the real world. By spotting any design conflicts or mistakes early on, this preventive visualization lowers the possibility of expensive post-construction repairs.

•Integration with BIM: MR becomes an effective tool for mistake identification and correction when used with Building Information Modelling (BIM). A thorough investigation of the design is made possible by the combination of MR's immersive visualization and BIM's extensive information about the building's components, guaranteeing that any inconsistencies are resolved quickly and effectively.

•Safety and Compliance: MR may also play a key role in determining if the design complies with safety norms and laws. In order to ensure that the building is not only visually beautiful but also structurally sound and safe for its residents, architects and engineers may anticipate and minimize any safety hazards by modeling various situations.

4. Client Engagement:

•Immersion Experience: Beyond conventional 2D plans or 3D models, MR offers its clients an immersive experience. Clients may more effectively communicate their preferences and concerns, make educated selections, and get a true sense of the space by entering the virtual depiction of their future home.

•Emotional Bond: The clients and the project might develop an emotional bond thanks to MR's immersive nature. Clients may visualize their future lives or workplaces by experiencing the space in a realistic yet virtual setting, which can be a significant deciding factor.

•Well-Informed judgments: Clients are better able to make judgments when they have a better grasp and a physical sense of the design. In addition to increasing client pleasure, this active participation fosters a sense of pride and admiration for the architectural masterpiece being built.

4. Interdisciplinary paradigms of MR

Chakraborty and Banerjee (2020) propose intriguing study within an interdisciplinary paradigm on a sort of frontier between urban studies, spatial design, and philosophy. The purpose of their study is to clarify the intricate connection between urban identity and relativity. In other words, the study focuses on the area between people and structures, where people utilize signals to establish relationships and meanings. A universal speed limit, relativistic mass, mass–energy equivalence, length contraction, time dilation, and relativity of simultaneity are only a few of the many implications of special relativity that have been empirically confirmed. The authors emphasize that spatial history may be employed as a tool, method, and approach. Humanistic viewpoints suggest a clear but nuanced link between the cultural identities of people who live in certain locations and the character of those places, arguing that (bounded) places are essential in giving their residents a sense of belonging. This reveals patterns concerning the inertia in the expansion of cities and their interactions with one another, leading to strong empirical proof of a high degree of regularity regarding time and spatial correlations in urban sprawl. One of the conceptual cornerstones of the evolution of real-time design in the MR environment is this method.

Special relativity (SR), often referred to as the special theory of relativity or STR, is the widely recognized and experimentally supported scientific theory in physics that explains how space and time are related. Two postulates served as the foundation for Albert Einstein's initial educational approach. A universal speed limit, relativistic mass, mass–energy equivalence, length contraction, time dilation, and relativity of simultaneity are only a few of the many implications of special relativity that have been empirically confirmed. The traditional idea of an absolute universal time has been superseded by the idea of a time that depends on geographical position and reference frame. An invariant space time interval exists between two occurrences instead of an invariant time interval.

One observer's measurements of an item's dimensions (such as its length) may differ from another observer's measurements of the same thing (for example, the ladder paradox, which includes a long ladder moving close to the speed of light while being housed in a smaller garage). This disparity may be eliminated by using MR environments, which enable different users and design project stakeholders to view the objects in their correct dimensions and spatial arrangement.

Furthermore, STR makes it possible to describe the real-time design philosophy itself. More precisely, it is anticipated that Beijing would foster a cultural connection between the local and the global, the traditional and the modern. Beijing's contemporary image is made up of the Central Business District's (CBD) skyscrapers, innovative urban sculptures, high-tech transit, and public infrastructure. Since it has managed to maintain its numerous historical artifacts as well as its traditional values and philosophies, the city continues to be the traditional cultural hub of China, an old oriental nation. In light of this, Beijing's visual navigation systems have been methodically arranged and enhanced since 2001 in an effort to promote urban competitiveness, enrich cultural experiences, realize city brand distinctiveness, and improve urban circulation and transportation efficiency. Communicating the identity of cities in MR is the goal of the prototype method for creating visual representations of those cities (Raval, 2023).

The mechanism incorporates aspects of painting, mapping, and urban design. The phrase "spatial image" suggests that an object's ability to withstand the erasure of contemporary space depends critically on how entrenched it is in a spatial framework (Ong & Shen, 2009). The site is framed as a "spatial image" that is read against the (otherwise nameless) abstracting processes of urban development, and local tradition highlights its link to its collective history. The "framing" is important since it has to maintain both the object and the encounter method. In this sense, the term "image" suggests a network of relationships rather than just a visual object; the "spatial image" therefore preserves not just the physical remnants of the place but also the remnants of the way that place was encountered. A visual culture method that interprets the picture in this way is essential to analyzing how a spatial image serves as place memory in a "memory contest" when dissecting the spatial images of the last fifty years in Berlin. There is a dispute over the meanings and stories that should be attached to a certain place, but this is not a conflict in the traditional sense. A landscape, or even a metropolis, is the result of an interaction between the observer and the surroundings; hence, an environment is not a "unique sight" in and of itself because the observer's location varies from time to time. The viewer's position in relation to the item also affects that interaction. Consequently, a real-time effect of the object's complex perception including its emotional component is offered. MR enables the creation of such phenomena and instantaneously verifies their practical embodiment.

As Dan et al. (2021) correctly point out, community planning that prioritizes maximizing urban stock assets has taken center stage as urban expansion supremacism gradually fades. Community planning must address the constraints arising from existing surroundings, in contrast to traditional urban planning and design, which concentrates on new areas of growth. Furthermore, it is challenging for designers to make design decisions and judgments because of the trivial details that are typically present in contemporary community environments, such as public facilities, street furniture, old buildings, and landscapes, which are hard to measure and accurately incorporate into traditional basic design drawings (Huang et al., 2018). In order to fully perceive and comprehend the environmental elements as well as to envision and develop design solutions on-site, designers have increasingly decided to return to the design site. The phenomenological movement's "back to the things themselves" idea, which urges designers to immerse their concepts in community contexts to capture the essence of the area, is the source of this on-site design approach. The existing on-site design of community planning, however, is mostly dependent on the designers' visual imagination, which is too abstract to support their intuitive design perceptions, precise design judgments, and practical design decisions due to technological limitations. Accordingly, it invariably results in laborious, repeated tasks (Schubert et al., 2015). According to Dan et al. (2021), MR technology combines the benefits of both VR and AR since it may create new visual landscapes where digital and physical items coexist and interact in real time by fusing the actual and virtual worlds. Some key technical features of MR, like 3D on-site visualization, natural control mode (based on gaze and gesture), precise spatial mapping, and real depth perception, are demonstrated by successful applications. These features have the potential to enhance the current on-site design's accuracy, convenience, and intuitiveness.

The goal of Dan et al. (2021) was to enhance on-site design experiences in community planning by utilizing mixed reality (MR) technology. The authors asked sixteen designers to take part in an on-site design experiment employing MR for a typical community planning and design setting in order to verify its viability. The findings confirm that MR may greatly increase the accuracy, convenience, and intuitiveness of on-site design in community planning. In particular, MR is capable of producing interactive visualization environments that display realistic 3D virtual design elements in the physical world. As a result, designers in MR settings are able to instinctively generate additional design deductions in addition to comprehending the particular community environmental characteristics and seeing possible design items. When designers are conceptualizing, subtracting, and evaluating their design suggestions, MR environments help them make precise position perceptions and size judgments because they provide a completely actual spatial interaction between virtual items and the real world. At the same time, MR's vibrant texture might help designers locate appropriate design elements in local contexts. Designers may learn the fundamentals of design control in MR settings with the help of the current portable MR-DSS and short use instructions. Instead of repeatedly observing, recording, drawing, and modeling between their studios and the design site, they may use MR to conveniently make real-time design revisions while immersing their design concepts in an actual community scenario.

Emotional connection and narrative possibilities exist. MR is capable of creating a profound sense of immersion by telling stories in a completely original way. The boundaries between the actual and virtual worlds become hazy when digital and physical realities interact, creating emotionally charged and unforgettable encounters. By allowing value co-creation in real time and allowing the same possibilities of objects and landscape perception by any user, independent of his placement (axes of reference), MR thus offers a sort of eco-system for designing the future in real time, not separated sharply from the past and social/emotional patterns/experiences.

El-Jarn and Southern (2020) investigate the advantages of utilizing extended reality (XR) technology for co-creation and co-design from the outset of the design process. The authors did an analysis of the new co-creation tools in XR and if they have the potential to enhance the design process.

The ability to express, explore, and invent is provided by co-creating in MR, which replicates an open area and frees one from the limitations of a two-dimensional digital screen. While traditional concepting and validation techniques have been expensive and time-consuming, immersive virtual environments allow users to contribute asynchronously without being constrained by technological know-how or physical location. The likelihood of a successful product is also improved by several iterations and the potential to produce a greater number of concepts in a shorter amount of time and at a lower cost. Automotive design, industrial design, media and entertainment, set design, illustration, media and entertainment concepting, previz for films, and layout are just a few of the industries demonstrating growing interest in these new technologies (El-Jarn & Southern, 2020).

XR provides the opportunity for co-creation with experiences that have never been produced at this scale before. When designers collaborate in a co-design setting with others, they generate more inventive thoughts and ideas than when working alone (Trischler et al., 2017). In participatory design/co-design, the user for whom the service/product is being developed is the expert in their experience and has greater agency in knowledge creation, idea formulation, and concept development. The researcher and designers supply the means for expressing and conceiving of wants and preferences. Sanders and Stappers (2008) state that "participation at the moment of idea generation" is an essential area to practice participatory design, but it is also vital throughout the design process, at all major decision points.

Thus, participatory design (PD) is a collaborative, democratic approach involving users, stakeholders, and designers directly in the creation of products, systems, and environments, often aimed at social justice and enhancing user experience. Its sociology focuses on power dynamics, "use-before-use" prototyping, and leveraging tacit knowledge to ensure designed outcomes align with user needs and values (Devisch et al., 2018). PD' core principles, values, design methods, and sociological discourse are summarized in Table 2.

Table 2. PD' core principles, values, design methods, and sociological discourse

Core Principles and Values
Democratic Participation: Empowering people affected by a design to have a voice in its development.
"Use-before-use": Providing tools for stakeholders to interact with prototypes and shape them before final implementation.
Mutual Learning: A collaborative process where designers learn from user expertise, and users understand the technical possibilities.
Socio-Material Assemblies: Treating design not just as creating objects, but as designing the social and physical context around them.
Participatory Design Methods
Future Workshops: Sessions for participants to critique the current situation, brainstorm ideal futures, and plan implementation.
Probes & Prototyping: Using tools like cultural probes (diaries, cameras), mock-ups, and game-based techniques to spark dialogue.
Co-design Techniques: Using workshops and brainstorming to foster collaborative creativity

between users and designers
Sociology of Design Perspectives
Power and Politics: Examining who is included in the design process and how knowledge is valued.
Social Justice: Using design as a tool for empowerment, particularly for marginalized groups.
Situated Knowledge: Recognizing that design must be grounded in the local context and experience of its users.
Common Challenges
Time and Resource Intensive: Requires significant planning and commitment from all parties.
Managing Conflict: Navigating opposing needs and desires among stakeholders.
Representation: Ensuring a truly representative group of users participates.

Source: developed by the authors based on van der Velden and Mörtberg (2015), Mumtaz (2026)

Dubois et al. (2007) rightly note that participatory design and model-based approaches are two major design approaches. Traditionally, the first ones encourage the inventiveness of the user, while the second ones offer a more methodical approach to the design environment. Combining these two elements is particularly important in the Mixed Reality area to support design and assist users in considering the vast array of developing technology.

The involvement of residents, designers, and other stakeholders in urban projects throughout the design process is the focus of public participation in urban planning and design, according to Dane et al. (2024). This guarantees that the design and decision-making process is the product of the combined creativity of a group of stakeholders with different backgrounds and interests rather than being the exclusive duty of a single expert. Urban densification, according to the authors, is encouraged for sustainable urban growth, but it also raises questions regarding potential harm to local residents' health. Therefore, it is essential to involve locals in the co-design of densification projects in order to accommodate their wants and concerns. By enabling residents to not only see but also feel the effects of future designs or "what-if" scenarios, immersive VR technologies have the potential to advance participatory co-design of healthier urban areas.

Reflexivity in participatory design, according to San Pedro and Kinloch (2017), functions on two levels: for designers, it necessitates an awareness of one's positionality and power within the co-design space; for participants, especially those from marginalized communities, it creates space to reflect on lived experiences and their roles in shaping the design process.

5. Discussion within practical insights: participatory practices

As previously stated, MR is made feasible by a mix of the most powerful elements of VR and AR technologies. AR overlays digital material onto the actual world, whereas VR creates a totally immersive digital experience. Because of the technology's capacity to map the user's actual environment, MR enables users to interact with 3D virtual objects using natural motions and gestures. As a result, users may view and edit digital items as if they were actually there in the same physical location. MR technology enables designers to view and examine many elements of their designs. This may be quite useful in the pre-construction stage, allowing designers to visualize their concepts before they begin building. "This technology allows you to not only see everything you're working on but also interact with it" (Raval, 2023).

The whole range of publications, even those issued in the first decade of our century, demonstrate that Mixed Reality (MR) is not a unified or stable concept within architecture, design, and construction literature. Instead, it is interpreted through multiple epistemological lenses ranging from technical infrastructure to spatial theory, design methodology, and experiential environments. These differences reveal distinct understandings of MR's purpose, scope, and implications.

In particular, in this work of Seibert and Dähne (2006), MR is primarily conceptualized as a computational and system-level framework. The focus lies on the technical architecture required to integrate virtual and physical environments. MR is defined as a modular system architecture combining hardware and software components, while emphasis is placed on system design, interfaces, and interoperability. However, in the authors' vision, MR functions as a technological infrastructure layer rather than a design or spatial paradigm.

The work by Wang & Schnabel (2009) positions MR as a practical instrument embedded within architectural workflows. In the work, MR is framed as an integrated design-support technology, bridging digital modeling and physical construction processes. At the same time, the authors claim that emphasis shifts toward real-time collaboration and visualization, and important purpose of MR is to support collaborative workflows across design and construction phases.

Janusz (2019) emphasizes MR as an immersive and user-centered design environment, particularly in interior architecture. MR in this work is defined as an interactive experiential space, and focus is placed on perception, immersion, and user engagement. The author claims that design becomes experience-driven rather than representation-driven, and users are repositioned as active co-creators of spatial outcomes. Here, MR is primarily understood as a medium of spatial experience and perception, MR supports participatory and perceptual design methodologies.

The unique characteristic of MR technology allows digital things to seamlessly interact with actual world components, breaking away from standard AR-like augmentative display techniques and avoiding complete immersion in VR. Mixed Reality represents an utter revolution for the product designers that employ it. Mixed Reality evolves from an inventive technology to an operational technology that fundamentally transforms product design development processes. Three industrial areas, including automotive, fashion, healthcare, and consumer technology, benefit significantly from the deployment of MR technology.

MR really became an instrument of 'designing the future'. MR solutions do not only provide excellent potential for improving quality and raising speed of designing in various fields, but also is a driver of paradigm shift in design, making it both real-time and participative.

Equity-centered co-design, a participatory method that emphasizes the early engagement of professionals, academics, and members of various communities, should be highlighted in this context. This approach makes sure that the particular requirements and issues of the most frequently disregarded groups are taken care of. Equity-centered co-design produces inclusive experiences that benefit everyone, drawing inspiration from the idea of curb-cutting, in which a solution intended for one group really helps a large number of people (Bazzano et al.. 2022).

The foundation of this method is the idea that creating with communities, as opposed to for them, results in far better product experiences for everybody. It is feasible to develop technologies that accurately represent the wide range of demands of users worldwide by incorporating people's distinct viewpoints, experiences, and insights into design choices. Co-design is therefore more than simply a process; it is a fundamental component of dedication at the nexus of innovation and inclusiveness.

A case study of the design process for the digital and physical versions of the Nordic pavilion, which is considered a cultural treasure, at the Venice Biennale is presented in Reaver (2022). In order to investigate how technologies affect user interactions and design decision-making, the case supported a multiuser collaboration in mixed reality. The case study took place between 2019 and 2022, mostly during the COVID-19 epidemic, and was renamed the "Sami Pavilion" in honor of the Sami artists from Norway, Sweden, and Finland that were represented in the show. The case presented intriguing challenges to popular Nordic architectural theory, particularly that of "genius loci" or the "spirit of place", which was a significant part of the building's heritage value and, therefore, an important design narrative. This was because the transferability of predictive design decisions in MR to the physical building depended on replication between user experiences. In order to replicate the spatial experience of the design possibilities, curators and designers evaluated artworks and their placements in several combinations within the MR model, as detailed in the case study. Based on the distinct perspectives provided by MR, a number of important design choices were made. After that, 2D technical documentation and installation instructions were created using the MR model and put into place on the job site.

Following the completion of the necessary preparations, the model was shown to the curatorial and artist teams in the aforementioned case study in order to create the exhibition. In order to verify the curatorial and creative vision from a first-person perspective using images and model walkthroughs, artworks were positioned in different ways over the first four workshop sessions. The duration of each session was around one hour. Each program typically has three to six participants. These were team members that worked as curators and exhibition designers. To mimic the spatial experience, artworks and their placements were examined in a variety of model configurations. The curatorial team mentioned that it was simpler to make judgments using the curation inside the MR model and expressed enthusiasm and curiosity in being able to view the exhibition space in such a media. In order to better understand the multiplayer concept in MR and to gather comments, the curatorial team visited it after the first sessions. The team utilized three Oculus Quest 2 headsets connected through the hosted Arkio session in a studio located within the Oslo School of Architecture and Design to accomplish this. Participants tested the artwork models and moved them interactively once they were within the standard MR model. In the model, participants interacted with one another while viewing several artwork locations and possibilities. Overall, the team discovered that testing in MR initially helped curators and artists better understand a number of perspectives and had a big influence on the finished design. Since the team saw numerous important decisions being made during the workshop sessions that informed the final design, it would be hard to see the final design turning out the way it did without the process. For instance, artworks were repositioned from wall placements to the floor in response to view corridors, and important pieces of art were repositioned totally because of vantage points inside the virtual model (Reaver, 2022).

The distinctive feature of Participatory Design, in contrast to other types of human-centered design approaches, is the methodical use of creative techniques that involve users' active engagement in idea generation. Finding interactive solutions for particular requirements is the goal. According to Bruce (2022), creativity methods are informal or projective procedures that show in tangible terms the forms of future systems that consumers desire. To put it another way, these techniques have a powerful revealing power and are a means of creating practical and useable prototype forms that are suitable candidates to address needs established throughout the Participatory Design observation phases. By encouraging the user's participation and involvement throughout the design process, participatory design techniques aid in the elicitation of user needs. Users may express requirements, participate in the development of design solutions, test those solutions, and discover new requirements. To put it another way, the widespread use of MR technologies in industrial and art/culture design has made the sharing and inclusivity paradigm a fundamental component of design, further integrating it with the sharing economy and relevant social advancements.

Addressing inequality and the emergence of new social interaction models is more crucial than ever in a society with a wide variety of perspectives. Positive social transitions may be greatly influenced by design, and practitioners highly regard social design and participatory practices as ways to engage vulnerable populations (Csernák, 2024). Park et al. (2022), for instance, discuss mixed reality real-time co-design for the preservation and maintenance of Maori (NZ) indigenous culture. The authors demonstrate that mixed reality experiences can be a useful tool for the expanding Maori diaspora to access and experience their language, genealogy, families, histories, and knowledge through co-design, close collaboration with indigenous partners, and careful consideration of cultural context (see Fig. 5). In particular, creating experiences that satisfy the requirements of local groups while reflecting and honoring their culture and worldview required cooperative co-design and an awareness of cultural values throughout the project.

Figure 5: Left: Entrance to the marae* (wharenui in the background); Center: User exploring the 3D reconstructed marae; Right: Screenshot of reconstructed marae as experienced by user

Source: Park et al. (2022)

* ceremonial meeting-grounds

According to Smith and Iversen (2018), trends in modern participatory design point to a shift away from involving a small number of stakeholders in predetermined design procedures and technology outcomes and toward more intricate and sustained interactions with diverse communities and broader ecologies of social and technological change. In the MR landscape, participatory real-time design enables the use of a design technique where future users of a design take part as co-designers. Its dedication to the democratic and social building of a better future makes it a value-centered design method.

To provide a structured synthesis of the mixed reality implementation scenarios discussed above, the principal technological, interactional, and workflow-related characteristics of the analyzed design cases are summarized in Table 3. This comparative systematization supports cross-case interpretation and enables the identification of recurring methodological patterns across heterogeneous spatial design contexts.

Table 3. Comparative Characteristics of Mixed Reality Design Implementation Cases

Parameter	*Aircraft Galley MR*	*Nordic Pavilion MR*	*Māori Cultural MR*
Application Domain	Industrial and aircraft interior design	Exhibition and spatial installation design	Cultural heritage and participatory design
Primary Design Objective	Ergonomic usability validation	Artwork placement and spatial coordination	Cultural knowledge preservation and community engagement
Type of Interaction	Task-based operational simulation	Multi-user collaborative spatial exploration	Participatory co-design interaction
Main Users	Crew member and human factors specialist	Curators and exhibition designers	Cultural stakeholders and community participants
Spatial Visualization Mode	Full-scale functional workspace simulation	Immersive gallery navigation	Narrative-based spatial exploration
Workflow Structure	Sequential usability testing workflow	Iterative collaborative workshop workflow	Community-driven co-design workflow
Number of Participants	Two users	3–6 participants	Multiple community participants
Key Design Feedback Mechanism	Ergonomic observation and task performance	Real-time spatial repositioning	Cultural consultation and iterative feedback
Observed Advantages	Reduced need for physical prototypes	Improved spatial decision-making	Enhanced cultural accessibility and preservation
Primary Limitations	Hardware dependency and calibration complexity	Learning curve and device accessibility	Technological accessibility and ethical sensitivity

Source: developed by the authors

The comparative synthesis presented in Table 3 demonstrates that despite differences in functional domains, all examined mixed reality implementations share common structural characteristics, including real-time visualization, iterative feedback cycles, and collaborative interaction frameworks. At the same time, domain-specific variations reveal the adaptability of mixed reality technologies to diverse spatial and cultural environments. The aircraft design case emphasizes ergonomic precision, the exhibition design case prioritizes collaborative spatial coordination, and the cultural heritage case highlights the importance of participatory and socially responsive design processes. These observations support the interpretation of mixed reality not only as a visualization technology but also as a methodological environment capable of transforming design workflows across multiple disciplinary contexts.

6. Societal Implications of Mixed Reality Design

Beyond technical and methodological considerations, the expansion of mixed reality technologies into spatial design introduces significant societal implications that influence how environments are conceptualized, communicated, and collectively experienced. As immersive technologies become increasingly accessible, their role extends beyond professional practice into broader cultural and civic contexts.

One of the most prominent societal implications concerns the democratization of design participation. Mixed reality environments enable stakeholders without formal architectural training to engage directly with spatial models, evaluate design alternatives, and contribute feedback during early project stages. This shift supports the development of more inclusive planning processes and aligns with contemporary participatory design principles that emphasize transparency, shared authorship, and collective decision-making.

The Māori cultural case discussed in this study demonstrates the potential of mixed reality technologies to support cultural preservation and knowledge transmission. Immersive environments enable the visualization of culturally significant spatial structures and narratives, facilitating intergenerational communication and safeguarding intangible heritage. Such applications extend the role of mixed reality beyond technological innovation into the domain of cultural sustainability.

Another societal implication relates to the transformation of educational and public engagement practices. Mixed reality technologies provide new opportunities for architectural education, museum exhibitions, and community consultations by enabling users to explore spatial environments interactively. This capability enhances spatial literacy among diverse audiences and supports more informed public participation in planning and design processes.

At the same time, the integration of immersive technologies raises critical concerns related to accessibility, ethics, and digital equity. Unequal access to advanced hardware and technical infrastructure may reinforce existing social disparities, particularly in communities with limited technological resources. Additionally, the representation of culturally sensitive spatial knowledge within digital environments requires careful governance to ensure respectful and contextually appropriate use.

In this regard, the responsible implementation of mixed reality technologies requires interdisciplinary collaboration among designers, technologists, cultural representatives, and policymakers. Establishing ethical guidelines and participatory governance models will be essential for ensuring that immersive design technologies contribute to socially responsible and culturally inclusive spatial development.

7. Conclusion

The conducted study confirms that mixed reality technologies represent a transformative force in the evolution of contemporary digital design, particularly within the paradigm of real-time interaction and participatory practices. The integration of physical and digital environments creates fundamentally new opportunities for designers to visualize, test, and modify concepts dynamically, ensuring higher levels of accuracy, collaboration, and user engagement throughout the design process. The structural and functional analysis applied in this research demonstrates that MR functions not only as a technological tool but also as a socio-cultural medium that supports the convergence of technological innovation and human-centered design approaches.

One of the key findings of the study is the growing significance of participatory and co-creative practices enabled by MR environments. Real-time digital design allows stakeholders, experts, and users to participate in decision-making processes from the earliest stages of project development, contributing to the democratization of design and the creation of solutions that better reflect the needs and expectations of diverse communities. Such practices foster inclusive design environments and enhance communication among interdisciplinary teams, ultimately leading to more sustainable and context-sensitive outcomes. The ability of MR technologies to support immersive visualization, rapid prototyping, and remote collaboration significantly reduces design errors and improves the efficiency of project implementation.

The interdisciplinary nature of mixed reality applications further reinforces their strategic value in architecture, urban planning, cultural heritage preservation, industrial design, and community-oriented projects. The findings highlight that MR environments facilitate the emergence of new design ecosystems where emotional, spatial, and social dimensions are integrated into the development of innovative solutions. In this sense, mixed reality becomes not only a technical instrument but also a conceptual framework for rethinking the future of design as an interactive and continuously evolving process.

In summary, MR functions as a multi-layered epistemic construct that operates across infrastructure, spatial, operational, and experiential levels. However, its effectiveness in architectural and design practice cannot be assumed a priori; it must be evaluated through context-specific criteria and methodologically transparent assessment frameworks.

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