CHAPTER 9

Climate Resiliency for Our Habitat Through Cross-Reality Technologies

YÉTINDRANATHSINGH VIPIN DHUNNOO

ABSTRACT

With the effects of Climate Change leading to adverse repercussions such as soil erosion, flooding and coastal displacement, at a macro scale, it is evident that our living spaces must be made resilient. With the detrimental effects of climate change not yet fully appreciated, there is an urgent need to model, illustrate and communicate climate change impacts. People living in vulnerable regions and coastal areas are at the ones at greater risk of climate change, particularly exposed small island developing states and coastal areas. The argument for this paper is for real-time mechanisms to help understand climate ramifications to mitigate and adapt the built environment. Advancements in Cross Reality (XR) technologies, such as Virtual Reality (VR) and Augmented Reality (AR), have led to promising multidisciplinary applications. With their unique interactive propensities, these technologies can be powerful aids at bridging the gap between actual and theoretical understanding of impending climate impacts. Drawing on experimental psychology and environmental research, this novel medium of visualisation can be utilised to strengthen communication and provide future resiliency. By leveraging the benefits of immersive technologies, this novel communication medium can transcend traditional language and accessibility barriers. This paper investigates the development of XR media as an innovative visualisation and effective communication instrument for climate resilience.

KEYWORDS:

Climate Change, Environment, Cross Reality (XR) Technology, Visualisation,

INTRODUCTION

Global warming has altered weather patterns with many countries experiencing some form of extreme climatic event, including flooding, mudslides, heatwaves and fire (Lindsey, 2021). There is an urgent need for quick and effective means of providing a clear understanding of the future consequences of the climate crisis (Ripple et al., 2021). With traditional media not necessarily driving the desired climate urgency, there is a call for innovations that provide idiosyncratic experiences on such effects. Cross Reality (XR) technology has the ability of replicating such encounters due to its immersive nature. XR is an umbrella terminology for immersive technologies which predominantly include Mixed Reality (MR), Augmented Reality (AR) and Virtual Reality (VR) (Flavián et al., 2019). Immersive technologies, traditionally used in the games industry, have begun to be adopted in other fields of work, for instance to visualise land ecosystems (Ahn et al., 2016), marine environments (Fauville et al., 2020), psychology (Roswell et al., 2020) and in medical sectors (Burkhardt et al., 2016; Won et al., 2017). Consequently, this investigative study will explore the possibilities of XR, as a visual instrument, to raise urgent awareness about critical climate action.

CLIMATE CHANGE AND THE IMPORTANCE OF VISUALISATION

The impacts of Climate Change will have long lasting repercussions on our living environment. Coastal areas are the most vulnerable, with these areas accommodating some 600 million people. With about 10% of the world's population living at less than 10 metres above sea level (United Nations,

2017) livelihoods will need to be adapted to new norms. Coastal cities and small island developing nations, which depend on limited resources for their livelihood and rely on tourism for their economy, will require constant infrastructure review and maintenance (Betzold, 2015). Furthermore, by 2100, a large number of homes in developed countries will be at risk of flooding and evaluated as being 'uninsurable' by the end of the century (Ting et al., 2020).

To build resiliency and extend communication to all stakeholders, urban experimentation is encouraged with greater contextualisation and collaboration (Madsen & Hansen, 2019). There are not enough questions being asked by the diverse stakeholders to challenge the current management of city and coastal assets. Valuable data can also be obtained when local know-how is tapped into and combined with scientific information (Bai et al., 2018). Learning from past climate occurrences can help prepare for future disasters and adapting such techniques with modern technology can provide improved mitigative nature-based solutions to climate issues. In spite of extensive research interest, there is limited real-world application of such knowledge (Robinson, 2020). Support in visualising to develop contextual action plans are therefore imperative to safeguard these nations (Petzold & Megnan, 2019).

Traditional methods of communicating phenomena to a population in the form of text and imagery (Lehtonen et al., 2019) are not always effective, especially with issues of magnitude like climate change (Ahn & Bailenson, 2011). Following calls, by distinguished organisations such as the National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), to improve climate literacy, it is argued for rapid information propagation with multiple media formats (Cooper, 2011). Having first-hand experiences have shown to increase awareness and to have more of an impact (Ahn & Bailenson, 2011). Visual anchors are a crucial element to climate literacy as they allow emotions to be evoked by creating a connection with Climate Change literature and its depictions (DiFrancesco & Young, 2011). With 65% of people being visual learners (Bradford, 2011) perception has a significant role to play.

One area which can benefit from comprehensive frameworks and tools to help make sense of climate change information is city planning (Sheppard et al., 2011). As such, disruptive and automated technologies can help map our infrastructure and develop real time urban modelling data to accelerate knowledge sharing of climate change repercussions (Bai et al., 2018). Integration of traditional know-how with advanced technologies can yield substantial benefits, especially with issues related to climate adaptability.

HIGHLIGHTS OF XR TECHNOLOGY

New immersive technologies have the potential of improving accessibility and reach of research information. XR technologies can better assist collaborators in their decision making: envisioning risks by visually stimulating natural calamities via computer-generated modelling (Vamvakeridou-Lyroudia et al., 2020). The research work by Vamvakeridou-Lyroudia et al. (2020) forecasted the erosion rate of beaches worldwide until the year 2100 and this modelling technique showed the potential dangers of future erosion and highlighted vulnerable areas. Similarly, three-dimensional time-based visualisations, with the assistance of Geographic Information System (GIS) (Seenu et al., 2019) and based on historical data, have been utilised to simulate flood risks under a number of scenarios. The study by Seenu et al (2019) used the city of Hyderabad, in India, as a flood simulation location. Thirty years' worth of rain data was replicated using a Storm Water Management Model (SWMM) and a four-dimensional geographic information system (4D GIS). When cross-examined with a flooding event which occurred in 2009, the modelling produced the same outcome, which demonstrated its efficacy. This method of mapping can also be useful especially where tourism is of economic importance (Chen et al., 2018). Immersive three-dimensional virtual environments have shown to have a better influence on users (Fauville et al., 2020) and immersive XR technologies can also offer a safer environment to learn of a site's challenges (Elghaish et al., 2020). To enhance user retention and improve awareness, inclusion of virtual interactions has proved to be advantageous (Markowitz et al., 2018) and along with the synthesis of Building Information Modelling (BIM), digital collaboration can be reinforced (Elghaish et al., 2020). Additionally, virtual environmental mimicry has allowed for better public participation by making complex infrastructural projects more approachable to the masses and has shown to provide sustainable outcomes (Stauskis, 2014). A summary of the studies discussed can be found in Table 1.

XR devices have been used in other fields of work which can provide a glimpse of their adaptability for climate action. The novel MR platform, Microsoft Mesh, which makes use of a head mounted display (HMD), allows individuals regardless of their geographical location to meet and collaborate via 'holoportation', a state of virtual holographic representation interacting with the same three-dimensional model (Langston, 2021). OceanX, a non-profit organisation, has been using the Hololens MR headset to help create awareness of ocean decay from the comfort of their offices (Langston, 2021). This new storytelling medium can thus provide immersive experiences without physically being on a hazardous site.

VR, a technology providing complete virtual immersion by means of a headset and controllers, has several advantages over other digital technologies. It possesses enhanced interactive attributes with its diverse built-in sensorial technologies (Fauville et al., 2020) and VR also allows for a technological dyad embodiment which enables the user to be physically part of a hybrid virtual setting (Flavián et al., 2019). As such, VR can help in fields which are highly technical and bring them to an understandable visual form. This makes it accessible to the general populace and has the benefit of providing experiences regardless of a user's geo location (Fauville et al., 2021). Additionally, VR can be used to increase empathy (Herrera et al., 2018; Roswell et al., 2020) which can subsequently give rise to positive behavioural changes (Nelson et al., 2020). This is attributed to the increase in emotional engagement, as the 360 exposure brings forth a unique point of view (Engberg & Bolter, 2020). Use of PC tethered VR devices, such as the Oculus Rift combined with Leap Motion, a technology which detects hand gestures, has shown multi-level immersion and enhanced collaboration (Nguyen et al., 2016).

Where HMD-based XR experiences shields to some extent the real world, AR overlays virtual assets over the physical environment (Klopfer & Sheldon, 2011). Implementation of AR has been undertaken via serious games such as TimeLab 2100. TimeLab 2100 is a multi-epoch game with the goal of managing a population's adaptation in a future affected by Climate Change. The AR component attempts at connecting players with their surroundings, thereby increasing their educational propensity within their environment by blending virtual and real worlds (Klopfer & Sheldon, 2011). Another such AR experiment is P.E.A.R, a serious game which aims at raising awareness of climate issues via a series of mini-games (Wang et al., 2021). These ecological mini-games allow participants to expand their knowledge of sustainability and know-how on climate issues (Table 1).

Institutions have been experimenting and encouraging the use of XR technologies to drive awareness of Climate Change through the Sustainable Development Goals (SDGs) framework. One such event, organised by the United Nations, is the SDG Global Festival of Action which aims at highlighting predetermined global targets. The SDGs are a set of 17 predefined goals which countries will have to align with by the year 2030, for the safeguard of the planet (UNDP, 2022). Submissions and presentations for this noteworthy yearly gathering range from serious games, AR, VR and also two-dimensional media (United Nations, 2021). The aim being to experiment with better methods of information sharing and promote the actions being undertaken worldwide for the welfare of our environment and people's wellbeing.

Studies have shown that immersive technology constantly outperforms its two-dimensional counterpart, in both assimilation and intuitive interpretation (Coburn et al., 2017) and immersive technology should be considered when the imperceptible needs to be made perceptible (Pantelidis, 2009). Ultimately, XR technology has the ability to place the user in situations which would otherwise be inconceivable or unfathomable (Pan & Hamilton, 2018). One study showed that the ability to provide real-time data can shorten time frames and improve participatory activities when used in the context of master-planning (Jamei et al., 2017). The experiment by Jamei et al. (2017) demonstrated enhanced engagement with the public, crucial when designing climate adaptive cities (Table 1). The proliferation of XR technologies has the potential of rapidly democratising scientific data. These connected computer technologies enhance the physical world by virtually enabling idiosyncratic experiences (Ziker et al., 2021) and these digital devices allow improved information assimilation to strengthen climate awareness (Markowitz et al., 2018).

Table 1

Summary of key papers investigating the use of XR technology for climate perception and for the creation of sustainable environments.

Research	Method and Characteristics	Successes	Failures	Efficacy
Sandy coastlines under threat of erosion. (Vamvakeridou-Lyroudia et al., 2020)	2100 computer modelling projection of beach erosion along coastal zones on continents and islands nations, worldwide.	Effectively showed real dangers of climate impact on shorelines. Regions of higher beach rate loss were earmarked, such as North Australia and South Asia.	Erosion, induced by intermittent storms, was not taken into consideration in this study.	There is no global dataset on beach width to allow proper calculation of beach loss. Therefore, only beaches with expected sand loss of >100m

				were taken into consideration.
Visualisation of urban flood inundation using SWMM and 4D GIS. (Seenu et al., 2019)	Simulation of flooding using Storm Water Management Model (SWMM) and four-dimensional geographic information system (4D GIS), for the city of Hyderabad in India. Thirty years of rainfall data was used for this study.	This provided an enhanced overview of flooding complexities for an urban environment. An intensity-duration-frequency relationship was created along with the simulation of an inundation map to identify flood prone zones. This helped to foresee the adaptation and mitigation measures required for these areas.	Lack of adequate historical data was an issue, making modelling a challenge.	The simulation experiment was compared to a flooding event in 2009 and the simulation corroborated with the past occurrence, thereby demonstrating the validity of the study.
Towards digitalisation in the construction industry with immersive and drone technologies. (Elghaish et al., 2020)	Literature review on the use of Unmanned Aerial Vehicles (UAVs) and immersive technologies in the construction industry.	The progress of a project can be coordinated with better efficiency using UAVs in tandem with 4D BIM software. Immersive technology can allow remote and risk-free management of construction projects.	Costs of these technologies are high and can be out of reach for small businesses. Development and training for these cutting-edge devices can be time consuming.	Only few researches are available on the use of UAVs and immersive technology. This specific study was limited at finding the shortcomings in an ideal scenario without any cost implications.
Development of methods and practices of virtual reality as a tool for participatory urban planning. (Stauskis, 2014)	Using virtual reality (VR) for public participation in a sustainable urban planning exercise for the city of Vilnius, Lithuania.	The use of VR and spatial modelling via gaming platforms provided an innovative tool for public collaboration. This subsequently led to a better use of resources and a more sustainable method of urban design.	Having the proper software and technical assistance is essential for the development of such virtual projects.	This allowed a more accessible way of communicating urban projects with increased reliability in the results.
Augmenting your own reality: Student authoring of science-based	Gamification of Climate Change repercussion between past and future scenarios, using AR and the	Participants were provided first-hand experience of what-if scenarios which increased their awareness of	The main challenges to developing such immersive AR experiences are limited	This study challenged people to think differently about their living environment, by

augmented reality games. (Klopfer & Sheldon, 2011)	MIT campus as the ground for the experiment.	environmental climate impacts. This also allowed the participants to explore and look at their everyday environment from a different perspective.	resources of cost and time. Additionally, specialised know-how on programming is required to create such a project.	directly integrating virtual elements onto their physical surroundings. This greatly engaged the users and was creatively educational.
Evaluating the effectiveness of an augmented reality game promoting environmental action. (Wang et al., 2021).	An immersive educational game promoting sustainable environmental action using geolocation and AR technology.	Enhanced the knowledge of participants on topics such as sustainability and Climate Change. This was achieved via a series of questions before and after playing the quests in a series of mini-games.	The game only had sustainability as the primary focus and did not measure the participant's actual impact on their surroundings following their interaction with the game.	There was a significant decrease in player engagement as the game progressed which was potentially due to the game design.
Investigating the role of virtual reality in planning for sustainable cities (Jamei et al., 2017)	Study on the capacity for VR\to visualise the impact of natural calamities on cities, via material modelling and simulation.	This study found that VR allowed solutions for urban issues to be visualised in real time, promoted efficient communication with all stakeholders and enabled sustainable designs within a better time frame.	Cost of VR headsets and its related computer peripherals, along with the expertise in software integration, have been the main challenges to adapting the process for real world use.	Using VR for planning has shown that the immersion successfully replicated real-world scenarios, which provided seamless interaction and holistic design outcomes.

CHALLENGES OF XR TECHNOLOGY

Despite the promises of immersive technology as an instrument for climate change visualisation, the technology currently has some limitations. Real-time engines are utilised for the development of immersive experiences. As such, they proportionately possess similar visual elements to that of video game design (Kitatus, 2019). The pessimistic connotations related to certain games including, aggression induced by gaming competition (Dowsett & Jackson, 2019) and dangerous behaviours (Chang & Bushman, 2019) can potentially stimulate unconscious prejudice on behalf of users, when attempting to use such a digital environment for education (Wilson & Soranzo, 2015). Additionally, the experience associated with immersive technology can negatively impact assimilation and critical thinking as a result of its unfamiliarity (Velev, & Zlateva, 2017). The software used in the creation of real-time experiences are game engines, such as Unreal Engine and Unity. These have been predominantly developed with game programmers as the main demographic (Brookes et al., 2020) and as a result, the use of these software in cross-disciplinary fields can yield a lengthy learning curve for scholars trying to create interactive environments for research (Brookes et al., 2020).

Due to the novelty of XR systems, interactive frameworks within the virtual environment can be complex. For instance, the current way to navigate in VR is by the teleportation technique, where the user jumps to a chosen location, which unfortunately detracts from real world movement simulation (Ramirez, 2018). Screen latency is also known to induce nausea, or sickness, (Korolov, 2014; Pan & Hamilton, 2018; Saredakis et al., 2020) and disorientation (Kim et al., 2018). Besides, such avant-garde technologies can take away from the actual message being presented, especially among an audience not used to technology, thereby tempering with the intended experiment's outcome (Markowitz et al., 2018). Furthermore, the novel factor and adaptation time for people to get used to the technology can be a considerable hurdle (Ylipulli et al., 2013).

The intrinsic nature of most XR platforms is immersion via a wearable HMD and this unequivocally shields the physical world from the user. There is also growing evidence that shows a correlation of decreasing capabilities and questionable credibility (Slater, 2009) when undertaking simulated activities whilst being in a state of physical imperception (Pan & Hamilton, 2018). There is additionally the issue of "uncanny valley", the condition of being preternatural, when attempting to digitally recreate human bodies (Pan & Hamilton, 2018; Ashtari et al., 2020; Engberg & Bolter, 2020). Compared to traditional experiments, certain XR devices demand a new type of setup and its recommended limited exposure in maintaining virtual presence poses a challenge for lengthy experiments (Pan & Hamilton, 2018). Correspondingly, AR compatible devices are not made for prolonged use, which can result in the device overheating, battery degradation and ergonomic issues with prolonged usage (Ilanković et al, 2020). As it is still early stages for certain XR technologies, some are either too expensive (Karthika et al., 2017), require extensive setup times (Karthika et al., 2017), solely intended for large organisations (Bohn, 2019) or discontinued due to lack of consumer interest (Altman, 2015).

Software development is key when creating immersive experiences for XR devices. However, these require specific knowledge and learning materials, along with technical support, are often challenging for the uninitiated (Ashtari et al., 2020). Additionally, frequent software updates often lead to compatibility issues during development (Ashtari et al., 2020). Compared with traditional two-dimensional media, immersive environments pose no control over participant navigation and activities, which can be a problem when attempting to predict a user's virtual conduct (Ashtari et al., 2020). Furthermore, there is a plethora of unknowns in XR development and as a result, Ashtari et al. (2020) indicates that developers spend most of their time bug fixing and attend to other technical complications, which compromises end user evaluation and user experience.

FUTURE OF XR TECHNOLOGIES

Advancements within the realm of XR development is essential to successfully adapt advanced environmental impact simulation on our urban spaces. Good interactions within a virtual environment contribute towards a positive immersive experience and as such, manoeuvering within an XR space using input devices like controllers can be unfamiliar for some. With Oculus Quest's new update, the built-in camera can now utilise hand tracking (Oculus Blog, 2020), without any additional piece of hardware. Such an implementation can provide a better natural interaction and be more appealing to the masses.

Use of other senses in XR environments can further enhance immersion. For instance, the potential use of the olfactory system within the virtual space can add an extra dimension of spatial perception, for instance the stench during a flooding scenario can accentuate specific emotions. Ericsson is investigating enhanced sensorial communication by an 'Internet of Senses' framework within the next decade (Ericsson ConsumerLab, 2019). This will allow integration of intangible abilities, such as detection of digital aroma and flavour, to proliferate using rapid 5G data transfer.

A major limitation of XR, especially MR and VR, is that it is still a niche product and unless it is widely adopted, dissemination of climate change information via this immersive platform will remain restrictive. One way of promoting public endorsement is by enhancing collaboration within an XR environment. Enabling multi-user access within the same digital XR realm can significantly drive mass adoption, thus promoting participation and cooperation regardless of the user's location.

Future development of XR points to a merger of technologies. In its current form, AR is accessible either via smart devices or glasses. A ground-breaking wearable tech from a company called Mojo Vision created and tested a smart contact lens with the ability to display AR content (Koetsier, 2022). Such a seamless blend of wearable devices with the human body could potentially make bulky XR headsets redundant and provide a streamline content experience. Moreover, the visualisation potential of XR can be further enhanced with the integration of Artificial Intelligence (AI). Merging these two bespoke technologies can create new possibilities and opportunities unfathomable by human minds, yet within the reach of AI systems (Reiners et al., 2021). Such a system can have tremendous positive impact and crucial time gain, especially with the current unpredictability of future climate scenarios.

With the proliferation of digitised content, the creation of a digital twin powerful enough to simulate the physical world can provide real-time simulative solutions to climatic problems. This would allow opportunities at finding answers to age old climate issues. One such programme is Nvidia's Earth2 project, which uses its Omniverse simulation engine (Sprinzen, 2022) and climate forecasting digital twin, ForeCastNet (Freund, 2022). Earth2 could be the portal where future solutions to urgent climate issues are harvested and subsequently assist with deployment. With the convergence of AI, machine learning and XR technologies, an almanac of Earth's ersatz could be generated which has the potential of being the reference for climate explorations and investigations. As the Founder and CEO of Nvidia, Mr Jansen Huang, framed it; With this technology, "what takes a classical numerical simulation a year, now takes minutes"(Freund, 2022). Such a revolutionary merger of technologies can greatly assist with the ever-growing urgency of Climate Change.

CONCLUSION

This paper explored the use of XR technologies and its potential as a tool for climate change awareness. A range of current XR technologies were explored, along with their advantages and constraints discussed. Studies on the uses of XR showed that immersive technology can have positive implications in the field of urban design, environmental planning and education. The upcoming developments in XR technology were also appraised, which offered a promising outlook on enhanced immersion and information dissemination pertaining to climate action. However, challenges to the adoption of such technologies revolved predominantly around the cost of acquisition and expertise required for the creation of digital applications for XR devices. It requires considerable time to custom make digital assets and virtual environments for simulation, an uncharted domain for many scholars.

Nonetheless, from the insights gathered there seem to be an opportunity for XR technologies to be pivotal in driving awareness of climate action. As such, prospective multidisciplinary investigations can explore integration of historical data to assist with adaptive and mitigative designs for our living environment, with future climate issues in mind. With the unique abilities of immersive technologies, these simulation devices can be influencing agents for climate change perception and can provide the required impetus for the safeguard of our planet.

REFERENCES

Ahn, S. J. & Bailenson, J. (2011). *[Technical report] Embodied experiences in immersive virtual environments: effects on pro-environmental self-efficacy and behavior.* Stanford University. https://vhil.stanford.edu/mm/2011/VHIL-technical-report.pdf

Altman, I. (2015). Why Google Glass failed and why apple watch could too. *Forbes.* https://www.forbes.com/sites/ianaltman/2015/04/28/why-google-glass-failed-and-why-apple-watch-could-too/?sh=50862ca844c4

Ashtari, N., Bunt, A., McGrenere, J., Nebeling, M., & Chilana, P. K. (2020). Creating Augmented and Virtual Reality Applications: Current Practices, Challenges, and Opportunities. CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1-13. https://doi.org/10.1145/3313831.3376722

Bai, X., Dawson, R., Ürge-Vorsatz, D., Delgado, G., Salisu Barau, A., Dhakal, S., Dodman, D., Leonardsen, L., Masson-Delmotte, V., Roberts, D., & Schultz, S. (2018). Six research priorities for cities and climate change. *Nature (London)*, 555(7694), 23–25. https://doi.org/10.1038/d41586-018-02409-z

BBC. (2013). *Deadly floods hit Mauritius capital Port Louis*. BBC. https://www.bbc.com/news/world-africa-21989070

Betzold, C. (2015). Adapting to climate change in small island developing states. *Climatic Change* 133, 481–489. https://doi.org/10.1007/s10584-015-1408-0

Blois, J. L., Zarnetske, P. L., Fitzpatrick, M. C., & Finnegan, S. (2013). climate change and the past, present, and future of biotic interactions. *Science, 341*(6145), 499-504. https://doi.org/10.1126/science.1237184

Bohn, D. (2019). Microsoft's hololens 2: a $3,500 mixed reality headset for the factory, not the living room. *The Verge. https://www.theverge.com/2019/2/24/18235460/microsoft-hololens-2-price-specs-mixed-reality-ar-vr-business-work-features-mwc-2019*

Bova, S., Rosenthal, Y., Liu, Z., Godad, S. P. & Yan, Mi. (2021) Seasonal origin of the thermal maxima at the Holocene and the last interglacial. *Nature, 589*, 548–553. https://doi.org/10.1038/s41586-020-03155-x

Bradford, W. C. (2011). Reaching the visual learner: teaching property through art. *The Law Teacher 11.* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=587201

Brookes, J., Warburton, M., Alghadier, M., Mon-Williams, M., & Mushtaq, F. (2020). Studying human behavior with virtual reality: The Unity Experiment Framework. *Behavior Research Methods*, *52*(2), 455–463. https://doi.org/10.3758/s13428-019-01242-0

Broto, V. C., & Bulkeley, H. (2012). A survey of urban climate change experiments in 100 cities. *Global Environmental Change, 23*(1), 92-102. https://doi.org/10.1016/j.gloenvcha.2012.07.005

Burkhardt, J. M., Corneloup, V., Garbay, C., Bourrier, Y., Jambon, F., Luengo, V., Job, A., Cabon, P., Benabbou, A., & Lourdeaux, D. (2016). Simulation and virtual reality-based learning of non-technical skills in driving: critical situations, diagnostic and adaptation. *IFAC-PapersOnLine, 49*(32), 66-71. https://doi.org/10.1016/j.ijdrr.2018.09.001

Callaghan, J. (2011). *Case study: Gold coast erosion, 1967*. Hardenup Queensland. http://hardenup.org/umbraco/customContent/media/614_GoldCoast_Erosion_1967.pdf

Chen, A. S., Khoury, M., Vamvakeridou-Lyroudia, L., & Stewart, D. (2018). 3D visualisation tool for improving the resilience to urban and coastal flooding in Torbay, UK. *Procedia Engineering, 212*, 809-815. https://doi.org/10.1016/j.proeng.2018.01.104

Chang, J. H., & Bushman, B. J. (2019). Effect of Exposure to Gun Violence in Video Games on Children's Dangerous Behavior With Real Guns. *JAMA Network Open,* 2(5). doi:10.1001/jamanetworkopen.2019.4319

Cheney, P. (1995). *Bushfires—An Integral Part of Australia's Environment*. Australian Bureau of Statistics. https://www.abs.gov.au/Ausstats/abs@.nsf/0/6C98BB75496A5AD1CA2569DE00267E48

Coburn, A., Vartanian, O., & Chatterjee, A. (2017). Buildings, Beauty, and the Brain: A Neuroscience of Architectural Experience. *Journal of Cognitive Neuroscience*, *29*(9), 1-11. DOI:10.1162/jocn_a_01146

Cooper, C. B. (2011). Media literacy as a key strategy toward improving public acceptance of climate change science. *BioScience, 61*(3), 231-237. https://doi.org/10.1525/bio.2011.61.3.8

Cooper, J. A. G., & Lemckert, C. (2012). Extreme sea-level rise and adaptation options for coastal resort cities: A qualitative assessment from the Gold Coast, Australia. *Ocean & Coastal Management, 64*, 1-14. https://doi.org/10.1016/j.ocecoaman.2012.04.001

DiFrancesco, D. A, & Young, N. (2011). Seeing climate change: the visual construction of global warming in Canadian national print media. *Cultural Geographies, 18*(4), 517–536. https://doi.org/10.1177/1474474010382072

Dowsett, A., & Jackson, M. (2019). The effect of violence and competition within video games on aggression. *Computers in Human Behavior, 99*, 22–27. https://doi.org/10.1016/j.chb.2019.05.002

Elghaish, F., Matarneh, S., Talebi, S., Kagioglou, M., Hosseini, M. R., & Abrishami, A. (2020). Toward digitalization in the construction industry with immersive and drones technologies: a critical literature review. *Smart and Sustainable Built Environment.* https://doi.org/10.1108/SASBE-06-2020-0077

Engberg, M., & Bolter, J. (2020). The aesthetics of reality media. *Journal of Visual Culture, 19*(1), 81–95. https://doi.org/10.1177/1470412920906264

Ericsson ConsumerLab, 2019. *10 Hot Consumer Trends 2030. Ericsson*. https://www.ericsson.com/4ae13b/assets/local/reports-papers/consumerlab/reports/2019/10hctreport2030.pdf

Faulkner, D., & Durbin, A. (2022). UK heatwave: Temperature tops 38C and likely to rise on Tuesday. BBC. https://www.bbc.com/news/uk-62201793

Fauville, G., Queiroz, A.C.M., & Bailenson, J.N. (2020) *Virtual reality as a promising tool to promote climate change awareness.* In Kim, J. & Song, H (Eds.) *Technology and Health: Promoting Attitude and Behavior Change* (pp. 91-108). Elsevier. https://doi.org/10.1016/B978-0-12-816958-2.00005-8

Fauville, G Queiroz, A.C.M., Hambrick, L., Brown, B. A., & Bailenson, J.N. (2021) Participatory research on using virtual reality to teach ocean acidification: a study in the marine education community. *Environmental Education Research, 27*(2), 254-278, https://doi.org/10.1080/13504622.2020.1803797

Flavián, C., Ibáñez-Sánchez, S., & Orús, C. (2019). The impact of virtual, augmented and mixed reality technologies on the customer experience. *Journal of Business Research, 100*, 547-560. https://doi.org/10.1016/j.jbusres.2018.10.050

Freund, K. (2022). NVIDIA Earth-2: Leveraging The Omniverse To Help Understand Climate Change. *Forbes*. https://www.forbes.com/sites/karlfreund/2022/04/03/nvidia-earth-2-leveraging-the-omniverse-to-help-understand-climate-change/?sh=6715f8e4491f

Herrera, F., Bailenson, J., Weisz, E., Ogle, E., & Zaki, J. (2018). Building long-term empathy: A large-scale comparison of traditional and virtual reality perspective-taking. *PloS One, 13*(10), e0204494. https://doi.org/10.1371/journal.pone.0204494

Ilanković, N., Živanić, D., & Zelić, A. (2020). Augmented Reality in Order-picking processes – Advantages and Disadvantages. In Editor M. Gubán*, Lim Folyoirat*, 4-11, DOI: 10.29177/LIM.2020.1.4

Jamei, E., Mortimer, M., Seyedmahmoudian, M., Horan, B., & Stojcevski, A. (2017). Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities. *Sustainability (Basel, Switzerland), 9*(11), 2006–. https://doi.org/10.3390/su9112006

Karthika, S., Praveena, P, & GokilaMani, M. (2017). Hololens. *International Journal of Computer Science and Mobile Computing,* 6(2), 41 – 50.

Kim, H., Park, J., Choi, Y., & Choe, M. (2018). Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment. Applied Ergonomics, 69, 66–73. https://doi.org/10.1016/j.apergo.2017.12.016

Kitatus. (2019) *The problems of using data from virtual reality experiments.* Medium. https://medium.com/kitatus/the-problems-of-using-data-from-virtual-reality-experiments-84d029b289fc

Klopfer, E. & Sheldon, J. (2011). Augmenting your own reality: Student authoring of science-based augmented reality games. *New Directions for Youth Development,* 2010(128), 85-94. Wiley. https://doi.org/10.1002/yd.378

Koetsier, J. (2022, May 18). “Mojo Vision’s Smart Contact Lens: Ready For Real-World Testing”. *Forbes. https://www.forbes.com/sites/johnkoetsier/2022/05/18/mojo-visions-smart-contact-lens-ready-for-real-world-testing/?sh=723fd0c02edf*

Korolov, M. (2014). The real risks of virtual reality. *Risk Management, 61*(8), 20. Accessed 13 March 2021.

Langston, J. (2021, March 2). *“You can actually feel like you’re in the same place”: Microsoft mesh powers shared experiences in mixed reality.* Microsoft. https://news.microsoft.com/innovation-stories/microsoft-mesh/

Lindsey, R. (2021). *Climate change: Global sea level.* NOAA. https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

Madsen, S., & Hansen, T. (2019). Cities and climate change – examining advantages and challenges of urban climate change experiments. *European Planning Studies, 27*(2), 282–299. https://doi.org/10.1080/09654313.2017.1421907

Markowitz, D. M., Laha, R., Perone, B. R., Pea, R. D., & Bailenson, J. N. (2018) Immersive virtual reality field trips facilitate learning about climate change. *Frontiers in Psychology, 9*, 2364. https://doi.org/10.3389/fpsyg.2018.02364

Middelmann, M., Harper, H., & Lacey, R. (2000). Flood risks. In K. Granger & M. Hayne (Eds.), *Natural hazards and the risks they pose to South-East Queensland,* (pp. 9.1-9.31). Geoscience Australia.

Nelson, K., Anggraini, E., & Schlüter, A. (2020). Virtual reality as a tool for environmental conservation and fundraising. *PloS One*, *15*(4), e0223631. https://doi.org/10.1371/journal.pone.0223631

Nguyen, M.T., Nguyen, H.K., Vo-Lam, K.D., Nguyen, X.G., & Tran M.T. (2016). Applying Virtual Reality in City Planning. In: Lackey S., Shumaker R. (eds) Virtual, Augmented and Mixed Reality. VAMR 2016. Lecture Notes in Computer Science, vol 9740. Springer. https://doi.org/10.1007/978-3-319-39907-2_69

Oculus Blog. (2020, October 22). *How researchers cracked hand tracking technology on quest.* Oculus. https://www.oculus.com/blog/how-researchers-cracked-hand-tracking-technology-on-quest/

Pan, X., & Hamilton, A. (2018). Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. *The British Journal of Psychology, 109*(3), 395–417. https://doi.org/10.1111/bjop.12290

Pantelidis, V. (2009). Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality. *Themes in Science and Technology Education, 2*(1-2), 59.

Peter, L. (2022). Heatwave: More evacuations as Mediterranean wildfires spread. *BBC.* https://www.bbc.com/news/world-europe-62196045

Petzold, J. & Magnan, A. K. (2019). Climate change: thinking small islands beyond Small Island Developing States (SIDS). *Climatic Change,* 152*, 145–165.* https://doi.org/10.1007/s10584-018-2363-3

Phipps, A. (2022). Record high temperature recorded in Derbyshire. *BBC.* https://www.bbc.co.uk/news/uk-england-derbyshire-62219930

Pierson, D. (2021). Summer of disaster: Extreme weather wreaks havoc worldwide as climate change bears down. Los Angeles Times. https://www.latimes.com/world-nation/story/2021-07-21/extreme-weather-worldwide-climate-change-disasters

Potts, A. (2020, February 16). *Gold Coast weather: Famous floods and storms destroy beaches and Surfers Paradise streets.* Gold Coast Bulletin. https://www.goldcoastbulletin.com.au/news/gold-coast/gold-coast-weather-famous-floods-and-storms-destroy-beaches-and-surfers-paradise-streets/news-story/8a9f7673332f2e4690ef49712ba2425b

Rainers, D., Davahli, M. R., Karwowski, W., & Cruz-Neira, C. (2021). The Combination of Artificial Intelligence and Extended Reality: A Systematic Review. *Frontiers in Virtual Reality.* https://doi.org/10.3389/frvir.2021.721933

Ramirez, E. (2018). Ecological and ethical issues in virtual reality research: A call for increased scrutiny. *Philosophical Psychology*, *32*(2), 211–233. https://doi.org/10.1080/09515089.2018.1532073

Review, H., Winston, A., McAfee, A., Disparte, D., & Mucharraz y Cano, Y. (2020). Climate change. Harvard Business Review Press.

Ripple, W. J., Wolf, C., Newsome, T. M., Gregg, J. W., Lenton, T. M., Palomo, I., Eikelboom, J.A.J., Law, B. E., Huq, S., Duffy, P. B. D., & Rockström, J. (2021). World Scientists' Warning of a Climate Emergency 2021. BioScience. https://doi.org/10.1093/biosci/biab079

Robinson, S. (2020). Climate change adaptation in SIDS: A systematic review of the literature pre and post the IPCC Fifth Assessment Report. *Wiley Interdisciplinary Reviews*. https://doi.org/10.1002/wcc.653

Roswell, R. O., Cogburn, C. D., Tocco, J., Martinez, J., Bangeranye, C., Bailenson, J. N., Wright, M., Mieres, J. H., & Smith, L. (2020) Cultivating empathy through virtual reality: Advancing conversations about racism, inequity, and climate in medicine. *Academic Medicine*, Advanced online publication. http://doi.org/10.1097/ACM.0000000000003615

Saredakis, D., Szpak, A., Birckhead, B., Keage, H., Rizzo, A., & Loetscher, T. (2020). Factors Associated With Virtual Reality Sickness in Head-Mounted Displays: A Systematic Review and Meta-Analysis. *Frontiers in Human Neuroscience, 14*, 96–96. https://doi.org/10.3389/fnhum.2020.00096

Seenu. P. Z, Rathnam. E. V, & Jayakumar, K. (2019). Visualisation of urban flood inundation using SWMM and 4D GIS. *Spatial Information Research,* 28(12), DOI:10.1007/s41324-019-00306-9

Sheppard, S., Shaw, A., Flanders, D., Burch, S., Wiek, A., Carmichael, J., Robinson, J., & Cohen, S. (2011). Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. *Futures: the Journal of Policy, Planning and Futures Studies, 43*(4), 400–412. https://doi.org/10.1016/j.futures.2011.01.009

Slater, M., Perez-Marcos, D., H. Ehrsson, H., & Sanchez-Vives, M. V. (2009).

Inducing illusory ownership of a virtual body. *Frontiers in Neuroscience.* https://doi.org/10.3389/neuro.01.029.2009

Sprinzen, M. (2022). The Metaverse: Saving The World Or Another Digital Distraction?. *Forbes*. https://www.forbes.com/sites/forbestechcouncil/2022/03/31/the-metaverse-saving-the-world-or-another-digital-distraction/?sh=5dde3d4238c8

Stauskis, G. (2014). Development of methods and practices of virtual reality as a tool for participatory urban planning: a case study of Vilnius City as an example for improving environmental, social and energy sustainability. *Energy, Sustainability and Society, 4*(1), 1–13. https://doi.org/10.1186/2192-0567-4-7

The Canberra Times (1967). *Storms tarnish Gold Coast (ACT: 1926 – 1995)*, p. 2. Retrieved February 13, 2021, from http://nla.gov.au/nla.news-article131663247

Ting, I., Scott, N., Palmer, A., & Slezak, M. (2020, January 3). *The rise of red zones of risk.* ABC News. https://www.abc.net.au/news/2019-10-23/the-suburbs-facing-rising-insurance-costs-from-climate-risk/11624108?nw=0

UNDP. (2022). What are the Sustainable Development Goals?.*United Nations Development Programme*. https://www.undp.org/sustainable-development-goals

UNFCCC. (2005). Climate change small island developing States. *United Nations.* https://unfccc.int/resource/docs/publications/cc_sids.pdf

United Nations. (2017). *Factsheet: People and oceans*. The Ocean Conference. New York. https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf

United Nations. (2018). *68% of the world population projected to live in urban areas by 2050, says UN*. United Nations. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

United Nations. (2021). SDG Global Festival of Action. SDG Action Campaign https://globalfestivalofaction.org/

Vousdoukas, M.I., Ranasinghe, R., Mentaschi, L., Plomaritis, T. A., Athanasiou, P., Luijendijk, A., & Feyen, L. (2020). Sandy coastlines under threat of erosion. *Nature Climate Change, 10*, 260–263. https://doi.org/10.1038/s41558-020-0697-0

Velev, D., & Zlateva, P. (2017). Virtual reality challenges in education and training. *International Journal of Learning and Teaching, 3*(1), 33-37. https://doi.org/10.18178/ijlt.3.1.33-37

Wang, K., Tekler, Z. D., Cheah, L., Herremans, D., & Blessing, L. (2021). Evaluating the Effectiveness of an Augmented Reality Game Promoting Environmental Action*.* *Sustainability*, 13(24), 13912. MDPI AG. http://dx.doi.org/10.3390/su132413912

Wilson, C., & Soranzo, A. (2015). The Use of Virtual Reality in Psychology: A Case Study in Visual Perception. Computational and Mathematical Methods in Medicine, 2015, 151702–151707. https://doi.org/10.1155/2015/151702

Won, A., Bailey, J.O., Bailenson, J.N., Tataru, C., Yoon, I., & Golianu, B. (2017). Immersive Virtual Reality for Pediatric Pain. *Children*, *4*(7), 52. https://doi.org/10.3390/children4070052

Wong, K. (2016). *Climate change*. Momentum Press.

Ylipulli, J., Suopajärvi, T., Ojala, T., Kostakos, V., & Kukka, H. (2014) Municipal WiFi and interactive displays: Appropriation of new technologies in public urban spaces. *Technological Forecasting and Social Change, 89, 145-160, https://doi.org/10.1016/j.techfore.2013.08.037*

Ziker, C., Truman, B., & Dodds, H. (2021). Cross reality (XR): challenges and opportunities across the spectrum. *Innovative learning environments in STEM higher education: Opportunities, challenges, and looking forward*, 55-77.