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Immersive Virtual Environments and Climate Change Engagement

Anna Carolina Muller Queiroz(✉) [1], Amy M. Kamarainen[2], Nicholas D. Preston[3], Maria Isabel da Silva Leme[1]

[1] University of Sao Paulo - Institute of Psychology, Sao Paulo, Brazil
acmq@usp.br
[2] Harvard Graduate School of Education, Cambridge, MA, USA
[3] University of Victoria, Victoria, BC, Canada

Abstract. Climate Change will affect our lives, yet communicating about climate change has proven to be more complicated than initially thought. Recent attention has turned to the potential affordances of immersive virtual environments (IVE) to support public engagement around climate change. We offer theoretical arguments for ways that IVEs may influence understanding, emotion, and behavior related to climate change, and we present a systematic literature review covering IVE applications to climate change. From 619 papers, 55 were fully reviewed. The findings were analyzed and discussed according to how IVEs may influence understanding, emotion, and action related to climate change. Findings suggest that IVE has a positive outcome in climate change engagement and the use of IVEs in the context of climate change warrant further investment of resources toward design and research.

Keywords: Climate Change · Immersive Virtual Environment · Virtual Reality · Augmented Reality · Mixed Reality

1 Introduction

1.1 Challenges in communicating about climate change

Although the effects of climate change are evident [1] it remains a struggle to communicate about causes and outcomes associated with climate change. Scientific articles that use numerical projections and text-based descriptions fail to capture the character of anticipated changes and possible futures. Climate change will affect all our lives [2], but the effects seem remote when reported at national or global scales.

In efforts to communicate about climate change, messages used in mass media tend toward stories that are emotionally charged, in efforts to grab attention. Yet, research shows that invoking fear can be counterproductive [3], and that effectively communicating about climate change is more complicated than initially thought [4]. Sparking awareness is only a start, and changing attitudes is still not enough; current thinking suggests that meaningful impact requires public engagement with climate

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change. Engagement is considered to have three components 1) understanding (knowledge), 2) emotion (interest and concern), and 3) behavior (action) [5].

Recent attention has turned to the potential affordances of immersive virtual environments (IVEs) – including virtual environments, virtual reality (VR), augmented reality (AR) and mixed reality (MR) - to support public engagement with climate change. Below we outline a theoretical rationale for the potential of IVEs to impact this space, and we provide a review of work that is represented in the literature.

1.2 Theoretical framework for the use of immersive virtual environments to support climate change engagement

Immersive virtual environments offer fundamentally new ways to communicate the causes and consequences of climate change. Building on the components of engagement, we outline theoretical arguments for how IVEs may influence understanding, emotion, and action related to climate change.

Supporting understanding. Prior work on the use of AR shows that vision-based AR can support student understanding of concepts that require interpretation of complex spatial relationships – concepts for which visualization is a useful tool [6]. For example, Shelton & Hedley [7] report on improvements in conceptual understandings of complex spatial concepts associated with earth-sun relationships while vision-based AR used in physics and astronomy laboratories had positive effects on students' attitudes, skills and conceptual understanding [8, 9]. The application of IVEs in K-12 educational contexts reveal other theoretical and empirical benefits of using IVEs to support reasoning about causal dynamics embedded in complex systems. Prior work on the EcoMUVE project, which uses a multi-user virtual environment as part of a middle grades ecosystem science curriculum, demonstrates that student use of the IVE supports new forms of thinking about time and scale as they relate to ecosystems [10], supports adoption of process- instead of event-based reasoning [11], and engages students in practices, like modeling, that align with expert approaches for understanding complex systems [12].

Engaging emotions. IVEs offer the potential to elicit emotional states through manipulating the visual, auditory and haptic stimuli presented to the user, and the strength of the emotion is linked with the users sense of presence [13]. By invoking a sense of presence, IVEs can support intense feelings that make a user think, feel and behave as though they are really embedded in the place represented by the computer-generated virtual space [14]. It is possible that such affordances of IVEs may be applied to climate change in order to position users in a context that elicits specific emotional responses, like a sense of wonder about the natural world or horror at the destruction caused by coastal flooding. However, design and use of IVEs to elicit emotional response remains poorly understood, and while some constrained designs systematically elicit intended user emotions [15], it is also common for users to have diverse emotional reactions to the same experience (J. Bailenson, pers. comm.).

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Inspiring Action. A core theoretical domain related to IVEs is that of embodied cognition. We interact, communicate and learn through movements, gesture and physical activities [16]. Research shows that designing learning activities that encourage actions that are linked with concepts can support the formation of memories, prepare users for future learning, and help people link observable and unobservable phenomena, but these interactions must be designed carefully for these purposes [17]. IVEs for kinesthetic training suggests that the medium can be particularly powerful when users have opportunities to practice movements and decisions that mimic those that will be made at a later time in a more complex context [18]. For example, in his book, Experience on Demand, Jeremy Bailenson recounts how quarterbacks in the US National Football League are using VR to train for games, and experiencing improvements in performance. Such affordance of IVEs to elicit movement, gesture and interaction might offer possibilities for encouraging embodied understanding related to climate change or supporting the habituation of pro-environmental behaviors.

2 Research Methodology

2.1 Search Strategy and Terms.

This review was based on published research papers available until early March/2018. Terms and databases used are described as follows. The terms used in the search were: Immersive Virtual Environment, Virtual Reality, Augmented Reality, Mixed Reality and Climate Change. The search thus used the following string in each online database, composed of Boolean operators (AND/OR): *(("immersive virtual environment" OR "virtual reality" OR "augmented reality" OR “mixed reality”) AND “climate change”)).* The online databases used and number of articles found (n) were: ScienceDirect (n=499), Scopus (n=78), Web of Science (n=29), IEEE Xplore (n=7), ACM Digital Library (n=5) and ERIC (n=1). These databases were chosen to cover the multidisciplinary nature of the use of IVE in climate change engagement. Papers were further subject to the inclusion and exclusion criteria below.

Inclusion Criteria.

- Peer-reviewed research papers written in English
- Studies directly investigating the research questions
- Papers describing the outcomes of using IVE in climate change

Exclusion Criteria.

- Papers not describing outcomes of using IVE in climate change engagement
- Papers not answering the research questions
- Papers not available through our institutional access and not available after requested to their authors (not retrieved)

2.2 Research Questions

1. How are the studies distributed geographically and temporally?

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2. What types of immersive medium are used?
3. Which topics and population are investigated?
4. What are the outcomes reported of using IVE in climate change?
5. What are the suggestions for future studies reported by the authors?

3 Results

The 619 total papers were evaluated according to the title and abstract. Of these, 55 were selected and fully evaluated. They were classified into 3 categories: Education and Communication (EdCom), Analytics, and Plan. "EdCom" focused IVEs for climate change communication, education and awareness; "Analytics" focused on IVE for analytics, modeling and data visualization; and "Plan" focused on IVE for environmental or urban planning and decision making at a community or landscape scale. After full evaluation, the papers were categorized according to their topics and outcomes (Understanding, Action and Emotion), as can be seen in the Table 1.

Table 1. Results

Topic / Outcomes	EdCom			Plan			Analytics		
	U	E	A	U	E	A	U	E	A
Animals	[19, 20]								
Carbon footprint	[21]						[22]		
Concepts about Climate Change	[23–28]	[29]		[30]					
Energy consumption			[31, 32]				[33, 34]		
Heritage Sites	[35, 36]								
Land use and Urban Planning			[37]	[38–40]	[43]	[38–43]	[44, 45]		[45]
Landscape visualization	[46–48]		[49]	[50–53]		[51, 53]	[47, 54, 55]		
Multiple environmental scenarios	[56, 57]						[58–64]	[60]	
Risk assessment / management		[65]	[65]	[66]			[67–70]		[69, 70]
Sea rise		[71]		[72]		[72]	[73]		

U:Understanding; E: Emotion; A: Action.

3.1 Distribution, Target Audience and Medium

Most of the studies are from US institutions (12 papers), followed by United Kingdom (11), Australia (9) and Canada (6). Germany and The Netherland count with four publications each. The following countries count with two publications each: Austria, China, Hong Kong, Israel, Italy, New Zealand and Spain. Finally, there is one publication of each of the countries: Denmark, France, Greece, Norway, Portugal, Republic of Korea and Sweden. The papers' publication date ranges from 2005 to 2018,

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with a peak of publications in 2010 (9), followed by 2015 (11), as showed in Figure 1. Maybe the increased interest EdCom in Climate Change in 2009 is due to the Copenhagen Climate Change Conference held in December by the United Nations.

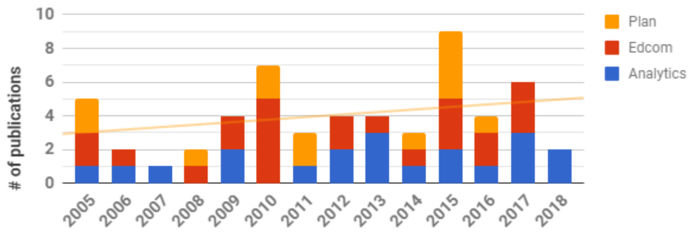

Fig. 1. Publications' year

Most of the studies in Plan target researchers and/or decision makers, as expected. Studies in EdCom target mostly students, with a balanced distribution among the school levels. Many studies focus in technological solutions and outcomes and do not specify the audience for which they are intended. Figure 2 shows the Target Audience distribution.

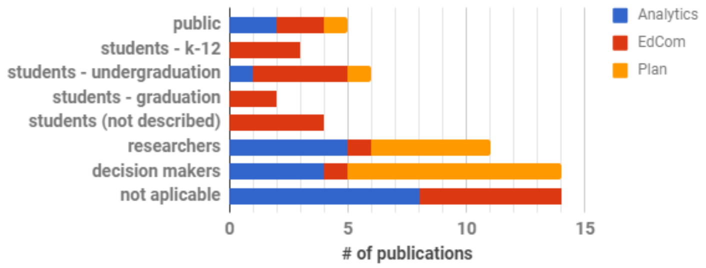

Fig. 2. Target Audience

Most of the studies used single screen (as desktop monitor) as the medium to project 3D images or animations, followed by Augmented Reality and HMD (Figure 4).

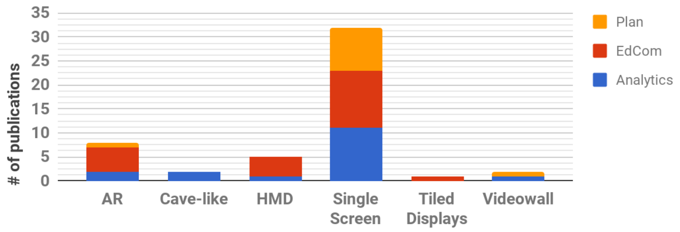

Fig. 3. Medium

3.4 Outcomes

Outcomes are summarized according to: Understanding, Emotion and Action.

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Understanding: studies reveal positive outcomes in climate change understanding, especially direct and indirect impacts and awareness of strategies to mitigate climate change [20, 28, 47, 57], higher engagement on the topic [19, 23, 25, 27, 46] and on related community problems [25] and greater ease in collecting and correlating data on climate change when using AR applications [47]; with the Plan category, papers prior to 2011 [30,38-40,43,53] focused on describing the technical infrastructure and value of using advanced forms of visualization of spatial data and information to support land use planning, landscape design and scenario exploration, with minimal attention to the describing or measuring the utility and value of these visualizations to the users, with the notable exception of [52]. From 2014 onward [41-42,50-51,66,72], the papers related to land use planning and landscape design bring up theoretical areas like "presence," which demonstrates co-development with theories in the field of immersive technologies. IVEs have the potential to advance climate science through immersive and interactive interfaces that democratize access to data models and simulations to scientists from a broad array of discipline and beyond, to the general public and citizen scientists. This utility has been demonstrated through a range of applications spanning health care, business, climate change, and natural disaster [61]. Broadly, they allow users to interact with complex scientific models without prerequisite training with the background and tools necessary to convert raw data into visualizations. The feeling of realism, demonstrated by examples such as VR-Ocean [73] allow users to gauge the impact of melting ice from complex global data sets such as altimeter and ice surface data. Furthermore, 4D models allows users to understand the past through climate reconstruction models [55] and to 'live' the future effects of sea level rise on their communities [70]. However, the current state of the science is biased towards Western, English speaking nations and powerful interests that shape our mediated experiences of climate change through the media [60].

Emotion: the use of IVE promotes occupant engagement in energy-saving building design [31]; also, people demonstrate increased willingness to engage with climate change issues in conjunction with rich media visualization[29]; Although virtual field trips can be expensive they generate positive engagement and feedback from students [23]. Teachers and students report that AR authoring is motivating and engage students beyond climate change issues, to issues within their communities [25]. An interactive flooding 3D simulation increased the motivation to evacuate from the virtual polder (low-lying, flood-prone, tract of land protected by dikes) as well to buy flood insurance [71]. The use of immersive and virtual environments for Planning addressed understanding and action, but emotion was not raised as a focal dimension. The emotional impacts of these visualizations can be mixed, on one hand they provide a lens to the scientific state-of-the art for laypersons without formal training; however, reports describing frightening case studies in sea level rise can be alarming to observers [73]. For instance, a thirty-five year simulation of sea level rise presented 348 South Florida home homeowners revealed that 75% of the participants were willing to support the costs of adaptation projects; however, many of the participants reported an interest in moving out of the region in an emotional response to seeing potential climate impacts [70].

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Action: an experiment done in an immersive virtual environment (HMD) using vivid images suggests that it can elicit pro-environment behavior[32]. A study comparing avatars to voice and text found that avatars in the IVE are more effective than voice and text to promote pro-environment compliance [37]. Also, a study suggests IVE may increase awareness of strategies to mitigate negative impacts of climate change [56]. Our theoretical concept of action was introduced from the perspective of an individual, but the papers also described VR and immersive visualizations as a way to engage stakeholders in process oriented VR experiences that were participatory and collaborative [41]. Platforms such as SUNPRISM [62] add an additional level of interactivity by allowing users to visually design application scenarios with limited or no coding experience.

Others reported that these interactive and extensible platforms would allow scientist to spend more time on their core research interests rather than database and processing challenges [61]. Among sectors that stand to mitigate or reduce the potential impacts of climate change, advances in IVEs are allowing designers to simulate and control energy chains via IVEs at the district level, coupling real time data from sensors with advanced simulations to assess the energy performance of buildings [33] Across the building sector, 4D IVEs are facilitating prototyping during project planning for construction projects to minimize carbon emissions [22] Again advances in IVEs are democratizing complex 3D building and power grid modeling, simulation, and logistics exercises for a wide range of users in sectors critical to mitigating climate change.

3.5 Future Studies

With regards to the technical medium used, some studies suggest the use of VR headsets to richly communicate cultural paradigms and important contextual factors [23]. For visualizations and imagery, it is suggested that additional psychological research on climate change perception and behavior is necessary, using controlled visual landscape imagery[49] and emotional, social and intellectual support to lead to deeper behavioral changes [24].; standardization across platforms[36, 46]; to investigate what kind of images best represent the scientific information to be communicated, how the audience is influenced by these images [29] and what scientific monitoring of real-world projects would help model future scenarios [49]. Also, one study suggests developing a low-cost VR platform for displaying forest monitoring data to support analytical reasoning and decision making [48]. When using IVE for energy-saving building, authors highlight the importance of future studies to identify prospective occupants [31], using avatars to enhance the communication between buildings and their occupants to support pro-environmental behavior [37]. Finally, others recommend integrating AR games into the daily life of students [25] and the need for strategies to compensate for GPS failure in dense vegetation locations [47].

In planning, considerations of realness, verisimilitude, and uncertainty were cited as focal points for future study [52-53]; Variability in the availability of VR hardware, and lack of standardization were listed as barriers to wider use of VR in environmental planning [41]. A number of studies cited the need to increase access to objects data and code [62] to facilitate extending the tools to other research and applied domains. Others stated that the tools they were developing could be readily extended to interdisciplinary audience if the codebooks for were made more accessible [60]. While many studies

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employed commodity hardware, there was the sense that new tools and algorithms would advance the state of the experience, the ability to extend the capabilities, incentivize climate investigation through gamification, and introduce semi-automation to shift data generation and analysis beyond form-filling and selective technologies with a high technical barrier to entry [47].

4 Discussion and Conclusions

There was a relative paucity of papers on the design and testing of IVEs to support climate change awareness, mitigation, and adaptation (n = 55), and only twenty two related to education and communication. Engagement and motivation were key outcomes in many of the studies. The limited number of publications indicates the need to understand how IVEs may be leveraged to support public engagement with climate change.

Ockwell, Whitmarsh & O'Neill [5] speak of engagement as a three-part construct (understanding, emotion and action), and argue that all three parts are necessary to elicit change in public perspectives related to climate change. There are compelling arguments how IVEs might influence all three; some of the research papers evaluated more than one of these dimensions [38–40, 43, 45, 51, 53, 56, 60, 65, 69, 70, 72], but none studied all three parts. Could rich immersive virtual experiences potentially tap into all dimensions?

A number of studies focused on the potency of visual aspects of the experience, especially images and details in the visual display. This is not surprising, given that IVEs tend to be richly visual spaces. More innovative are the studies that focused on new forms of interaction that are enabled by IVEs. A number of the experiences drew on user input and interaction, requiring users to interact with virtual objects or data, thus activating a sense of agency in the virtual space. Also, in some cases, designers integrated forms of simulated social interaction by using avatars to personify data. These forms of kinesthetic and social interactions warrant further research, as the work presented here suggests these can provide powerful contexts for eliciting motivation, self-efficacy, and action.

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