REDEFINING MIXED REALITY: USER-REALITY-VIRTUALITY AND VIRTUAL HERITAGE PERSPECTIVES

MAFKERESEB KASSAHUN BEKELE[1] and ERIK CHAMPION[2]
[1]*UNESCO Cultural Heritage and Visualisation, School of Media, Creative Arts and Social Inquiry (MCASI), Curtin University*
[1]*mafkereseb.bekele@postgrad.curtin.edu.au*
[2]*UNESCO Cultural Heritage and Visualisation, School of Media, Creative Arts and Social Inquiry (MCASI), Curtin University*
[2]*erik.champion@curtin.edu.au*

Abstract. The primary objective of this paper is to present a redefinition of Mixed Reality from a perspective emphasizing the relationship between users, virtuality and reality as a fundamental component. The redefinition is motivated by three primary reasons. Firstly, current literature in which Augmented Reality is the focus appears to approach Augmented Reality as an alternative to Mixed Reality. Secondly, Mixed Reality is often considered to encompass Augmented Reality and Virtual Reality rather than specifying it as a segment along the reality-virtuality continuum. Thirdly, most common definitions of Augmented Reality (AR), Augmented Virtuality (AV), Virtual Reality (VR) and Mixed Reality (MxR) in current literature are based on outdated display technologies, and a relationship between virtuality and reality, neglecting the importance of the users necessarily complicit sense of immersion from the relationship. The focus of existing definitions is thus currently technological, rather than experiential. We resolve this by redefining the continuum and MxR, taking into consideration the experiential symbiotic relationship and interaction between users, reality, and current immersive reality technologies. In addition, the paper will suggest some high-level overview of the redefinition's contextual applicability to the Virtual Heritage (VH) domain.

Keywords. Mixed Reality; Reality-Virtuality Continuum; Virtual Heritage.

1. Introduction

Over the last decade, the segments of the reality-virtuality continuum have witnessed fascinating technological advancements, yet their definitions have remained relatively untouched since they first appeared in the literature back in the 1990s. It is a natural process for definitions and scientific assertions, especially in the technology realm, to continuously align themselves towards current advances and even encode key conceptions that could highlight future developments in

the realm. Contrary to this natural development, however, the definitions of the reality-virtuality continuum have continued to appear unchanged, still being referred in their original forms. However, their market share keeps growing exponentially and a significant number of research labs dedicate their resources towards advancing immersive reality's applicability and technological bases across diverse domains ranging from medicine and engineering to education and cultural heritage. Hence, given recent developments, redefining the continuum, especially its most contesting segment (MxR), is warranted.

In this paper, therefore, we present a redefinition of the reality-virtuality continuum from a perspective emphasizing the relationship between users, virtuality and reality as a central basis. In addition, a zoomed-in view will be dedicated to MxR and its contextual applicability to Virtual Heritage (VH), a domain emerging in Cultural Heritage (CH) following the advances of immersive reality.

The motivation to redefine MxR is influenced by existing limitations observed in immersive reality and VH studies. This paper aggregates those limitations into three problem spaces: (1) AR and MxR are perceived as alternates, (2), MxR is perceived as a combination of AR and VR, and (3) users are excluded from the defining relationship between reality and virtuality.

Hence, our primary goals here in this paper are: (1) to delineate a boundary between AR and MxR rather than replacing their current definitions with new once, (2) to redefine MxR from a perspective that views the segment as a self-standing form of reality-virtuality instead of an approach that combines AR and VR settings, (3) to augment users' experience into the reality-virtuality relationship in order to redefine the continuum from a perspective that emphasises the relationship between users, reality and virtuality as a central point, and (4) suggest some contextual applicability of the redefined MxR to the VH domain, especially for future VH application that aim to exploit MxR to disseminate virtual reconstructions and simulations of cultural heritage.

To this end, we start by reviewing the current literature in immersive reality technology and exemplar case studies from different application areas to show trends in the uptake of AR, AV, VR and MxR. Moreover, we will compare this trend with the most common definitions of AR (Azuma et al., 2001; Azuma, 1997) and with the reality-virtuality continuum (Milgram & Colquhoun, 1999; Milgram & Kishino, 1994; Milgram et al., 1995) and discuss the interchangeable appearance of AR and MxR in the literature. Secondly, we argue that a relationship between users, reality and virtuality (User-Reality-Virtuality) resolves the issues discussed above and requires redefining MxR. Finally, we outline how the redefinition of MxR can be adopted into VH applications, especially when an application's primary aim is to ameliorate the relationship between users/visitors, cultural heritage sites and their virtual reconstructions or simulations.

2. Existing Definitions of the Reality-Virtuality Continuum

The reality-virtuality continuum (see Figure 1), first introduced by Milgram and Kishino (1994), classified the span between the physical and virtual environments

to Augmented Reality (AR), Virtual Reality (VR), Augmented Virtuality (AV), and Mixed Reality (MxR). The continuum and its segments are briefly discussed below as per their appearance in the existing literature.

One of the most widely cited papers, also one of the first definitions of the segment, defines AR as a system that combines real and virtual content, provides a real-time interactive environment, and registers in 3D to enhance our understanding of the physical environment (Azuma, 1997). The sole purpose of AR is to enhance our perception and understanding of the real world by superimposing virtual information on top of our view to the real world.

VR is often referred as a segment of the reality-virtuality continuum that transports users into a computer-generated virtual world, where users are expected to experience a high level of presence in the environment (Carmigniani et al., 2011; Steuer, 1992). Virtual environments detach the users' sense of being here and now in the physical world and create artificial presence in a virtual one instead. To date, the advances in VR have enabled virtual environments to deceive our hearing, visual, and kinaesthetic senses. VR also has the potential to simulate imaginative and existing physical environments along with their processes and environmental parameters to engage and affect all of our senses including touch and smell.

While Augmented Virtuality (AV) augments virtual environments with live scenes from the real-world events, it is commonly understood as a variation of VR. This is problematic since the whole purpose of augmenting virtual environments with live scenes is to enhance our understanding of the underlying virtual environment, which diverts from VR's aim, transporting users to a completely virtual world. Essentially, AV is closely aligned to AR in terms of purpose, because both aim at enhancing the environment they are applied to. VR, on the other hand, has no direct implication on our perception of the real world. However, our interaction and presence in a virtual environment that simulates the real world might indirectly influence our perception of the physical reality.

Milgram and Kishino (1994) defined Mixed Reality (MxR) as "...a particular subclass of VR related technologies that involve the merging of real and virtual worlds." More specifically, they say that MR involves the blending of real and virtual worlds somewhere along the "reality-virtuality continuum" which connects completely real environments to completely virtual ones. However, there are instances where the terms AR and MxR are used interchangeably (Papagiannakis et al., 2018; Raptis et al., 2018). These immersive reality technologies, to some extent, share a common objective, that is enhancing our understanding of the physical environment. However, AR achieves this by overlaying digital content over our view of the physical world and this portion of the continuum is placed closer to reality, whereas MxR achieves a broader goal, enhancing our understanding of the real and virtual worlds, by blending elements from the real and virtual environments. Moreover, contrary to MxR, the academic literature has noted that AR has a limited visual and spatial immersion (Leach et al., 2018). MxR, on the other hand, combines interactivity and immersion from AR and VR, respectively, to bring immersive-interactive experience to our view of the real-virtual word. MxR is thus a broad portion combining different properties of the continuum into a single immersive reality technology. This puts AR in a

technically challenging position for consideration as a substitute to MxR.

In conclusion, the most widely known definitions of the reality-virtuality continuum and its segments are derived from a relationship between reality and virtuality and technological advances from their respective eras, most of which are already outdated. In addition, the definitions emphasise on displays rather than on users' experience. A redefinition of the continuum from a perspective that doesn't rely on technology and augments users' experiential aspect into the reality-virtuality relationship is crucial.
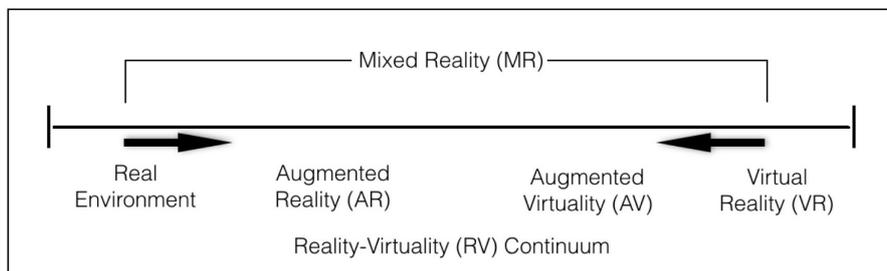

Figure 1. Reality-Virtuality (RV) Continuum (Milgram & Kishino, 1994). Existing definitions adopt this continuum.

3. Augmented, Virtual and Mixed Reality: Interchangeable, Collective, and Exclusive

This section discusses further the main gaps observed in existing definitions of the reality-virtuality continuum, particularly MxR. We would like to remind readers that the main objective of this paper is redefining the continuum, especially MxR, by redefining existing definitions rather than replacing them with new once.

3.1. AUGMENTED REALITY AND MIXED REALITY ARE PERCEIVED AS ALTERNATES

The term MxR is sometimes used for application that comprise AR characterises (Papagiannakis et al., 2018; Pollalis et al., 2017; Pollalis, Gilvin, et al., 2018). While it is technically challenging to create an immersive reality system or application that delivers AR and MxR experiences at the same time, it has become common to see the terms AR and MxR in the literature, especially since the last two years following the recent display technologies such as Microsoft HoloLens (Scott et al., 2018). However, most of these immersive reality applications demonstrate distinct AR characteristics. Hence, the terms AR and MxR appear in the literature representing identical experiential context. It is technically challenging for immersive systems to exhibit both AR and MxR functionalities because of the technological limitations related to displays. The technical challenge of developing a system that twines AR and MxR features rises mainly from the difficulty in blending dynamic content with dynamic lighting. As such, blending

elements from the real and virtual environments to the extent that the fusion appears as believable and immersive as virtual environments in VR is impossible. In addition, MxR application are rare due to lack of robust and real-time tracking and 3D registration, realistic virtual environments, natural interaction interfaces, and presentation devices for vivid experiences (Bekele et al., 2018).

3.2. MIXED REALITY IS PERCEIVED AS A COMBINATION OF AUGMENTED AND VIRTUAL REALITY

Mixed Reality (MxR) is sometimes considered as an umbrella term for systems that comprise both AR and VR characteristics rather than a specific segment of reality along the reality-virtuality continuum (Papagiannakis et al., 2018). These two segments are placed far apart along the continuum and often perceived as the end points of the continuum. AR is positioned close to physical reality whereas VR is the end point of the virtuality side. MxR combines some properties from both segments, interactivity and immersion from AR and VR, respectively. However, it is only VR that is one of the end points of the continuum, AR doesn't qualify as such since it enhances the real world (the other end point of the continuum).

3.3. USERS ARE EXCLUDED FROM THE REALITY-VIRTUALITY RELATIONSHIP

Incorporating users' experience needs to be treated as a fundamental part of any system or application design that somehow involves interaction between users and information. This relationship is a crucial factor that determines the efficiency of interaction interfaces. However, existing definitions of immersive reality and the reality-virtuality continuum haven't incorporated users' experience into the relationship between reality and virtuality that underlies the definitions of the continuum (Azuma, 1997; Milgram & Kishino, 1994). Akin to other Human-Computer-Interaction (HCI) studies in VH (Rahim et al., 2017; Slater & Sanchez-Vives, 2016), where users' experience is highlighted as a crucial aspect of the design and development processes, the interaction and experiential aspects of immersive reality systems need to establish a continuous relationship between users, reality and virtuality. Instead, they try to attract users towards the already established relationship between reality and virtuality. This has made users external observers of the relationship instead of active participants or collaborators in the relationship, influencing its forms and properties.

4. Redefining Mixed Reality: Integrating User's Experience into the Reality-Virtuality Continuum

The novelty of this paper is integrating a users' experiential aspect into the existing reality-virtuality continuum and establish a relationship between users, reality, and virtuality. The redefinitions presented in this paper are inferred from this relationship. The relationship is further discussed in terms of User-Reality-Virtuality Interaction and Relationship aspects in order to clarify the base for the redefinition.

4.1. USER-REALITY-VIRTUALITY INTERACTION AND RELATIONSHIP

Immersive reality technology's role is not just to enable interaction between users and information, it is more a continuous relationship between users, reality and virtuality that puts users at the centre, affects their senses, and allows users to be part of any change and process in the environment. This contradicts the conventional way we interact with virtual information and virtual environments presented via immersive reality systems. Figure 2 below demonstrates the contextual interaction between users, reality and virtuality. This interaction space can be considered as an extension of the original reality-virtuality continuum.

Arguably, MxR is a tread that connects elements form the real and virtual environments. The notions behind connecting elements form the two environments and connecting the two environments themselves differ. From a technological point of view, a complete fusion of the two environments is very challenging. Even if the two environments are blended completely, the fusion makes no sense as it provokes a fight between the two layers to win the user's attention. The logical approach is, therefore, to merge elements from both environments so that the fusion exhibits real-virtual characteristics. This enables the virtual environment to appear as real as the real. The real-virtual environment helps enhancing our understanding of both worlds, meaning the virtual elements enhance the real world and elements from the real world enhance the virtual one.

For instance, imagine a virtual simulation of a captain on a historic ship, our understanding of the significance of either the ship or the captain will be completed when the two are put together in a real-virtual environment. Alternatively, the captain's simulation can be experienced in a VR environment, but the historical significance may not be noticed or communicated as much as in the real-virtual environment, unless of course the virtual environment in the VR simulates both the captain and the ship. Such environments comprise a unique characteristic of MxR since this segment balances inputs from the real and virtual environments. Contrary to this, the other segments of the reality-virtuality continuum incline either to reality or virtuality. Hence, MxR needs to be positioned somewhere in the middle of the continuum.

Adding users' experiential and interactivity perspectives to the real-virtual environments allows to establish a relationship between users, reality and virtuality. This strengthens the redefinition of MxR, especially in terms of delineating a boundary between AR and MxR. This relationship takes into consideration four aspects: (1) the fusion of real and virtual environments or elements, (2) interaction between users and virtuality, (3) interaction between realty and virtuality, (4) immersion in a virtual environment. Figure 2 shows the interaction between users, different forms of immersive reality, and the real world. Figure 3 shows the relationship between users, fusion of real and virtual environments, immersion, and interaction between users, reality and virtuality. Considering a combination of these aspects, the different forms of immersive reality are redefined as follows.

- Virtual Reality (VR) occludes users' view to the real world and users' interaction is limited to the virtual environment. The sensorial effects on

users, users influence on the environment, and interaction with the virtual elements are constrained to the affordance of the underlying technology. The fundamental characteristic of VR is that a continuous two-way interaction and relationship could be established between users and virtuality. In addition, the virtual environment in VR is a completely computer-generated one. Hence, there is no direct relationship and interaction between reality and virtuality.

- Augmented Virtuality (AV) is a virtual environment supplemented by elements from the real world. Unlike VR, there is a relationship between reality and virtuality in AV, that is elements from the real word enhance the virtual one. Users primarily interact with the virtual environment but not with the elements from the real world that are augmented into the virtual environment. It is very rare to find AV applications because feeding live scenes from the real environment into a virtual environment is challenging, let alone interacting with and manipulating those elements. If fully exploited with the right enabling technologies, however, AV has the potential to: (1) generate 3D models, environmental parameters and spatial sound on the fly from live scenes and merging them with virtual environments, (2) allow users to interact and establish a relationship with both the virtual environment and the elements being streamed from the real world. In a broader sense, AV is comparable to AR since both try to enhance the primary environment they are based upon.

- Augmented Reality (AR) supplements the real word with virtual elements and enables users to interact with the virtual elements. Even if virtual elements are superimposed around the physical environment, the interaction in AR is always between users and virtual elements. More importantly, the real environment is dominant and benefits from the virtual elements in order to enhance users' perception of the real world.

- Mixed Reality (MxR) blends elements from both the real and virtual environments to create a real-virtual environment that enhances our perception of both environments. This environment enables interaction between users, virtual elements, and the real world, leading to a user-reality-virtuality interaction and relationship space. Unlike AR, where the real environment is dominant, MxR doesn't allow one environment to dominate the other, instead both environments benefit from each other's elements. This is perhaps one of the fundamental factors putting MxR ahead of AR or any form of reality-virtuality, because MxR targets at enhancing our understanding of both the real and virtual environments. One of the reasons why AR is confused with MxR is that they both seem to benefit from virtual elements. However, AR doesn't enhance virtual elements while MxR enables mutual or reciprocal benefits between the real and virtual elements. MxR is, therefore, an integration of elements from virtual and real environments that allows users to interact with the two worlds that benefit from each other's elements in order to enhance users' understanding of the two worlds.

5. Contextual Applicability of Mixed Reality to Virtual Heritage

Virtual Heritage (VH) is an emerging field that applies immersive reality technologies and digital tools to Cultural Heritage (CH) in order to simulate, preserve, and disseminate tangible and intangible cultural assets in a form of

diverse multimedia approaches. In general, MxR enables user-centred and personalised presentation of VH and makes cultural heritage digitally accessible in a form of virtual reconstruction or virtual museum/exhibitions. Such characteristics are viable for CH knowledge dissemination, especially when physical access to artefacts is limited.
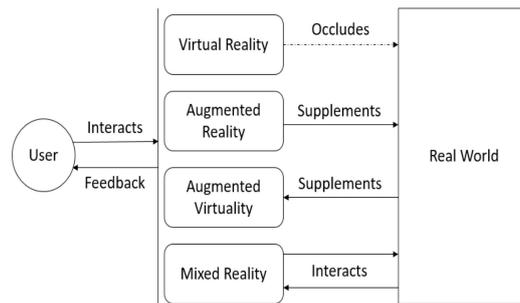
Figure 2. User-Reality-Virtuality (URV) Interaction: Interaction between users, display technologies and the real world.

MxR applications are very rare to find in any domain. Very recently, however, a few applications are emerging in the VH domain following recent advances in immersive reality technologies, such as the Microsoft HoloLens. For instance, Pollalis, Minor, et al. (2018) present an MxR application that utilises Microsoft HoloLens to allow object-based learning through mid-air gestural interaction with virtual representations of museum artefacts. Other examples of HoloLens based applications in the domain include (Baskaran, 2018; Bottino et al., 2017; Pollalis et al., 2017; Scott et al., 2018). Given the redefinition of MxR proposed in this paper, however, these recent studies are more exemplar cases of AR applications that can be tuned to attain the MxR characteristics as per the redefinition.

Following the recent advances and the redefinition presented in this paper, two contextual applications of MxR are proposed for the VH domain. These application areas are, namely, virtual reconstruction and virtual exhibition.

Virtual reconstruction aims at enabling users to visualise and interact with reconstructed historical views of tangible and intangible heritages. Such applications allow merges between historical views from the past with their current appearance. Especially, partially damaged or fully demolished architectural heritages can be virtually reconstructed at their historical location. Additional information beyond the virtual reconstruction itself can also be overlaid along with the virtual elements. MxR plays a great role in the restoration of lost heritages, starting from the reconstruction of statues and extending to reviving cultural practices in their original forms. Leach et al. (2018) present an outdoor AR application that partially achieves a virtual reconstruction of a historical building.

Virtual museums/exhibitions intend to improve visitors' experience at physical museums and heritage sites, typically through personalised virtual tour guidance. In general, such applications simulate or enhance physical museums and heritage

sites including their tangible and intangible assets. Such simulations are equipped with potential to enhance cultural presence, thereby bringing a sense of being there and then to visitors. MxR can extend the simulation by including virtual-human characters and cultural agents into the simulated virtual environment. In such cases, the simulation should consider environmental parameters, physical properties, and cultural/historical context of heritage sites. The redefined MxR allows interaction between users, heritages, and virtual simulations. Arguably, such interaction creates a perception of physical movement inside a real-virtual environment. This allows VH application designers to establish a relationship between users and their immediate heritage environment.
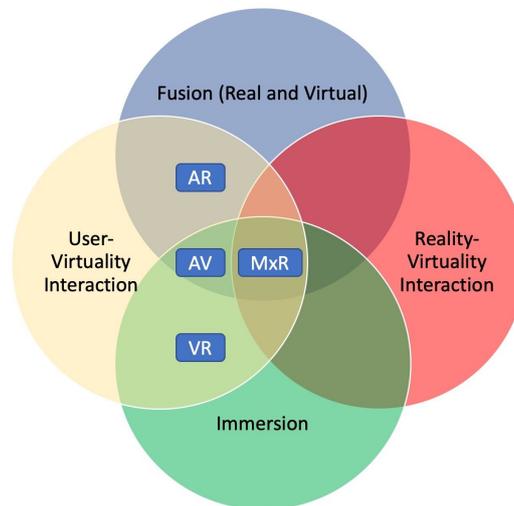

Figure 3. User-Reality-Virtuality (URV) Relationship Space: A relationship between users, fusion of real and virtual environments, immersion, and interaction between users, reality and virtuality. This relationship is the basis for redefining Mixed Reality.

6. Conclusion

In this paper, we have identified major gaps in existing definitions of the reality-virtuality continuum and its segments. Following this, we have presented a redefinition of the continuum from a perspective underlining the important relationship and interaction between users, reality and virtuality. Also, a special focus has been dedicated to MxR when redefining the reality-virtuality continuum. MxR is, therefore, redefined as an integration of elements from virtual and real environments that allows users to interact with the two worlds that benefit from each other's elements in order to enhance users' understanding of the two worlds. Following recent advances and the above redefinition of MxR, two contextual applications are proposed for the VH domain. These application areas are, namely, virtual reconstruction and virtual exhibition.

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