Visualising Climate Change using Extended Reality: A Review

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***Abstract*—Global energy demands have escalated due to the industrial endeavour and urbanization which further led to the surge in greenhouse gases worldwide. Consecutively, carbon-dioxide emissions are majorly responsible for human-induced climate change and is a major global concern. Therefore, tackling some of the world's toughest environmental challenges requires widening the scope of education and training to accelerate our energy transition to zero carbon emissions by 2050. The aim of this article is to review the literature on extended reality (XR) for training students about the implications of climate change and how these can be addressed in an effective manner. Furthermore, our review explores the social as well as psychological impacts of using an immersive and engaging environment using XR technology for delivering meaningful climate change visualisation. In addition, we include a critical review and analysis of recently published manuscripts on climate change research in XR. A total of 10 articles satisfied our search criteria. Based on our search results, we discuss the types of headsets used, the game engine and overall student perceptions.**

***Index Terms*—Climate change, Extended reality, Immersive Environment, User Engagement.**

Introduction

Since the Industrial Revolution, the development of factories, railroads, vehicles, and chemical products has made human existence more comfortable and prosperous. Various studies have shown that Earth's resources are depleting exponentially and thus, the extensive use of fossil fuels has led to a sudden increase in carbon dioxide emissions, which have a direct impact on climate change and overt global warming [1]. Hence, human life is at threat due to these environmental concerns and the aim of this article is to review previous pedagogical and technological techniques in addressing these climate change issues [2].

The implementation of effective teaching strategies for environmental education can have a profound impact on students' ability to learn as well as how they develop healthy environmental attitudes. Teaching could become more effective if teachers used alternative teaching strategies and resources to advance students' environmental ethics and environmental literacy [3]–[5]. Therefore, our hypothesis is that extended reality (XR) methods can be used to create engaging and impactful experiences to target climate change.

The words "virtual reality," "augmented reality," and "mixed reality" (VR, AR, MR) relate to technologies and theoretical concepts of spatial interfaces that have been investigated by researchers in engineering, computer science, and human-computer interaction (HCI) for a number of decades. XR is a term that encompasses VR, MR, and AR technologies - figure 1. The degree of mixing between actual and virtual items is expressed by the seminal continuum developed by Milgram and Kishino in 1994 [6]. They describe an immersive continuum spanning from the real environment (RE) end, where there is no digital immersion in the outside world, to the completely immersive VR end, where digital immersion is at its most intense.

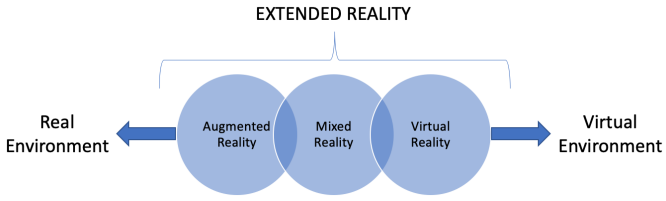

Fig. 1: The representation of Extended reality in terms of virtual reality, mixed reality and augmented reality in real environment and virtual environment respectively.

There is a growing body of research on XR technology in education and training purpose. This technology allow educators to develop new tools for multi-sensory teaching that promote learning via guided haptic and visuals [7]. VR is fully contrived of computer-simulated images that produce an immersive virtual environment that obscures the real environment. It is widely used in applications such as teaching/education, gaming, automotive, healthcare and designing a system giving a sense of realism [8].

There's a lot of literature available discussing the applications of XR in the health industry, medicine, gaming and the military, however, the applications of XR are not well explored in the field of climate change impact. We will discuss the integration of XR methods for designing engineering systems, precisely solar energy systems. Further, we will explore the literature of using XR for educating and teaching students in an immersive environment. Head-mounted displays have been utilised by academics and researchers to study users

attitudes and actions towards climate change. Furthermore, our review discusses the research papers published worldwide that incorporate XR methods to provide a solution to the climate change.

METHODOLOGY

We reviewed the precedence of XR and its impact on climate change for the purpose of meeting the sustainable energy development goals. The sustainable energy development goals set by the United Nation's SDG-13 not only aim to combat climate change and it's impact, but also to contribute towards the UK government's target of net-zero carbon emissions by 2050. In this section, we define our research methodology in collecting and synthesizing evidence on climate change using clearly defined criteria. For our study, we considered only academic journals and conference papers for our review, given their relatively high impact.

A literature search was conducted using a prior review protocol. The search was further limited to journal articles published in English in the time period from 2015 to 2022. Further, the search strategy was developed based on a combination of keywords, 'Augmented Reality for Climate Change', 'Net zero carbon-emission Augmented Reality','Climate change impact using AR/VR', 'Immersive Environment for Climate change', 'Immersive System for Climate change' and '3D/VR Climate Change'.

Using these methods, we will review our hypothesis whereby XR technologies can be used to create user engagement and impactful experiences to target climate change. We will not only review different domains of climate change but also discuss how XR can facilitate and thus, improve user experiences. Lastly, we discussed, VR used in various domains in order to visualize the critical challenges of climate changes across the globe.

RESULTS

The following section reviews and discusses the result depending upon our criteria set in Methodology. David *et al* [9] discussed the relationship between VR and climate change with respect to psychology and thus, presented appropriate suggestions for improving an accessible and impactful virtual experience for users. Climate change is perhaps the most important global issue of our time, and thus, our review aims to avoid its repercussions. Therefore, it necessitates the use of creative experiential methods to explain its impacts and alter attitudes in favour of pro-environmental behaviour.

A: Immersive VR user impactful experiences on climate change

Huang *et al* [10] developed a workflow that interpret data from an ecological model called LANDIS-II into a highly accurate VR model. In order to give users the opportunity to experience a forest in northern Wisconsin (WI) under two climate scenarios, ecological modelling, analytical modelling, procedural modelling, and VR were merged. Users can investigate and engage with the forest under various climate conditions, investigate how climate change will affect various tree species, and access data from a three-dimensions (3D) tree database. This developed application was used with HTC Vive and Oculus Rift. The authors believed that intuitive and concrete visualisations of complex data help in comprehension, evaluation, and verification of data and models, and innovate scientific communication.

The study presented by Monica *et al* [11] was to develop a VR teaching experience using a user-centered design (UCD) methodology that may foster empathy and promote behaviour change with respect to climate change in a U.S. community. They created a VR prototype that explores Miami flooding brought on by climate change. Further, techniques included a literature survey, interaction design, interview guides, and a focus group. Unity and Blender were the primary tools utilised to bring the story to life. They incorporated such viewpoint into the VR prototype using data from the literature and used participants feedback on what they thought might have affected their thinking on climate change. This study highlighted that VR headsets are not always readily available in universities however, Google Cardboard or phone VR headsets can be a good starting point to start incorporating VR into education.

Pimentel *et al* [12] demonstrated a VR simulation that relates the negative effects of climate change to the individual. Users of the "Virtual Seafood Buffet" experience can choose from hundreds of lifelike virtual seafood products and observe how that particular species is degrading in light of the expected effects of climate change. This application was developed using Unity for the HTC Vive headset. The experiment was about designing an interactive seafood buffet where customers can choose the seafood they want and then watch it degrade. The experience fosters an emotional connection to the problem of climate change and leads to pro-environmental results.

B: Students impact of environmental educational awareness related to climate change

Further, Gustav *et al* [13] discussed the investigation stage of an inquiry-based learning (IBL) climate change intervention included immersive virtual field trips. This field trip involved a virtual visit to Greenland and experience of the albedo and greenhouse effects of climate change. A group of 102 students in the seventh and eighth grades were selected at random to one of two teaching scenarios, either narrated pre-training accompanied by immersive VR exploration, or the identical narrated training material incorporated into the immersive VR exploration.

The results of an another study by Qiong *et al* [14] which used 360 students from Yangtze University in Hubei as research samples, indicated the impacts of environmental education on college students. According to the findings, recommendations are made with the hope that correct teaching techniques would be applied to environmental education to facilitate it and successfully foster students' environmental ethics and environmental literacy.

Xu *et al* [15] describes the creation of a climate change educational awareness application for VR that uses prediction data to mimic virtual scenes of local scenery and a rising sea level until the year 2100. The paper also discusses upcoming

efforts to evaluate the system as well as ongoing work to transfer the technology to AR. The VR application was developed with Unity and run on the Oculus Quest.

C: VR used in different domains for visualizing critical challenges of climate issues

Markowitz *et al* [16] evaluated the effectiveness of immersive VR as a teaching tool for explaining the effects of climate change, especially the acidification of the ocean. The authors demonstrate four studies, two controlled lab and two field trips. An immersive underwater environment was presented to over 270 participants from four different learning environments in order to demonstrate the causes and impacts of increasing seawater acidity. The virtual environment was developed using Worldviz's Vizard software and an Oculus Rift DK2 headset was used to visualise the application. Further, their findings clarify the potential for using immersive VR to promote knowledge seeking of significant social concerns like climate change and environmental education.

Another study conducted by Chandler *et al* [17] illustrated an endangered Australian Box Gum Grassy Woodland habitat, which is challenging to view in its pre-European colonisation state, modelled by a team of landscape ecologists and immersive visualisation specialists to demonstrate the potential of VR. In addition, their study outline highlighted the design criteria for the immersive virtual environment, such as the development of animated 3D plants that change with the seasons and alter throughout a simulated day. The Oculus Go all-in-one headset was used for their research and thus, evaluated the potential of immersive VR landscape modelling by using a heuristic review of specialists. Also, 27 ecologists in biodiversity conservation evaluated the VR experience produced by this cross-disciplinary collaboration in a series of sessions. The results showed that participants believed virtual landscapes held tremendous potential for teaching, public participation, and land management.

Furthermore, Aidan's *et al* [18] research attempts to produce extremely lifelike virtual forests that are based on empirical forest data. The virtual forest scenarios use visuals to communicate the effects of sustainable forestry practises on the health, aesthetic appeal, and carbon sequestration capacity of forests. Also, a real-time game creation engine, forest tree models are produced utilising a hybrid method combining photograph and 3D modelling. ArcGIS, Rhinoceros 3D, and Unity are used to generate a digital landscape model from the storyboard. An actual location representative of a northern hardwood forest where a certain approach would best be applied is recreated using geospatial data from the real world. High degrees of realism are achieved in the woodland scene using Unity's High Definition Render Pipeline (HDRP). The fabricated sceneries demonstrated diverse forest conditions as well as the effects of various natural and human factors.

Liestøl *et al* [19] presented a project called ClimSim, that aimed to look at how location-based digital media technologies can enable individuals to create their own tangible representations of the likely effects of climate change. Two programmes for visualising and simulating climate change on smartphones and tablets have been created, tested, and deployed in Norway. In this research, situated simulation, a type of indirect augmented reality, was used to address critical challenges of climate change.

Discussion and Recommendation

Incorporating visualisation tools in the area of climate change is quite popular among researchers [20]. In addition, it is noted in the literature that the use of XR in education and training has become widespread. However, our review showed that few studies were related to climate change using XR technology. The use of XR technology in climate change education increases the quality of teaching and reduces the learning process time. Due to the presence phenomenon, where users see and react to the virtual environment as real, immersive virtual environments are predicted to be effective persuasion techniques. Previous studies indicate that immersive virtual environment promotes positive attitudes more effectively than conventional media [21].

In addition, integrating game characteristics can provide an effective method that helps in enhancing and improving students' willingness to learn. Gamifying education may be the most effective strategy for grabbing and holding students' attention. Loureiro and Bilro [22] present a review papers using VR and gamification in higher education.

TABLE I: Summary of the results section discussing the headset used, type of XR used and the cost of the device.

Ref	Devices Used	XR Technique	Cost ($)
10 12	HTC Vive	VR of forest under two climate scenarios (10) VR of seafood items & experience of degradation of species based on climate change (12)	799
10	Oculus Rift	VR of forest under two climate scenarios	599
11	Google Cardboard Phone VR headsets	VR using User-Centered Design (UCD)	-
13	Samsung Gear VR	Used Immersive VR for virtual field trip	54.99
15	Oculus Quest	VR of local scenery and rising sea levels	399
17	Oculus Go	VR of woodland ecosystem in various seasons	199
16	Oculus Rift DK2	VR of underwater world demonstrating process and effects of ocean acidification	350
18	-	Creating 3D immersive environment using Unity's High Definition Render Pipeline (HDRP).	-
19	Smartphone Tablets	Situated Simulation Indirect AR	-

On comparing headsets used in the manuscripts reviewed - table I, we have found that tethered headsets are used more often. There are pros and cons to both tethered and untethered headset. For example, tethered headsets may restrict movement of the user due to connection cables, however, are able to handle more graphically intensive apps and systems. Alternatively, untethered headsets offer the user more freedom of movement but may not handle graphically intensive apps and systems due to limited processing power of the hardware. More often the necessity of greater processing power outweighs the necessity for freedom of movement and therefore tethered VR headsets remain the most popular choice of VR headset. Further, many of the studies were conducted with Oculus headsets which offer overall lower cost than other headsets such as the HTC Vive. A lower costing headset is beneficial to education due

to the number of headsets needed to efficiently teach many students at the same time.

It is noted that newer headsets have a larger display resolution and wider field of view (FoV). Resolution can have impact on the user experience as studies have shown that larger screens/images give users high emotional viewer arousal [23]. This is particularly important in connecting issues surrounding climate change with the user. Increasing the user's FoV means that it is closer to resembling the user's actual FoV and images can be perceived more naturally than headsets with a narrower FoV. This can have a positive effect on the level of immersion, increase the user's sense of presence, as well as improve spatial awareness [24]. Together, the user may exhibit better memory of the virtual environment and therefore improved knowledge retention.

CONCLUSION

Thanks to the high level of immersion and engagement, XR technologies can make transformational impact in enhancing and improving user understanding of climate change issues. Addressing climate change problems at an early stage provides great opportunities for users by engaging them in a virtual environment as if they are in the real world and allowing them to interact with 3D objects within the application. Our review has shown that XR technology can be used as a medium in classrooms in order to embed sustainable development goals. Whilst using the XR technology, there are several aspects that are recommended when choosing an XR headset. Based on our results, many kinds of headsets have been used to address climate change concern, but tethered headsets were prevalent. Moreover, the Oculus headsets offer a lower cost than HTC which may be beneficial to larger teaching groups. While the Google cardboard as well as other VR phone headsets are offered at even lower costs, however, have limited application immersion and interaction. In addition, the majority of the studies have used the Unity game engine for developing 3D immersive environment. Consecutively, incorporating XR methods with climate change will help to meet the UK governments' Net Zero Carbon emissions by 2050 and thus, offers many features that aid the learning process in an immersive environment. In addition, the XR technologies have the potential to take education beyond the conventional online learning experience and thus, help us achieve the Sustainable Development Goal-13 of cutting carbon to net-zero and building resilience against physical impacts of climate change.

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