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Immersive Technologies in Architecture

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ABSTRACT

An immersive technology is a dynamic emerging technology that challenges traditional notions of art and architecture. Immersive technologies have the potential to change how we communicate and learn by offering new opportunities for engagement, creativity, and problem-solving. Architects and designers use these technologies to create virtual walkthroughs, 3D visualizations, and interactive models of buildings and spaces. The use of immersive technologies in architecture is rapidly becoming increasingly significant, and it is transforming the way architects design, conceptualize, communicate, construct, and collaborate. Immersive technologies like virtual reality (VR), augmented reality (AR), and mixed reality (MR) are used in architecture to help designers visualize and communicate their ideas. Architects use them to communicate their ideas to clients and colleagues. In this paper, we will explore how immersive technologies are reshaping our understanding of reality and virtual environments in architecture.

***KEYWORDS:** virtual reality, VR, augmented reality, AR, mixed reality, MR, extended reality, XR, immersive technologies, architecture, architecture industry*

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INTRODUCTION

In the ever-evolving realm of architecture, the integration of cutting-edge technologies has revolutionized the way architects and designers conceptualize, plan, and communicate their ideas. Immersive technologies (ImT) have emerged as a groundbreaking tool that is transforming the field of architecture. They create highly interactive and engaging digital experiences, blurring the boundaries between the real and virtual.

Immersive technologies have the potential to impact the way we work, learn and interact with one another. They allow architects to step inside their designs, engage clients in immersive experiences, collaborate more effectively, and enhance overall project efficiency. Figure 1 shows a typical massive architectural design [1].

Immersive technologies, commonly used in gaming and entertainment, have become integral to architectural design, altering how spaces are envisioned. They create distinct experiences by merging the physical world with a digital or simulated reality. They are providing a new way for architects to design buildings and interior spaces, allowing for a more detailed and interactive experience for clients. They provide an improved means of communicating the experience of unbuilt designs to clients who cannot always envision a spatial experience from 2D representations. As immersive technologies have matured, they provide a powerful way to put that data to work.

WHAT ARE IMMERSIVE TECHNOLOGIES?

The first step in understanding how to use immersive technologies is to learn the differences between its various forms. In their simplest form, immersive technologies consist in adding virtual objects to the real world. There are four types of digital realities leading to different types of immersive technologies [2,3]:

- *Augmented reality* (AR)- designed to add digital elements over real-world views with limited interaction.
- *Virtual reality* (VR)- immersive experiences helping to isolate users from the real world, usually via a headset device and headphones designed for such activities.

- *Mixed reality* (MR)- combining AR and VR elements so that digital objects can interact with the real world means businesses can design elements anchored within a real environment.
- *Extended reality* (XR)- covering all types of technologies that enhance our senses, including the three types previously mentioned.

These devices also enable new user interactions including spatially tracked 3D controllers, voice inputs, gaze tracking, and hand gesture controls.

Extended reality (XR) is the overarching term used to describe employing technology to blend real life and the digital world. It includes all the machine-human interfaces beyond the physical realm (reality) such as augmented reality (AR), mixed reality (MR), assisted reality (aR), and virtual reality (VR), as illustrated in Figure 2 [4]. Figure 3 shows the XR spectrum [5]. Immersive technologies reside along a continuous scale ranging between the completely real and the completely virtual world. At one end, the real environment refers to the actual physical space, objects, and people that exist in the tangible world around us. At the other end, the virtual environment represents a completely computer-generated and immersive digital space, distinct from the physical reality. The space in the middle is called mixed reality, which is a blend of the real and virtual environments, where digital and physical elements coexist and interact in real time. A range of devices makes up XR, and these are used by consumers and in many industries for entertainment, safety, training, or productivity purposes.

1. *VIRTUAL REALITY:* Virtual reality (VR) is XR at its most extreme. It completely immerses the user in a digital world, often using a computer-generated environment with scenes and objects that appear to be real. The term “virtual reality” essentially means “near-reality.” Virtual reality is the key technology for experiencing sensations of sight, hearing, and touch of the past, present, and future. VR is a fully immersive technology where users wear a head-mounted display and experience a simulated world of imagery and sounds. VR enables active learning. The terms, “virtual reality” and “cyberspace” are often used interchangeably. A cyberspace may be regarded as a networked virtual reality. A person using virtual reality can look around an artificial world, move around it, and interact with virtual features or items. This effect is commonly created by virtual reality headsets. Head-mounted displays immerse the user in a virtual environment. Virtual reality is a simulated experience that can be similar to or different from the real world. It is a computer-generated, 3D environment that completely immerses the senses of sight, sound, and touch. The complete immersion of the senses overwhelms users engrossing them in the action. Virtual reality technology includes multiple components divided into two main groups: hardware and software components [6].

- *Hardware Components:* The hardware components include a computer workstation, sensory displays, a tracking system, wearable devices, and input devices. Sensory displays are used to display the simulated virtual worlds to the user. The most common type is the head-mounted displays (HMDs), which is used in combination with tracking systems. Head-mounted displays are shown in Figure 4 [7]. Users interact with the simulated environment through some wearable devices. VR depends on special responses such as raising hands, turning the head, or swinging the body. A wearable device is important in making these effects realistic. Special input devices are required to interact with the virtual world. These include the 3D mouse, the wired glove, motion controllers, and optical tracking sensors. These devices are used to stimulate our senses together to create the illusion of reality.
- *Software Components:* Besides the hardware, the underlying software plays an important role. It is responsible for the managing of I/O devices and time-critical applications. The software components are 3D modeling software, 2D graphics software, digital sound editing software, and VR simulation software. VR technology has been designed to ensure visual comfort and ergonomic usage.

2. *AUGMENTED REALITY:* Augmented reality (AR) is a technology that combines real-world environments with computer-generated generated information such as images, text, videos, animations, and sound. It can record and analyze the environment in real-time. In augmented reality, the user typically experiences the real world through a device such as a smartphone, tablet, smart glasses, or head-mounted display. For example, AR allows consumers to visualize a product in more detail before they purchase it. This feature enhances consumer interaction and helps them never to repurchase the wrong item. The key objective of AR is to bring computer-generated objects into the real world and allows the user only to see them. In other words, we use AR to track the position and orientation of the user’s head to enhance/augment their perception of the world. Augmented reality falls into two categories: 2D information overlays and 3D presentations, like those used with games. AR blends the virtual and real worlds by overlaying digital

objects and information onto the users' view of the physical world.

To obtain a sufficiently accurate representation of reality, AR needs the following five components [8]:

- *Sensors:* AR needs suitable sensors in the environment and possibly on a user, including fine-grained geolocation and image recognition. These are activating elements that trigger the display of virtual information.
- *Image augmentation:* This requires techniques such as image processing and face recognition.
- *Head-mounted Display*: HMDs are used to view the augmented world where the virtual computer-generated information is properly aligned with the real world. Display technologies are of two types: video display and optical see-through display.
- *User Interface:* This includes technologies for input modalities that include gaze tracking, touch, and gesture. AR is a user interface technology in which a camera-recorded view of the real world is augmented with computer-generated content such as graphics, animations, and 2D or 3D models.
- *Information infrastructure:* AR requires significant computing and communications infrastructure undergirding all these technologies. The infrastructure determines what real-world components to augment, with what, and when.

3. *MIXED REALITY:* Mixed reality (MR) is a term used to describe the merging of a real-world environment and a computer-generated one. Physical and virtual objects may co-exist in mixed reality environments and interact in real time. This is an extension of AR that allows real and virtual elements to interact in an environment. MR liberates us from screen-bound experiences by offering instinctual interactions with data in our living spaces and with our friends. Online explorers, in hundreds of millions around the world, have experienced mixed reality through their handheld devices. Mixed reality is a blend of physical and digital worlds, unlocking natural and intuitive 3D human, computer, and environmental interactions, as shown in Figure 5 [9]. This new reality is based on advancements in computer vision, graphical processing, display technologies, input systems, and cloud computing. Mixed reality has been used in applications across fields including design, education, entertainment, military training, healthcare, product content management, and human-in-the-loop operation of robots [10].

4. *ASSISTED REALITY:* Like mixed reality, assisted reality (aR) is an extension of augmented reality, with a few notable differences to both. One of these differences is that aR is primarily hands-free through the wearing of a headset, whereas AR usually requires the holding of a device such as a mobile phone. While MR is a digital-first, real-world second reality, aR is a real-world first system. It combines software and a head-mounted display. It is best experienced using smart glasses or other wearable technology. The aR market is growing rapidly and promises to be the next great leap to boost workers' productivity. A worker wearing an aR device is shown in Figure 6 [11].

5. *EXTENDED REALITY:* The term "extended reality" (XR) has recently gained favor as an umbrella term that encompasses all of AR, VR, and MR. The primary user inputs for XR devices are described as follows. Voice interfaces are now ubiquitous thanks to mobile devices and standalone smart speakers. Apple's Siri, Amazon's Alexa, Google's Assistant, and Microsoft's Cortana are all voice-driven software interfaces that are continuously gaining new capabilities. Many XR devices enable user control with handheld controllers, which have capabilities beyond button press inputs. Both voice-driven interfaces and human-computer interactions have been developed specifically for XR devices, including gaze and gesture controls [12]. Figure 7 compares conventional computing with extended reality [12].

IMMERSIVE ARCHITECTURE

In a world where technology continually blurs the boundaries between the real and the virtual, architecture is undergoing a revolutionary transformation. Architecture has gradually changed from traditional 2D drawings and physical models in recent years.

Immersive architecture is at the forefront of this gradual change, acting as a bridge between two distinct worlds: the physical environment we inhabit and the virtual landscapes we explore. It is redefining the concept of architecture design and revolves around creating environments that go beyond the static confines of traditional spaces. It weaves the physical and virtual realms together, immersing individuals in experiences that are both tangible and intangible.

Immersive architecture takes the concept of architectural design to a whole new level by creating environments that fully immerse the user in a sensory experience. Immersive technology in architectural design allows the creation of virtual project representations where space use can be optimized and potential design problems can be identified. Virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies play a significant role in immersive architecture, allowing architects to figure the exterior architecture design that transport occupants to other worlds or provide unique and captivating experiences. Architects can use VR for conducting user studies, presenting collaborative designs, building management, and design education. AR can be utilized for client communications in the same universal way that email, video calls, and 3D design software have in the past. Unlike VR, which creates a totally new and independent environment of the real world, AR includes virtual elements that interact with what already exists. MR combines the real-world environment and a virtual content world, enabling architects to collaborate in real time using holograms. Immersive technology tools and software often need other supporting technologies like headsets, 3D displays, 3D audio, gesture recognition readers, spatial sensing, speech recognition devices, haptics, drones, cameras, and omnidirectional treadmills that are used to fully connect with the various immersive technologies [13]. Figure 8 shows an example of how ImT is used in architecture [1].

As virtual, augmented, and mixed reality technologies continue to advance and be integrated into the architecture industry, there may be a learning curve involved for many in the industry. These immersive technologies in architecture have begun to be used in the design process.

APPLICATIONS OF IMMERSIVE TECHNOLOGIES IN ARCHITECTURE

The potential applications and future directions for immersive architecture are vast and exciting. Immersive technologies have integrated many fields, including gaming, entertainment, education, training, healthcare, architecture, retail, real estate, and design. We can anticipate its further integration into urban planning, public spaces, design visualization, client engagement, and even personal homes. This could lead to the creation of smart cities with immersive urban experiences, sustainable buildings with adaptive interiors, and personalized virtual environments tailored to individual preferences. Common areas of applications include the following [14-16]:

- *Design Visualization:* Virtual reality offers architects an unprecedented opportunity to bridge the gap between imagination and reality. Real-time visualization is crucial, not only for speeding up workflows but also for maintaining the creative momentum that is essential in architectural design. Traditionally, architects relied on 2D drawings and static 3D models to convey their design concepts. VR, however, empowers architects to create immersive, interactive 3D environments that provide a true sense of scale, proportion, and spatial relationships. Through VR, architects can navigate through their designs as if they were physically present within them. It aids in making design decisions, as architects can experience the design from various angles, lighting conditions, and even simulate user interactions. A typical design visualization is shown in Figure 9 [17].
- *Spatial Design:* As virtual worlds and spatial experiences evolve, our holistic perception of design is gradually changing. Design principles currently re-shaping Web3 and XR are also influencing real architectural environments. Apple has done a great job in providing design standards for spatial user interfaces. An example of spatial design using ImT is shown in Figure 10 [18].
- *Client Engagement:* One of the key advantages of incorporating virtual reality in architecture is the ability to actively engage clients in the design process. For clients, understanding architectural plans and visualizing the end product can be challenging, as they often lack the technical expertise to interpret traditional architectural drawings. VR solves this problem by offering a highly intuitive and immersive way for clients to explore and understand architectural designs. With VR, clients can put on a headset and walk through their future space, experiencing the design firsthand. They can provide feedback on the design in real-time, enabling architects to make adjustments and refinements on the spot.
- *BIM with AR*: The vast amount of information that a BIM model holds within it is difficult to structure and exchange, which can affect efficiency at a construction site in addition to a huge amount of time for site workers. However, AR is an effective way of retrieving the information and providing a seamless medium to project the information. The vast amount of data and interaction involved in the construction project can be accessed easily by AR, thus making it an important and seamless possible way for detecting aspects involved with the view of a user. The amalgamation of BIM with AR in particular and with ImTs in general is not only leveraging the smart and convenient way to be adopted in the AEC industry, rather they have a considerable impact on many other facets, namely the business promotion of projects, research studies in institutions, and enhancing the education of AEC professionals.

- *GAMMA Augmented Reality*: This is a building site monitoring application that uses augmented reality technology to overlay BIM 3D buildings via smartphones or tablets. It enables 3D BIM models to be viewed before and during the building process, creating an understanding of planning, avoiding errors, and reducing construction costs.
- *Simulation:* Immersive technologies enables architects and engineers to analyze potential issues before construction begins. Simulation tools using AR/VR help designers predict how a building will perform in the real world. By incorporating data such as weather patterns, traffic flows, crane and pedestrian movements, engineers can test the limits of a design before a brick is even laid. By using immersive virtual mock-ups, professionals can identify and address potential challenges more efficiently. Simulating real-world scenarios such as lighting conditions or energy performance can aid in the optimization of the building design. Developers can let stakeholders and end-users walk through new buildings without being physically on-site or immerse themselves in simulated environments.
- *Real Estate:* ImT has been a game-changer in various industries, and its applications in the real estate sector are no exception. In the real estate industry, immersive technology has made it increasingly possible to provide potential buyers with realistic, interactive experiences of properties. By utilizing VR and AR, real estate agents can showcase their properties to clients located anywhere in the world without the need for physical viewings. This not only saves time and money but also opens up new possibilities for international clientele, allowing the industry to expand its reach.
- *Home Tours:* Using VR/AR, prospective buyers can explore properties remotely. This convenience allows for a more efficient and streamlined viewing process, benefiting both the agent and the buyer. For example, AR can revolutionize the way potential buyers visualize properties by providing realistic, 3D representations of homes and their interior spaces.
- *Property Management:* AR tools can help property managers better understand their assets, monitor the state of their properties, and make informed decisions about maintenance and renovation requirements. ImT can enhance the communication and collaboration between property managers, landlords, tenants, and construction teams during the planning and execution of projects, ultimately improving efficiency and outcomes.
- *Education and Training:* Immersive technologies are making inroads into architectural education and professional training. They can be used in architecture education to help students experience spaces that they might not otherwise be able to. Architecture students can use VR to explore historic buildings, iconic structures, and renowned architectural designs from around the world, offering them valuable experiential learning opportunities. Immersive technologies offer new possibilities in education and training. They create immersive learning environments that simulate real-world scenarios for training purposes, enhance visualization and understanding of complex concepts, and provide interactive and hands-on experiences. ImT can be used to train real estate agents, architects, and other professionals in a more engaging and interactive way. This can help them better understand complex concepts and improve their skills.

BENEFITS

Virtual reality and augmented reality can improve design reviews, client presentations, spatial planning, virtual prototyping, and product design. With the advent of augmented reality (AR), architects will have new opportunities to blend the virtual and physical environments, offering enhanced design and construction experiences. Other benefits include the following [19]:

- *Collaboration:* In the architecture and construction industry, collaboration is a fundamental aspect of successful project delivery. VR has emerged as a transformative tool for enhancing collaboration among architects, designers, engineers, and other stakeholders. It overcomes the limitations of traditional communication methods by enabling real-time, interactive, and immersive collaboration. Architectural projects often involve a myriad of professionals with diverse expertise. With VR, these professionals can virtually come together in a shared digital environment, regardless of their physical locations.
- *Communication:* Communication with stakeholders in the AEC industry has always been heavily reliant on visual means such as sketches, two dimensional (2D) drawings and images. Further advancements in technology, such as building information modelling (BIM) and immersive technologies, made it possible to

project designs in three-dimensions (3D), which profoundly revolutionized the industry.

- *Cost Reduction:* Immersive technologies, such as VR, enable architects and real estate professionals to create realistic simulations of properties and spaces, through virtual property tours, virtual staging, design visualization, collaborative design, training and education, reducing the need for physical models and on-site visits. This leads to significant cost savings in the long run.
- *Efficiency:* Efficiency is a critical factor in architecture, where time and resources are often limited. Immersive technology enables faster decision-making as virtual reality enables stakeholders to make quicker and more informed decisions about design elements and property investments. Virtual reality plays a vital role in streamlining the design process, reducing errors, and saving both time and money. Through VR, architects can conduct design iterations rapidly and assess the impact of design changes immediately. VR aids in minimizing construction errors.
- *Sustainability:* Immersive technologies like VR, AR, and BIM are revolutionizing sustainable architecture by enabling architects to incorporate eco-friendly principles from the very beginning. VR can be instrumental in sustainability considerations. Architects can use VR to simulate various environmental conditions, such as natural lighting and thermal comfort, to optimize energy efficiency and reduce the building's ecological footprint.
- *Storytelling:* Immersive architecture is not only about aesthetics but also about storytelling and creating emotional connections between the architecture and its occupants. As a storytelling medium for architects, VR allows individuals to immerse themselves in the atmosphere, explore, and interact with the functionality and purpose of a digital representation of a proposed design. It encourages self-expression, customization, and the exploration of individual needs.
- *Infrastructure Design:* Immersive technologies help government planners visualize and assess proposed infrastructure projects, such as a new bridge, allowing stakeholders to explore 3D models to simulate scenarios and understand the potential impact on the environment and communities before implementation.
- *Heritage Preservation:* Immersive technologies can preserve and showcase cultural heritage sites and artifacts by allowing users to virtually explore historical sites, museums and archaeological sites, providing access to cultural experiences and artifacts that may be physically inaccessible or at risk.
- *Marketing:* The potential for VR in architectural marketing and presentations is substantial. Real estate developers, for example, can use VR to showcase properties to potential buyers, providing immersive experiences that convey the atmosphere and functionality of spaces that are yet to be built.
- *Smart Materials:* The intersection of light, material, and architecture is at the heart of frameless immersive art experiences. The development of smart materials (materials that can change properties in response to external stimuli) offers new possibilities for ImT. These materials can be designed to change color, transparency, or texture in response to light, temperature, or touch, creating dynamic, responsive environments.

CHALLENGES

Modernization was one of the biggest challenges faced by the AEC industry. Recently, however, the industry has been exposed to immersive technologies. Immersive technologies come with challenges like cost and technical expertise. With the expected increase of integration of immersive tools as the technology advances, it will become more accessible, with lower costs, better hardware, and more user-friendly software. To develop VR content that is truly engaging and compelling is a challenge that requires a considerable set of skills as well as resources. Other challenges include the following [19]:

- *Cost:* The cost is one of the major challenges that could restrain accessibility to ImT devices. The high cost of peripherals is a major concern for the wide adoption of ImT across various industries. Immersive technologies are expensive to implement since the cost of both procurement and maintenance of sophisticated devices and applications become prohibitive. The cost of immersive technologies may be too high to convince management to adopt it. Newer technologies rapidly make older systems obsolete and increase their life-cycle costs. As technology evolves, VR hardware becomes more accessible and affordable, making it a viable tool for architects of all scales and budgets.
- *Side Effects:* The use of immersive technologies can bring side effects to the user. The most common being nausea, similar to motion sickness, as the brain cannot correlate the motion

observed by the eyes with that of the body standing still in a room. Physical discomfort and ocular fatigue may also occur from prolonged use of immersive devices.

- *Ethics:* Ethical considerations around privacy and data security will become increasingly important as VR is used in sensitive architectural applications. Ethical issues also include prolonged exposure to the virtual environment resulting in users facing difficulties in performing normal tasks in the real world.
- *Emerging Technologies*: Designers can leverage emergent technologies to create and design new structures. For example, virtual reality (VR) and artificial intelligence (AI) are rapidly transforming the way we design and experience architecture. VR enables remote collaboration, while AI is a game changer for the residential architecture, real estate, and design industry.
- *Error:* As the AEC industry is accident-prone, the incorrect interpretation of information is common, mainly due to a less skilled workforce, which eventually increases the cost of a project, reduces the quality, and delays the schedule.

CONCLUSION

Immersive technology is already impacting architectural practice in all phases of the project lifecycle, from its use as a visualization platform to its function as an analytical tool. The significance of immersive technologies in architecture continues to grow, and the future holds even more promise. As technological advances expand, these immersive experiences reshape the ever-growing architectural field. Architects who embrace these technologies will be better positioned to create innovative, efficient, and sustainable structures that meet the ever-evolving needs of society.

Both interactive and immersive architecture concepts are instrumental in shaping the future of architecture design. They enable modern architects to push the boundaries of creativity, offering endless possibilities for creating spaces that are not only visually striking but also highly functional and engaging [20]. More information on the integration of immersive technology into the architecture industry is available from the books in [21-26] and the following related journals:

- *Technologies*
- *Automation in Construction*

REFERENCES

[1] R. Nieminen, “Immersive technology may be architecture’s best tool for communication,” May 2018, https://www.archpaper.com/2018/05/immersive-technology-architectures-best-tool-communication/

[2] M. N. O. Sadiku, C. M. M. Kotteti, and S. M. Musa, "Augmented reality: A primer," *International Journal of Trend in Research and Development,* vol. 7, no. 3, 2020.

[3] “What is augmented reality or AR?” https://dynamics.microsoft.com/en-us/mixed-reality/guides/what-is-augmented-reality-ar/

[4] L. van Heerden, “What is extended reality?” August 2021, https://journeyapps.com/blog/what-is-extended-reality/

[5] A. Xperteye, “What is assisted Reality? Here is what you need to know,” March 2022, https://blog.amaxperteye.com/what-is-assisted-reality-here-is-what-you-need-to-know

[6] M. O. Onyesolu and F. U. Eze, “Understanding virtual reality technology: Advances and applications,” *Advances in Computer Science and Engineering*, March 2011, pp. 53-70.

[7] “VR rundown: What you need to know before buying a VR System for your school,” https://vreddo.com.au/vr-rundown-what-you-need-to-know-before-buying-a-vr-system-for-your-school/

[8] M. Singh and M. P. Singh, “Augmented reality interfaces,” *IEEE Internet Computing*, November/December 2013, pp. 66-70.

[9] “What is mixed reality?” January 2023, https://learn.microsoft.com/en-us/windows/mixed-reality/discover/mixed-reality

[10] “Mixed reality,” *Wikipedia*, the free encyclopedia, https://en.wikipedia.org/wiki/Mixed_reality

[11] “What is assisted reality? Here is what you need to know,” March 2022, https://blog.amaxperteye.com/what-is-assisted-reality-here-is-what-you-need-to-know

[12] C. Andrews et al., “Extended reality in medical practice*,” Current Treat Options Cardiovasc Medicine,* vol. 21, no. 4, March 2019.

[13] “Architecture trends: Immersive technologies,” https://www.re-thinkingthefuture.com/architectural-styles/a11643-architecture-trends-immersive-technologies/#:~:text=Immersive%20technologies%20provide%20an%20improved,relatively

%20uncommon%20in%20architectural%20practice.

[14] "The significance of virtual reality in architecture: An immersive evolution," https://www.cuubstudio.com/blog/the-significance-of-virtual-reality-in-architecture-an-immersive-evolution/#:~:text=Virtual%20Reality%20(VR)%20has%20emerged,and%20enhance%20overall%20project%20efficiency.

[15] A. Prabhakaran, A. Mahamadu, and L. Mahdjoubi, "Understanding the challenges of immersive technology use in the architecture and construction industry: A systematic review," *Automation in Construction,* vol. 137, May 2022.

[16] "Immersive technology in architecture," https://drawandcode.com/sectors/immersive-in-architecture/

[17] M. Terenzio, "Immersive spatial design-Unifying the best of the physical and virtual world," https://interiorarchitects.com/immersive-spatial-design/

[18] G. Boulet, "Immersive technologies explained," September 2023, https://www.csps-efpc.gc.ca/tools/articles/immersive-technologies-eng.aspx

[19] "Immersive architecture: A new connection between two worlds of reality and virtual," https://huurstudios.com/immersive-architecture-connection-reality-virtual/

[20] A. Prabhakaran et al. (eds.), *Applications of Immersive Technology in Architecture, Engineering and Construction: A Handbook (Spon Research).* Routledge, 2025.

[21] L. Psarologaki, *Site-Reliant Immersive Experiences: Sensing Affective Spaces in Art and Architecture.* Bloomsbury Visual Arts, 2025.

[22] S. Eloy, A. Kreutzberg, and I. Symeonidou (eds.), *Virtual Aesthetics in Architecture: Designing in Mixed Realities.* Routledge, 2021.

[23] A. Kreutzberg, I. Symeonidou, and S. Eloy (eds.), *Virtual Aesthetics in Architecture: Designing in Mixed Realities.* Taylor & Francis, 2021.

[24] M. A. Schnabel and X. Wang (eds.), *Mixed Reality In Architecture, Design, And Construction*. Netherlands: Springer, 2009.

[25] D. Bertol and D. Foell, *Designing Digital Space: An Architect's Guide to Virtual Reality.* Wiley, 1997.

Figure 1 A typical massive architectural design [1].

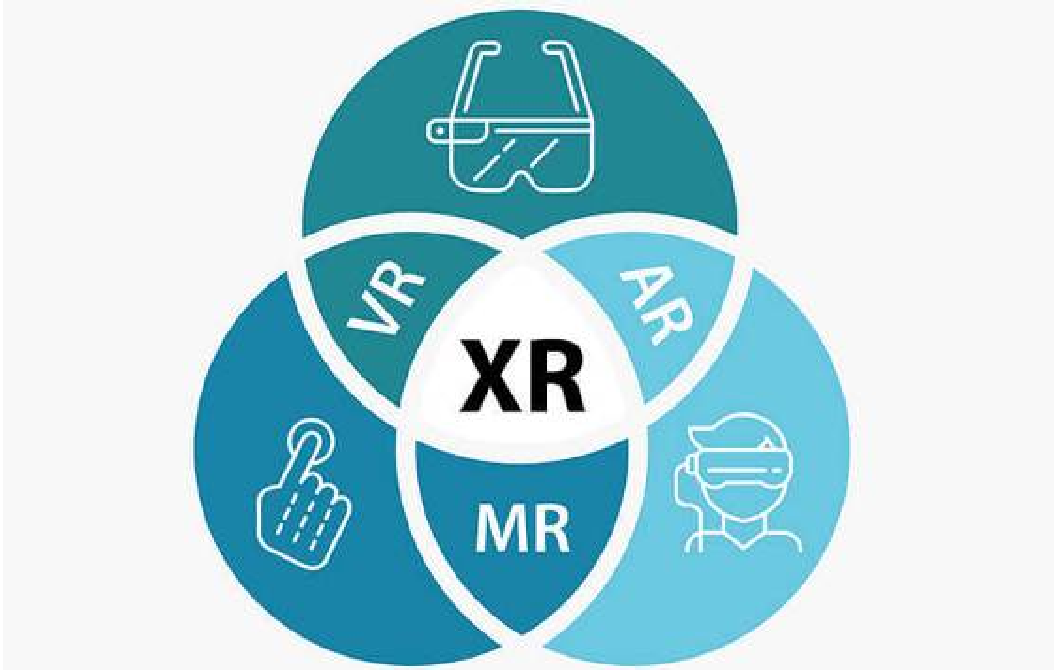

Figure 2 Extended reality (XR) includes AR,MR, and VR [4].

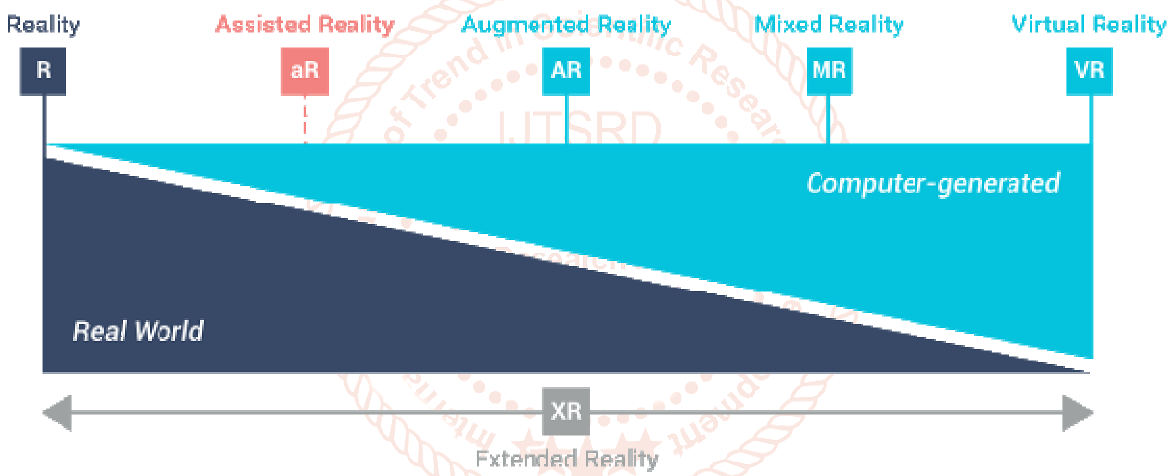

Figure 4 The XR spectrum [5].

Figure 4 Head-mounted displays [7].

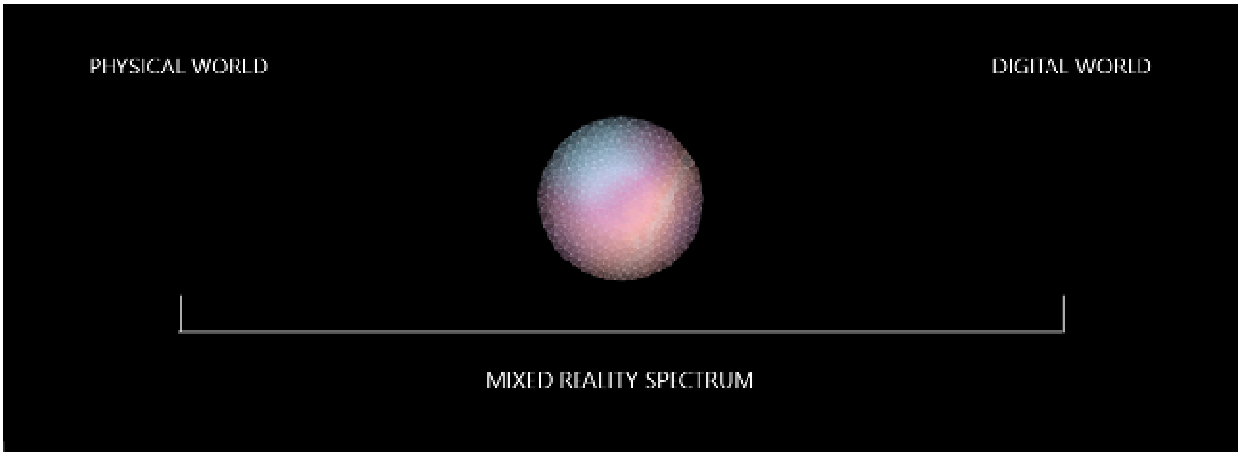

Figure 5 Mixed reality is a blend of physical and digital worlds [9].

Figure 6 A worker wearing an assisted reality device [11].

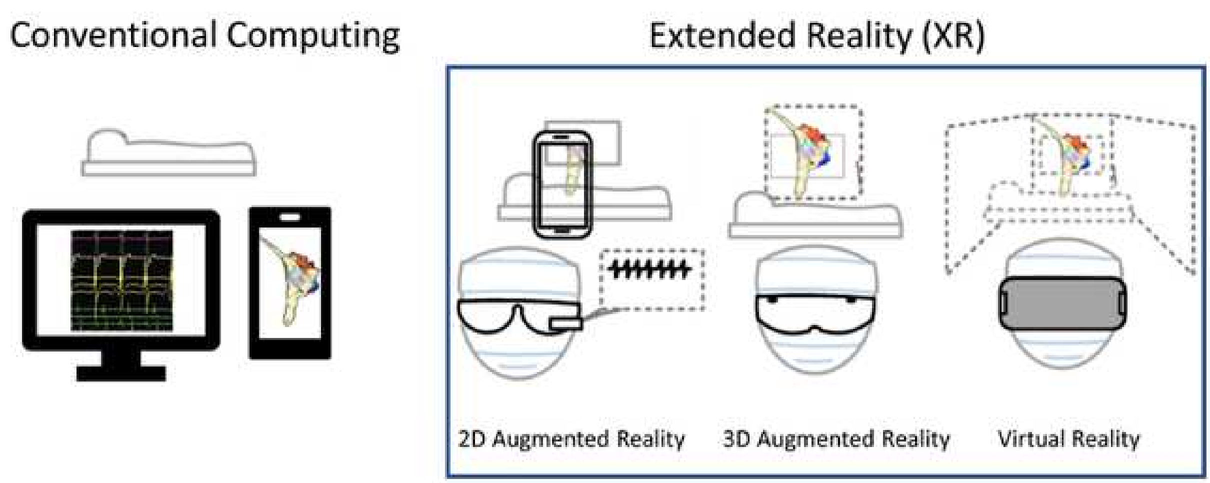

Figure 7 Comparing conventional computing with extended reality [12].

Figure 8 How immersive technology is used in architecture [1].

Figure 9 A typical design visualization [17].

Figure 10 A typical spatial design using immersive technology [18].