CHAPTER 7

Mixed Reality: A Bridge or a Fusion Between Two Worlds?

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Abstract

Virtual heritage (VH) is one of the few domains to adopt immersive reality technologies at early stages, with a significant number of studies employing the technologies for various application themes. More specifically, virtual reality has persisted as a de facto immersive reality technology for virtual reconstruction and virtual museums. In recent years, however, mixed reality (MxR) has attracted attention from the VH community following the introduction of new devices, such as Microsoft HoloLens, to the technological landscape of immersive reality. Two variant perceptions of MxR have been observed in the literature over the past two decades. First, MxR is perceived as an umbrella/collective term for a virtual reality (VR) and augmented reality (AR) environment. Second, it is also presented as a distinctive form of immersive reality that enables merging virtual elements with their real-world counterparts. These

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perceptions influence our choice of immersive reality technology, interaction design, and implementation, and the overall objective of VH applications.

To address these concerns, this chapter attempts to answer two critical questions: (1) what MxR from VH perspective is and (2) whether MxR is just a form of immersive reality that serves as a bridge to connect the real world with a virtual one or a fusion of both that neither the real nor the virtual world would have meaning without a contextual relationship and interaction with each other.

To this end, this chapter will review VH applications and literature from the past few years and identify how MxR is presented. It will also suggest how the VH community can benefit from MxR and discuss limitations in existing technology and identify some areas and direction for future research in the domain.

Introduction

Despite the significant advancements observed in the technological landscape of immersive reality and its expanding applicability across various domains, the perceptions of immersive reality technologies in general or at least their depiction in the VH literature remains influenced by earlier theoretical and technological perspectives – missing current contextual and domain-specific views. For instance, one of the earliest and widely accepted definitions of augmented reality (AR) by Azuma (1997), a segment of the reality-virtuality continuum proposed by Milgram and Kishino (1994), depicts AR as 'a system that combines real and virtual content, provides a real-time interactive environment, and registers in 3D.'

In addition to AR being presented as a system/technology, the characteristics that identify the segment from the rest of the continuum are that it 'combines real and virtual' content and 'provides real-time and 3D interactive environment'. These properties are observed similarly in MxR systems and environments, making AR and MxR identical or interchangeable as they attempt to combine real and virtual content and provide 3D interactive environments. As such, distinguishing AR from MxR relying on such properties is difficult. One of the primary objectives of this chapter is, therefore, to delineate a boundary between AR and MxR, at least from the VH point of view (the assumption is that the boundary between MxR and VR is much clearer as much as it is between AR and VR). To this end, establishing the current depiction of AR and MxR in the literature is required. Furthermore, distinguishing MxR from the rest of the segment requires identifying key factors from the VH perspective.

To date, there are two widely conveyed definitions of MxR in the literature. First, MxR is perceived as a combination of AR and VR. For instance, Elrawi (2017), Makino and Yamamoto (2018), and Plecher et al. (2019) present MxR as a combination of AR and VR environment and/or a collective term representing both AR and VR. This has led to the consideration of AR and VR as

the primary platforms for highly immersive and interactive VH applications (Haydar et al. 2011; Papagiannakis et al. 2018). Further to this, the technical complexity and requirements of fusing real and virtual elements, which is a unique property of MxR, to the extent that the blended environment appears as real as the real world has remained extremely challenging. This has to some extent resulted in a lower number of MxR applications and paved a favourable path for AR's and VR's position as the default platforms/technologies.

Second, contrary to the first view, some studies consider MxR as a unique segment of the reality-virtuality continuum that is characteristically and technologically different from both AR and VR. For instance, Jacobs and Loscos (2006), Okura et al. (2015), Bekele and Champion (2019b), and Hammady et al. (2020) present MxR as a technology and virtual environment that amalgamates real and virtual worlds into a single and shared real-virtual spectrum.

Hence, it is evident that a common understanding of MxR is required before an attempt is made to answer the critical question 'Is mixed reality a bridge between two worlds or a fusion of two worlds?'

Contextual Relationship in Augmented and Mixed Reality

The widely accepted definitions of AR and MxR in the literature rely on systems and technological perspectives. Distinguishing MxR from AR and the rest of immersive reality technologies, therefore, requires identifying additional factors from a different perspective rather than the underlying technology and theoretical basis. To this end, an article published by Bekele and Champion (2019b) identifies a contextual relationship between users, the real world, and the virtual environment as a factor that differentiates a specific form of immersive reality from the rest of the segments of the spectrum.

The contextual relationship is realised when the combination/blend of the real and virtual environments enables a three-way interaction between users, reality, and virtuality. Establishing a contextual relationship also relies on how the blended environment resembles and feels as real as the real world. The outcome is an enhanced and engaging real-virtual space that ultimately allows users to establish a contextual relationship with the real-virtual environment. The fusion and the three-way interaction are equally important factors to outline a boundary between AR and MxR. From a VH point of view, communicating or obtaining meaning and cultural significance through immersive reality without a mechanism to establish such a contextual relationship will be a difficult task. Considering fusion and contextual relationship as additional differentiating factors, AR and MxR can be outlined as follows.

Augmented reality is a form of immersive reality that enhances our perception of the real world and allows users to interact with reality and virtuality. Usually, virtual content is superimposed onto our view of the real world. The content could be in any multimedia format ranging from text to 3D models.

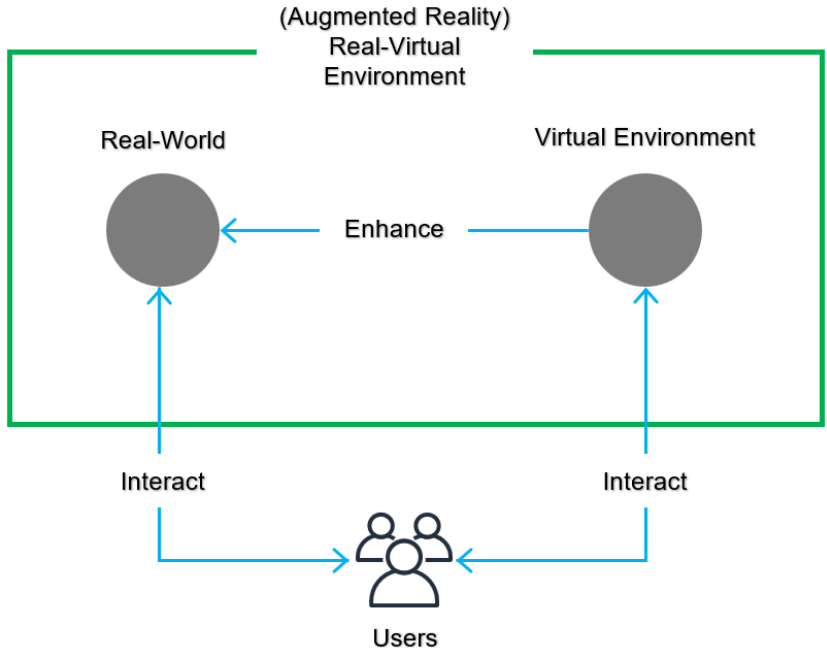

Figure 19: Augmented reality is a form of immersive reality that enhances our perception of the real world and allows users to interact with reality and virtuality (figure produced by the author).

As a result, there is relatively less expectation of the real-virtual environment resembling the real-world.

In addition to this, the resulting real-virtual space in AR does not allow a three-way interaction between users, reality, and virtuality. Users are usually at the centre of the interaction establishing a direct relationship with the real world and the virtual environment. For instance, digital content (text, video, audio, 3D models) of cultural heritage assets can be superimposed over our view of the real world. In some cases, such as virtual reconstruction, digital content can be superimposed on top, or projected next to the same heritage assets in the real world. In this scenario, the virtual environment that is visible to users through AR technology relies on the assets in the real-world to communicate the complete meaning of the multimedia content. The physical assets in the real world would have meaning on their own but users' understanding of the assets' cultural significance would be enhanced with the AR technology. Figure 19 presents AR as immersive reality technology that allows users to interact with a real-virtual environment, enables a contextual relationship between users and the real-virtual environment, and enhances the users' understanding of the real world.

Mixed reality, on the other hand, is a distinctive form of immersive reality that enhances our perception of both the real and virtual environments and

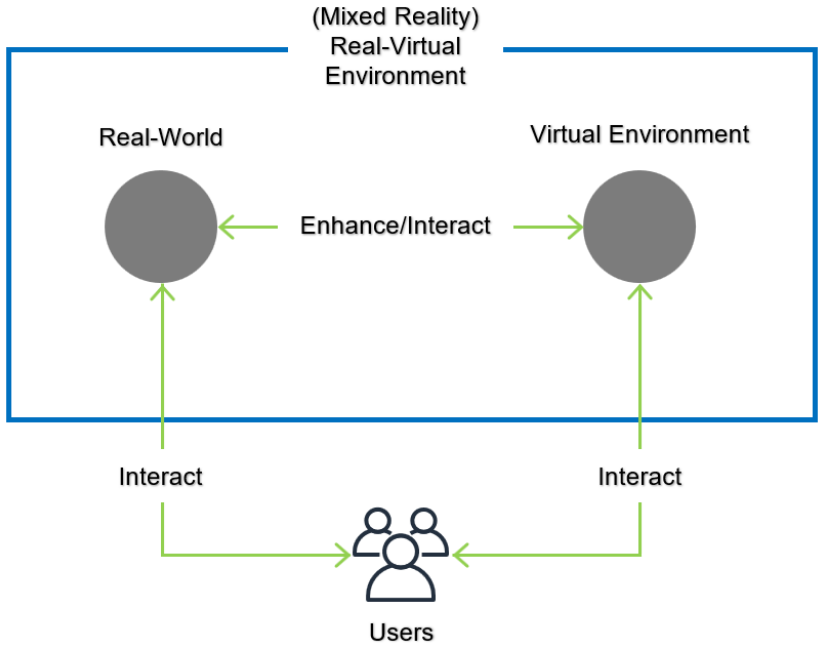

Figure 20: Mixed reality is a form of immersive reality that enhances our perception of both the real and virtual environments and allows interaction between users, reality, and virtuality (figure produced by the author).

allows interaction between users, reality, and virtuality. Figure 20 presents MxR as immersive reality technology that allows users to interact with a real-virtual environment, enables a three-way contextual relationship between users, the real world, and the virtual environment, and enhances users' understanding of both the real world and the virtual environment.

The real-virtual environment (a combination of real and virtual) provides a shared space that elements from both worlds utilise to enhance our understanding of both worlds. In this regard, the difference between AR and MxR is that the virtual environment in AR is limited to enhancing our understanding of the real world. Hence, the relationship between the real and the virtual environment in AR is limited to a one-way direction. The virtual environment in MxR, however, is not limited to enhancing the real world. It also benefits from the real word for delivering enhanced meaning. This arrangement results in a three-way relationship between users, reality, and virtuality.

For instance, consider shipwrecks or physically recreated replica of ships in a museum. Conveying the history and cultural significance of the ships to visitors can be realised via AR (superimposing multimedia content and 3D models) or via MxR (blending virtually simulated 3D animated model of the crew and the physical recreation of ships). Both approaches can enhance visitors'

understanding of the ships. However, the MxR approach provides a shared space for both the physical ship and the virtual simulation to communicate the complete picture of the story of the ship. Because, in this scenario, the simulation and the physical heritage asset are highly dependent on each other.

In summary, VH can adopt multiple forms of immersive reality technology to achieve a similar objective (i.e., whether explicit or implicit, VH applications tend to aim at communicating/transmitting the significance and value of heritage assets to visitors/users of the applications). However, considering the available technologies (AR, VR, AV, and MxR), a specific form of immersive reality can deliver the expected outcome more effectively than the rest. This is even more evident when comparing AR and MxR against their potential to enable a three-way contextual relationship between users, reality, and virtuality and blending the real and virtual environments.

As Table 1 shows, MxR exhibits unique aspects especially in terms of establishing a contextual relationship between reality and virtuality and blending the real and virtual environments to the extent the fusion is as real as the real world that results in benefiting both worlds. These unique features of MxR make the technology an ideal choice for VH applications that aim at virtuality recreating or simulating partially or completely lost tangible and intangible heritage assets and blending them with their counterparts that still exist in the real world.

Table 1: Comparison of AR and MxR against their potential to enable a three-way contextual relationship between users, reality, and virtuality and blending the real and virtual environments.

Factor	Augmented Reality	Mixed Reality
Blending the real and virtual environments	Overlays virtual content onto the real world	Virtual content is blended with the real environment resulting in a shared real-virtual environment
Interaction between users and the real world	Users can interact and establish a contextual relationship with the real world	Users can interact and establish a contextual relationship with the real world
Interaction between users and virtual environment	Users can interact and establish a contextual relationship with the virtual environment	Users can interact and establish a contextual relationship with the virtual environment
Interaction between the real world and the virtual environment	There is no interaction between the real world and virtual environment in AR and the sole purpose of the virtual content is enhancing the real world	There is a continuous contextual relationship between the real world and virtual environment in MxR to the extent that specific meaning (e.g., cultural significance in VH) can only be derived from the relationship

Mixed Reality: Bridge versus Fusion

Having the boundary between AR and MxR outlined, this section attempts to determine whether MxR is a bridge that connects the real and virtual world or a fusion of the two worlds that serves as a shared space where contextual relationship, collaboration, and engagement can be realised to a higher degree of realism. To answer this crucial question, we need to establish the aspects and scope of *immersive reality as a bridge* and *immersive reality as a fusion* from the context of VH and the objectives of this chapter.

Immersive reality technology can serve as a bridge between two worlds connecting us to past and/or lost cultures and heritages. In the context of the applicability of immersive reality in VH, the 'two worlds' refer to the existing physical world and a virtually simulated environment that is spatiotemporally distant from the existing physical world. The bridge analogy is, therefore, characterised as a spatiotemporal vehicle that can transport us to a different time and/or a different place. A typical immersive reality technology with such capability is VR. This technology can deliver a platform for highly immersive virtual environments that can simulate multiple dimensions of past traditions, cultures, and heritages. The immersivity of VR is not limited to the spatial and geometrical aspects of the simulated virtual environment. An ideal simulation will consist of multidimensional aspects of the simulated culture/heritage such as temporal, attributive, and environmental parameters. Such simulations can effectively transport us to the past to the extent that we are tricked to believe we are situated there and then.

Alternatively, immersive reality technology can also fuse the real and virtual worlds. From a VH perspective, the fusion of the two worlds is a real-virtual environment that serves as a shared space for the past and the present to coexist (Brondi et al. 2016). Past cultures and civilisations can virtually reoccupy or blend with the existing physical environment. Unlike the bridge analogy, which transports us to a past and distant world, the fusion of two worlds lets us experience the same past and distant world interacting with the existing physical reality that surrounds us. The fusion, therefore, exhibits properties of both the real and virtual environments that ultimately enables a contextual relationship between the two worlds.

All forms of immersive reality technologies except VR can blend real and virtual environments at different levels of interactivity, immersivity, and contextual relationships between components. For instance, a properly designed and implemented augmented virtuality (AV) system can blend the real and virtual environments in real-time. In this case, a live scene from the real world is streamed into the virtual environment rather than cases of AR where the fusion results in virtual content augmenting the real world. With both AV and AR, there is always a dominance of one environment over the other. The third alternative is an MxR technology where the fused real-virtual environment serves

as an equally shared space for both realities. However, technological advancement is far from a state that such fusion can be realised to its full extent. Considering existing technologies, however, MxR is a typical form of immersive reality that is best suited for fusing the real and virtual environments.

Relying on how MxR is outlined in the context of VH in this chapter, the environment in MxR is a fusion of two worlds rather than a bridge between two worlds. This is because:

- MxR enables a contextual relationship between users, reality, and virtuality.
- MxR provides a balanced and shared space for elements from both the real and virtual worlds to interact with each other.
- Both the real and virtual worlds can be meaningful by themselves (unlike AR, where the virtual environment relies on the real world to be meaningful).
- Both worlds depend on each other for enhanced meaning.

Mixed Reality and Virtual Heritage

A significant number of studies have demonstrated the role of immersive reality technology in terms of enriching cultural heritage sites and museums with engaging, interactive, and immersive experiences (Hammady et al. 2020). Recent technological advancements have made MxR even more beneficial and accessible to VH applications that tend to target virtual reconstruction in situ. Considering such recent development and trends, the followings have been identified in the literature as viable application themes of VH:

1. Virtual reconstruction. Virtual reconstruction relates to the recreation of fully or partially lost tangible or intangible cultural heritages. MxR is the best choice for VH applications with such themes because the technology can blend the reconstructed virtual environment with physical objects that exist at the historical location of the cultural heritage assets (Montagud et al. 2020).
2. Virtual exploration. VH applications designed for virtual exploration aim at knowledge and insights discovery because of the VH application's capability to afford manipulation and meaningful interaction with the underlying data and real-virtual environment (Okura et al. 2015; Tennent et al. 2020).
3. Virtual exhibition. Virtual exhibitions either replace physical museums and heritage sites with simulations in VR or improve/enhance users' experience at museums and heritage sites by blending virtual content with the real world, for instance, virtual tour guides in MxR (Trunfio & Campana 2020).

4. Virtual educational tools. To some extent, all the above applications serve as tools to educate/inform users regarding the historical and cultural aspects of the content presented in the applications. However, effective dissemination of cultural significance (cultural learning) requires VH applications that primarily focus on the outcome and learning aspects of the virtual content, application design, and implementation of immersive reality. To this end, MxR is a viable choice as the technology enables engagement, interaction, and contextual relationship with the real-virtual environment (key characteristics of VH applications that aim at cultural learning).

Current Issues and Future Directions

Mixed reality technology as it stands has several limitations hindering its wider adoption. The limitations identified in existing studies include rendering performance, lack of robust environmental tracking solutions, and a lack of easy-to-use multimodal interaction interface (Bekele 2019). Considering ongoing research on cloud-based immersive reality and human-computer-interaction (HCI), it is expected that future research will focus on the following areas:

1. *Cloud-based rendering*. Rendering is perhaps one of the key technical issues that MxR applications face across domains. It is even more problematic in VH applications that present sophisticated 3D models with millions of polygons. Even the market-leading MxR device, Microsoft HoloLens, struggles to render 3D models with such a large number of polygons. As a result, decimation is required to reduce the number of polygons, which will then deduce details from the model impacting user experience and the vividness of the rendering. However, Microsoft Azure announced a cloud-based remote rendering service as part of their MxR solutions. The remote rendering service will handle all the graphical computation workloads from the MxR device. Meaning, sophisticated 3D models can be rendered remotely and streamed to the MxR device, which is the Microsoft HoloLens.
2. *Cloud-based tracking*. Sensor and camera-based tracking solutions are commonly adopted in existing VH applications. However, these solutions, particularly in outdoor settings, remain error-prone, impacting user experience. In this respect, new cloud-based services, such as Microsoft Spatial Anchor, provide the possibility of utilising cloud computing to store, share, and retrieve location data of points of interest for MxR applications across multiple platforms and devices. Meaning, VH applications can target multiple devices for user experience while maintaining a shared and centralised pose tracking solution.

3. *Multimodal interaction interface*. An ideal multimodal interaction interface combines multiple modes of interaction allowing users to interact with virtual environments as they would interact with the real world (Bekele & Champion 2019a). This is a key property of MxR experience. Existing technologies rely on gaze, gesture, and speech inputs to enable multimodality in interaction interfaces. For instance, Microsoft HoloLens utilises all three inputs. As research advances in sensor technology, artificial intelligence, and tangible interaction, more advanced multimodal interaction interfaces will likely become a common method of interaction in VH, thereby enabling engaging, interactive virtual environments that users can effectively relate to and interact with through all their senses.

Conclusion

This chapter has presented different perceptions of MxR, especially in the VH domain. It has also outlined a boundary between AR and MxR before attempting to answer the key question raised in the chapter 'Is MxR a bridge between two worlds or a fusion of two worlds?' Immersive reality technology's capability to establish a contextual relationship between users, reality, and virtuality and believability and realism of the real-virtual environment resulting from the fusion of the real and virtual worlds were used as differentiating factors. I have identified application themes and limitations for MxR and VH applications as well as future research areas and directions that I invite you to explore.

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