A REVIEW OF VIRTUAL, AUGMENTED AND MIXED REALITY TECHNOLOGIES FOR CONSTRUCTION

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Abstract- Construction is an important industry which has a potential to uplift the social and economic progress of any country and is directly related to improve the quality of humans' life. Unfortunately, its operations are very complex that hinder its performance to its full potential, thus, very less improvements are made to increase its productivity and efficiency as compared to other industries. Furthermore, it is a slow adopter of new technologies due to associated cost and risk. Recent visual technologies, such as, Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) are developed and being adopted in different trades. With the development of Building Information Modelling, it is possible for the construction industry to employ these technologies. This study is aimed at reviewing the latest developments in VR/AR/MR technologies and presents a fundamental understanding of these technologies. The adoption of these technologies by the construction industry at present is also given. Furthermore, a few practical applications of VR/AR/MR for the industry are outlined. Nonetheless, few research gaps are highlighted that need to be explored by the research community. The VR/AR/MR technologies seem promising to offer benefits to many industries including the construction sector, however, as these technologies are new at present, an in-depth exploration, investigation and analyses are required for a practical and profitable adoption.

Keywords- Augmented Reality, Construction industry, Mixed Reality, Virtual Reality

1 INTRODUCTION

The construction sector is a significant player in the socio-economic development of a country [1], however, it falls short when it comes to productivity as compared to other industries [2-3]. The construction industry is unique as contrary to other industries due to the following facts: its operations are conducted in natural conditions on site encompassing huge supply chains; it is labor intensive; a considerable number of public and private stakeholders are involved. Furthermore, it does not quickly adopt the latest technologies [4] due to associated cost and risk [5]. However, due to increasing complexity of construction projects and global pressure to adopt sustainable practices, the industry is gradually moving to adopt the latest technologies to realize its full potential.

Building Information Modelling (BIM) is a revolutionary development in the Architecture, Engineering, Construction and Operations (AECO) industries [6]. There are lot of definitions of BIM explaining different significant benefits it provides. In its core, it is a technology-enabled process that enables stakeholders of a project to collaboratively work throughout the lifecycle of a project, such as, planning phase, execution phase, as well as, operations phase of a facility [7]. However, BIM in its standalone form cannot provide an immersive experience of a facility at the design stage, placement of the model on site to be critically analyzed within its surroundings where the facility is going to be constructed, and/or information to a construction worker in real-time while executing the task on site to improve their performance.

Lately new technologies, such as, Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) have emerged. It is pertinent to know that these technologies did not develop specifically for the construction industry, but due to their apparent potential construction researchers and practitioners are exploring the possible benefits they can provide to the industry. As the adoption of BIM is on the rise, it is making the utilization of VR, AR and MR possible for the construction sector [8].

There are numerous studies available that focus on one or two technologies but not all three in one study. Additionally, no clear distinction is being made among these technologies. To address this research gap, this review paper encompasses all three realities (VR/AR/MR) in one study and provides fundamental understanding of these technologies. Furthermore, a differentiation is offered among these technologies for better understanding, which is not widely present in the literature. Thus, the main purpose of this review paper is to identify and outline VR/AR/MR applications for design and construction. This investigation is significant for academicians and practitioners of the construction sector so as to increase their understanding about these new technologies before they can employ these realities in their work. Moreover, this study also outlines the research gaps for possible future research work.

2 RESEARCH METHODOLOGY

Research methodology adopted for this review paper is systematic literature review of VR/AR/MR, their historical development, and adoption in the construction sector. A critical analysis of the published research work is conducted so as to clearly outline what is VR/AR/MR, historical development, functionality and devices required to employ each of these technologies. Moreover, differentiation among these technologies is made to explicitly know the functional boundaries of VR/AR/MR. In addition, their utilization at an appropriate project life cycle is also noted. Furthermore, adoption of these technologies in construction industry with the help of BIM as a back-end support system is outlined. The study also presents a few practical applications for the industry, as well as, research gaps for academia to explore further.

3 RESULTS

This section presents the discussion based on critical analysis of VR, AR, MR, their utilization in the construction industry at present and research gaps that should be investigated for a holistic understanding and subsequent utilization of these technologies.

3.1 Background.

Milgram [9] gave the concept of reality continuum as shown in Figure 1. The two extremes of the continuum separate real world (on the left-hand side of the continuum) and a virtual world (on the right-hand side of the continuum). It means that the real world and the virtual world are two separate entities. In between these two extremes, comes the AR and Augmented Virtuality (AV); both AR and AV fall under the category of MR. An MR is a combination of the real and virtual worlds. The difference between AR and AV is that in the former virtual information is overlaid on to the real world, whereas, in the latter virtual objects are used as a background for the real world. AR gained more recognition and adoption in different sectors, such as, medicine, education, manufacturing and construction as compared to AV, which is just used in the entertainment sector [10].

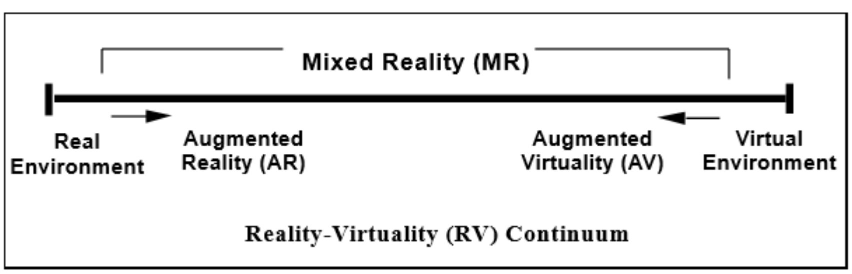


Figure 1: Reality Continuum by Milgram [9]

3.2 Virtual Reality (VR):

The VR as the name suggests, is a virtually created reality as contrary to an actual reality surrounding us [11]. It is created through computers that replace physical reality. These two realities do not overlap with each other, meaning only one reality can only be experienced at a time. The aforementioned explanation is evident from Milgram [9] reality continuum.

A VR is experienced with the help of a virtual reality headset, also known as Head Mounted Display (HMD) device. The HMD is locked on to the head for an immersive 360^o experience. The virtual reality created through a computer with the help of HMD displays a 360^o field of view within the headset. The formation of a headset, as shown in Table 1, is such that it completely blocks the physical world around the user and the 360^o field of view tricks the human senses to believe that the user is a part of the virtually created digital world [11].

The VR can improve the design process of a construction facility by providing an immersive experience at the design phase [13]. The designers can make better design while having an immersive walkthrough before it is finalized and shown to a client. On the other hand, clients and end users can have an immersive visualization [14] to have a better comprehension of the design right at the outset that can support rapid decision making on their part to give a go-ahead to the project. Further, it can improve a customer's satisfaction of the design, thus reduces scope creep and delay in a construction project due to constant change orders from the client. Additionally, the VR is employed for health and safety trainings of workers [14] for a construction site to reduce loss of life and injuries due to risks at construction sites.

3.3 Augmented Reality (AR):

The AR as the name suggests, augments actual reality. It means that AR enhances the physical reality around a user with virtual object(s), thus, supplementing and enhancing actual reality [11]. The user can see the real reality, as well as, superimposed virtual objects at the same time unlike VR, where either the virtual or actual reality can be experienced at a particular point in time [12]. It is also observed from the reality continuum that AR is closer to the actual reality [9].

The AR is usually observed through mobile phones and tablets as shown in Table 1. Numerous AR applications, mostly gaming and entertainment, have been developed and are available in Apple App Store and Android Play Store. Different virtual objects can be overlaid in surrounding and seen through a screen of a gadget. A user cannot interact with those virtual objects in a way to feel it as a real object. It is just a virtual object that can be seen through a screen on to the real environment around a user.

There are different applications, such as, 'Augment' and 'Architecture', through which design model of a construction facility can be overlaid in physical reality through mobile phones and tablets. These applications, for instance, Augment, also works with BIM and the model can be transferred to the app to be shown in AR. It would be a better approach to discuss the design through a 3D BIM based AR during a client meeting rather than a paper based 2D design. Nevertheless, all these applications are new and paid at the moment, thus rigorous scrutiny and adoption is not taken place.

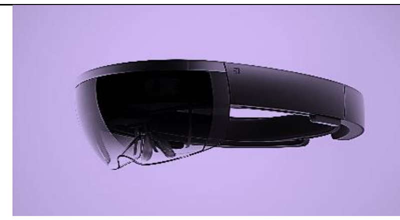
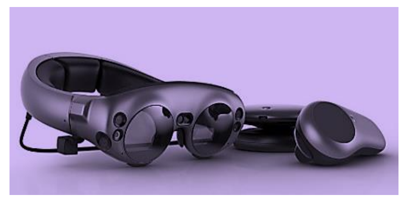
3.4 Mixed Reality (MR):

The MR as the name suggests, is the combination of two realities i.e. real and virtual. According to Cheng *et. al.* [10] MR and AR are confusing and there is no clear differentiation between them; the AR is regarded as a subset of MR and both are considered one and alike at times. Nevertheless, a subtle difference between the MR and AR is based on 'interaction' and 'devices' used to experience these realities.

The MR is experienced through a headset, but contrary to a VR headset, it does not block a user's complete field of view. The headsets, for instance, Microsoft HoloLens and Magic Leap One as shown in Table 1, overlays virtual information on to the screen of the headset in the form of text, diagram or video etc. in real time for the user's support to do a task efficiently, such as, a technician assembling a car engine or construction work assembling pipes [8]. The purpose of MR is to make available the relevant information at the time of performing a task so that it can improve productivity. Nevertheless, MR is a fairly new technology and is still under examination to be employed by different sectors, such as, automotive, remote assistant, engineering and teamwork [15].

For the construction sector MR can be helpful in design creation and on-site client's meeting by placing a 3D holographic 1:1 model on a site. The stakeholders of a project can view, analyse and take decisions about the project using this hologram. Furthermore, the technology can support in efficient working such as assembling on a construction site [8].

Table 1: Devices Required for VR, AR and MR Technologies

VR	**AR**	**MR**
		
Oculus Rift S	Mobile	Microsoft Hololens
		
HTC Vive Pro	Tablet	Magic Leap One

3.5 Practical Applications:

There can be various practical applications of VR/AR/MR in the construction industry. The application of these technologies depends on the requirements of users. Some of the practical applications are noted below:

1) Designers can employ VR to provide an immersive experience of a design to the clients for rapid decision making and approvals [13]
2) VR can be used to have a fair idea of spatial availability of a facility by having an immersive walk through [16]
3) AR is useful in terms of clients' meeting so that participants can see a 3D model to discuss for further refinement [17]
4) MR can be adopted for workers to improve productivity at the job site by providing the necessary information to perform a task when it is required [8]
5) AR/MR can be utilized to place 1:1 3D holographic model of a facility on-site, among its surroundings, at the pre-construction phase to ponder upon different design options for the optimum suitability [8]

3.6 Research Gaps:

As these technologies are developing, thus, there are many aspects that need to be studied. However, top four aspects are highlighted in this section.

1) Firstly, indeed different industries are adopting these technologies at their own pace, nevertheless, adoption of these technologies still requires cost-benefit analysis to make a strong case in terms of profitability [14].

2) Secondly, in the case of the construction sector, where stakeholder i.e. consultant, contractor and/or client should employ these technologies to get the most out of it in terms of cost and value.

3) Thirdly, most of the studies are conducted to explore or investigate the technologies from a technical point of view; can these technologies facilitate effective project management is yet to be explored.

4) Lastly, it is also significant to know the limitations of the technologies, such as, software and hardware issues.

4 CONCLUSION

It is apt to state that VR, AR and MR, though new technologies, have a potential to change the way many industries work and AEC is no exception. The construction industry can also benefit from these technologies in terms of design creation, decision making, visualization, health and safety trainings. However, promising prospects, as stated by the developers of these technologies for obvious reasons, are still under examination by academicians and industrial experts. Furthermore, cost-benefit analysis is yet to be taken to provide a strong business justification to invest in these technologies and associated roles to make it a practical and profitable adoption.

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