Amplifying Immersive Climate Learning

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Abstract. Climate change poses an existential threat to our heritage and the way we live, yet its impacts are still often perceived as distant, which in turn acts as a barrier to achieving the behavioural and societal changes required to solve this emergency. This paper summarises impacts of climate change, psychological barriers to effective action, and how experiential climate learning can help overcome these challenges. Surveys of community perceptions of threats to cultural and natural heritage in Scotland's Western Isles, and the increasing engagement of heritage practitioners with this emergency point to the power of heritage as a positive actor in the climate crisis. A strategy for using virtual reality to extend experiential climate learning is proposed and evaluated through the creation and deployment of a climate heritage exhibit. The exhibit enables climate impacts and potential climate futures for the Western Isles to be experienced. The workflow used is then applied to global landscapes experiencing climate change. This demonstrates the way that virtual reality can represent the diversity of landscapes impacted by this crisis and enable immersive climate learning experiences.

Keywords: Climate Change, Virtual Reality, Heritage, Immersive Learning.

1 Introduction

The impacts that climate change is predicted to have on the world's cultural and natural heritage are considered by the international scientific community as "one of the major challenges of the twenty-first century" [39]. Immersive climate education shows great potential in contributing to the resolution of the climate emergency. Yet, this is still an underdeveloped field that requires further technical, psychological and social evaluation [37,32]. This research aims to explore why Virtual Reality (VR) could be an effective climate communication tool for museums, analysing both external and internal projects. This serves as the foundation for the second research objective of this paper, which is the development of the first prototypes of immersive simulations of flooding caused by climate change in Scotland that enhance the user learning experience. This builds on insights we gathered through surveys where we investigated perceptions of climate change within vulnerable groups from Scotland's Outer Hebrides Isles.

2 Context of Research: Climate, Distance and Immersion

This work is based upon three fundamental concepts. Firstly, climate change is a global threat, but it manifests differently across different regions. For instance, in Scotland, coastal erosion and flooding are expected to intensify because of sea level rise and precipitation. Secondly, our collective response to climate change is limited by psychological distance from this phenomenon. Thirdly, that immersive technology has great potential as a communication tool within museums to transform climate change from an abstract concept to an experienced reality.

2.1 Climate Change in Scotland

In Scotland, scientists are urging the public to take urgent action into preserving the country's coastal environment [17]. Rising sea levels and extreme precipitation contribute to coastal erosion and flooding, impacting nearly a third of Scotland's coastal infrastructure [26]. Significant natural heritage sites for biodiversity and carbon sequestration are also endangered [17,20], with machair as a primary example. Machair is a rare soil that is particularly important to Scotland as approximately 67% of global machair resides in the country's Outer Hebrides islands [9]. Most cultivated machair can be found in the Isle of North Uist, playing a critical role in the economy of Hebridean people [40]. The isle also hosts UK's most complex saline lagoon system and kelp forests, some of the most productive ecosystems on Earth for marine biodiversity and for the global carbon sink. These offer coastal protection and act as soil fertilisers and animal feed in Scottish traditional agriculture [24,8]. Yet, these are at risk of extinction due to flooding since North Uist is mostly composed of low-lying land with shallow lakes and marshes [7,23]. Past flooding events already damaged roads and infrastructure [5], enhancing the isolation faced by islanders and reducing their access to vital health, educational and transportation facilities. The Scottish Environment Protection Agency (SEPA) predicts that 50 homes and businesses will be damaged by 2080 in the Isle of North Uist alone, with significant losses to arable land [23]. As it will be discussed in section 3, the residents do not trust their government to take appropriate climate action because they believe that the public has yet to accept the reality of climate change.

2.2 Psychological Distance from Climate Change

The 2023 conference for the Network of European Museum Organisations (NEMO) remarked the public lack of acceptance of the reality of climate change as one of the biggest challenges in addressing the climate emergency. The conference further highlighted how the role of museums is shifting from powerful hubs of lifelong learning that safeguard heritage for future generations to a sector that is taking mass action against climate change [2]. Museum practitioners from across the globe emphasised their dedication to communicate the impacts of climate change effectively and drive ecological action. However, climate change information is often perceived as abstract by the public, which acts as a barrier to the actions needed from individuals, corporations and institutions to slow down and limit global warming [30]. Information perceived as concrete instead of abstract is demonstrated to have a much bigger influence on behaviour [10]. This phenomenon is called psychological distance and is described as *"'a subjective perception of distance between the self and some object, event, or person'"* [41]. This particularly develops with long-term complex processes such as climate change, as perceived distance is created amongst a multitude of dimensions: likelihood of occurrence, time, geographical space or social distance [33]. Most digital developments that illustrate the coastal impacts of climate change are in the form of web maps, such as the ones developed by SEPA [1] and Dynamic Coast [26]. The field of vulnerability mapping is becoming more pivotal in climate communication [18], but are these tools sufficient. Through a survey evaluated in [6], we discovered that digital maps might reinforce how abstract climate information is perceived.

While psychological distance creates passivity, personal experiences of climate change have been shown to drive concern and action [41,33]. For example, farmers who noticed changes in water availability and people who experienced floods or hurricanes are more inclined to support ecological initiatives. Perceived exposure to climate change has also been linked to pro-environmental behaviour [33]. Consequently, addressing psychological distance is crucial for effective climate communication, and investigating how museums can achieve this through their exhibitions is of great societal importance. Studies show that first-hand accounts of climate change are more powerful than second-hand information due to the Experience-Perception Link [29]. This suggests how psychological distance could be tackled by applying principles of experiential learning: the idea of observing, engaging with, and making sense of personal experiences as integral parts of the learning and understanding process [21,34]. For instance, extending experiential learning with Virtual Reality (VR) simulations of remote or future climate change has the potential to address multiple aspects of psychological distance by simplifying complex phenomena and by enhancing engagement with environmental issues [12,32,38,37]. What is more, 98% of the partakers in the aforementioned survey expressed that their preferred method of learning about climate change would be immersive Virtual Reality experiences when compared to digital maps and written articles [6].

2.3 Immersive Learning for Climate Education and Communication

Virtual Reality has shown many advantages in training and education, with participants studying for longer, making fewer errors and grasping abstract concepts more easily [31,11,35]. Museums have also leveraged immersive technology to engage people with the past through 3D reconstructions of historical sites, deriving great benefits in preserving and promoting heritage, and in building connections with local communities [15,27]. Since direct experiences of climate hazards are more powerful than second-hand information, and given VR's ability to simulate any location and time period, researchers have been prompted to explore how this technology can support understanding of long-term complex causal processes, such as ecosystem dynamics and climate change impacts. One study showed that fifth and sixth graders exhibited deeper understanding of causal relationships and change over time when they evaluated the reasons behind a fish die-off in a virtual pond [25]. These discoveries are of great value, as spatial and temporal space from the impacts of climate change adds to their perceived complexity and generate psychological distance, which in turn hinders ecological attitudes and behaviour [41,33]. People's remoteness from the ocean can lead to sea level rise being perceived as a distant phenomenon - *"out of sight, out of mind"* [12]. This is accentuated by the temporal distance between present and future states of the coast, as sea-level rise is *"a slow and temporally distant process"* [12]. 630 million people are living in areas that are expected to get flooded annually by 2100 [12]. This is addressed by a series of VR experiences titled *The Sea Level Rise Explorer* that simulate how three cities in the United States are projected to be flooded in 100 years. Nearly 1000 participants showed great interest in the simulations, agreeing that they are more impactful than 2D models or photographs because they turn *"sea level rise into a reality"* [12]. There has been consistent evidence showing that changes in attitudes and behaviour can occur when individuals feel the impact of an experience in a more concrete, immediate and approximate way [32]. Virtual reality has also been described as the *"'ultimate empathy machine"* because it evokes an emotional response that brings participants closer to global issues such as climate change [32]. What is more, visualising climate change with Virtual Reality has the potential to immerse users in novel experiences which may otherwise be unattainable, impractical, resource-intensive, or perilous in the real world. For example, the practical impossibility of fast-forwarding time to witness the unfolding effects of climate change can be overcome through with VR. Varying formats of VR - immersive, desktop and mobile - have the capability to not only convey meaningful content, but to test human cognition, emotional responses, and reactions towards these global issues [32,37]. Despite these advantages, there is only a limited number of such projects, and most of them incorporate expensive hardware, while also not being available online. An additional gap within this research sphere is that some of the most challenging impacts of climate change are not yet represented, as is the case for Scotland.

3 Perceptions of Climate Change

This section analyses primary research accounts regarding perceptions of climate change that we collected from global heritage stakeholders, as well as from stakeholders and inhabitants living on the Isle of North Uist.

3.1 Heritage Stakeholder Perceptions of Climate Change

In September 2023, the Audiovisual, New Technologies & Social Media subcommittee of the International Council of Museums (AVICOM) hosted an online workshop titled *Museums, Virtual Reality and Sustainability in the Climate*

Emergency. Attracting over 20 contributors[1] and 180 participants, this enabled us to survey heritage stakeholders who presented on their climate action initiatives.

Participants Twelve stakeholders from the workshop responded to the Qualtrics survey which was distributed online during the event. They came from several European countries including Scotland, as well as Barbados, Egypt, Nigeria, the Philippines and the United Arab Emirates, and were predominantly between the ages of 25 and 44.

Materials The survey had four sections: the first assessed perceptions regarding threats of climate change, such as coastal erosion and wildfires; the second section assessed opinions on the roles of heritage organisations, governments, digital tools and citizen science within monitoring climate change; the third question investigated how the stakeholders view the public and their individual understanding of climate change, and their opinions on museums and immersive technologies within climate communication; the final section of the survey evaluated perceptions of individual, community, and governmental climate actions. The questions were a mixture of Likert scale and qualitative questions. For Likert questions, the participants indicated their level of agreement with statements on a 5-point scale ranging from "Strongly agree" to "Strongly Disagree". An example is "The public underestimates the threats of climate change".

Results Unsurprisingly, all the practitioners were worried about how their communities will be impacted by climate change. After highlighting how concerned they were about different effects of global warming, 11 stakeholders further noted that flooding events, exorbitant storms and heatwaves are the main threats to their home regions. When asked about any other concerns, their answers varied from glacial melts and coastal erosion, to resource scarcity and human perception i.e. humans not understanding "their impacts and responsibilities on climate change". All stakeholders strongly agreed that enhancing public understanding on the impacts of climate change is important, whilst stating that museums and galleries can support this mission and help public audiences become active. We carried out the same survey with seven stakeholders from the Isle of North Uist which was distributed as paper versions during a digital festival hosted as part of the *Aire air Sunnd* (Attention to Wellbeing) project in collaboration with the North Uist Historical society. All participants highlighted flooding, storm formations and coastal erosion as the primary climate hazards in their locality. When asked what they perceive to be the biggest challenges in resolving climate change, some notable answers were *"acceptance of its existence from major governments to individuals"*, *"public and political will for change"*, *"denial"*, and "assuming that it is likely to get the required behaviour changes needed when people assume their lifestyles can never be changed". All stakeholders believe

[1] Contributers included practitioners from the Australian, Barbados and Timespan museums, alongside representatives from the University of Siena and the Red Cross

that governments should take measures to respond to climate change, yet none trust their administration to do so effectively. Five practitioners highlighted the political system as one of the biggest challenges in resolving climate change, whilst others remarked the lack of a consensus on what actions can be taken by individuals, organisations and governments as a significant impediment. Most stakeholders strongly agreed that communicating the impacts of climate change is an integral part of our collective response to this complex issue, with four believing that museums should support this mission. What is more, all agreed that Virtual Reality is an effective communication tool. These results emphasise the high potential of applying immersive technology to successfully educate public audiences on climate change, which confirm the analysis in section 2.3.

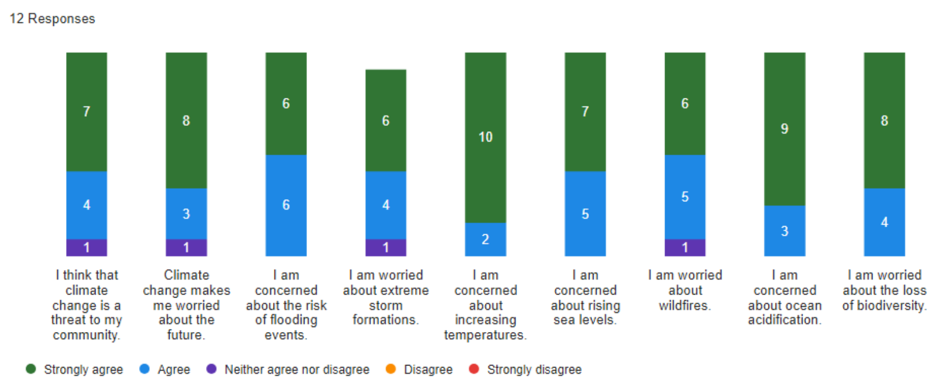

Fig. 1. Stakeholder responses about climate threats from the AVICOM workshop

3.2 Community Perceptions of Climate Change

The previous insights further corroborate the results we have gathered through another community wellbeing survey distributed as part of the *Aire air Sunnd* project. This was first discussed in [36] and has now been completed. The wellbeing survey was developed by representatives of the North Uist Historical Society and researchers from the Universities of Aberdeen, St Andrews, and the Highlands and Islands. Key components of community and personal wellbeing were analysed, such as wellbeing connections to heritage, culture, Gaelic, natural heritage, and the use of digital tools.

Participants The participants included 83 residents of North Uist and Benbecula. The study was advertised through the Historical Society's email and social media. Participants were self-selected. It was available online (via Qualtrics) and a paper version was made available in popular shops, cafes and restaurants and by request.

Materials The survey had four sections: the first one gathered perceptions of residents regarding their heritage and wellbeing, including concerns about current issues such as the environment and Gaelic preservation; the second section gathered feedback and suggestion about the use of the Society's new premises; the third section was an Edinburgh-Warwick study assessing wellbeing, and the last section analysed technological connectivity and social media use amongst residents. The questions were a mixture of Likert scale and qualitative questions. For Likert questions, the participants indicated their level of agreement with statements on a 5-point scale ranging from "Unimportant" to "Very Important". An example item is "What is the importance of the North Uist land and sea environment in your life?".

Results The combined results from all sections sum up the perceptions and wellbeing of the community. For instance, 92% of respondents said that the North Uist land and sea environment was important to very important in their life. Some of the environmental concerns highlighted by the respondents were coastal erosion, the loss of machair, climate change, and cases of flooding on the island. The community was also asked to voice its concerns in relation to decisions taken at a wider regional and national level. 69% felt that their concerns are not heard at a wider level, whilst 72% said they are not fully consulted on decisions that affect them. When asked to comment, community members said that there was a lack of meaningful engagement between government and community. This was exemplified in the recent opposition to the Scolpaig spaceport development and its environmental effects[14]. As per the stakeholders' perceptions, this creates a sense of distrust in the government and political systems to effectively deal with communities' concerns on areas that are of significant importance to the local community. In the same survey, the community members had an opportunity to add free-text comments on the importance of the natural environment to them. This allowed us to understand what the community values in its environment and why it is important for the effects of climate change to be better communicated.

The responses were coded into the following topics of importance: wellbeing, crofting, animals and biodiversity, exercise and water sports, and art and craft. These results show that the environment is central to the islanders, it is important *"for health and wellbeing of body and mind"*. As with many of the Scottish isles, crofting has been integral to the culture of North Uist and is still being performed. One respondent commented on how they *"live on a croft and grow trees to encourage bio-diversity"*. The community members are aware of the importance of traditional knowledge to maintain *"environmentally friendly crofting traditions as implemented by our forebears"*, but they also see its importance for future generations: *"The North Uist environment is important to me as it plays a huge part in my children's upbringing - from exploring the beaches, to taking a boat to uninhabited islands, crofting on the land..."*. They are also actively reporting on visible effects of climate change on their environment, with one respondent saying *"I have realised how vulnerable our coastlines are, as e.g. how Busdara (East-) beach in Berneray has changed in a period of 12 years (Erosion on one side, filling up on the other)"*. When asked how they envisaged digital tools to be used in their community, workshops on developing digital skills were requested, as well as accessing heritage through websites or alternative media platforms. Almost 60% of the respondents said that digital exhibits that represent local place, stories, and objects will help communicate their heritage. This legitimises this research to similarly communicate climate change through holistic digital exhibits.

4 Developing Immersive Climate Learning Experiences

In previous projects [2], we leveraged game engines to allow people to visualise the past through VR reconstructions of cultural landscapes. Virtual reality represents an aspect of a holistic approach to heritage that explores cultural landscapes, investigating the relations between natural and cultural heritage. Since game engines allow dynamic adaptation, we propose utilising them to create immersive simulations of landscapes in their present and future states. Our research follows a practice based methodology which places creative and practical work at the centre of the inquiry process [13].To achieve this, we offer a guide to the workflow and materials we have refined through our own developments of game enhanced climate simulations.

4.1 Workflow and Materials

After deciding on the climate effects to be represented, the first milestone is importing a 3D terrain model of the desired landscape into a game engine. If these 3D models are not readily available online, elevation data needs to be obtained and then developed into a 3D terrain model. To download terrain data, we have mainly been using the free academic platform Digimap, as it contains high quality data of most of the landscapes we have represented in 3D. The elevation data needs to be processed in a geographical information system (GIS) software. We have been utilising QGIS, which is a renowned cross-platform software that is also open-source and regularly gets updated. The next step is inputting the updated elevation map into a 3D terrain generator software. World Machine is our program of choice as the software is very intuitive to use and we have a professional license readily available within our team. However, the free version of World Machine also offers high quality outputs that are compatible with game engines that allow for VR development. The 3D terrain model gets imported into a game engine, which generates a virtual landscape that has the exact heights of the real one. We have done most of our VR modelling in Unreal Engine (UE), as this has been shown to render more realistic virtual environments, which can be more useful in training and education [16]. UE has been developed by Epic Games, and is written in C++. It provides its own complete programming language for game scripting called Blueprint, which allows for any 3D modelling

[2] Previous projects from our research group can be accessed at https://www.openvirtualworlds.org/reconstructions/

of climate scenarios. This is how we developed climate simulations of flooding in Scotland. Using Blueprint, we programmed that a second body of virtual water starts rising over 10 seconds when the user presses a specific button on the keyboard or joystick. The interaction also triggers rain to start, which was build using the Niagara particle system available in Unreal Engine. Unreal also offers its own design and environment tool-kits such as Brushify that enable users to freely model the textures and composition of the virtual landscape so that it resembles the physical one. To assess our simulations and gather insights from relevant stakeholders and communities, we have been collecting primary data through surveys built in Qualtrics, a free and accessible tool that comes with its own data analysis features. To divide answers into clear categories, we have predominantly been applying Likert scale questions alongside open-ended questions.

4.2 Simulating Climate Change in Scotland

One key objective has been to develop VR projects of climate change in Scotland, building on simulations of how the Tentsmuir nature, is expected to inundate in 100 years [6]. We then developed a VR experience that visualises a 10-meter future flood in Glasgow (Fig. 2). This is based on the height of sea levels when CO_2 concentrations were as high in the past as they are now [22]. We further applied our holistic approach through an exhibition about the St Kilda volcanic archipelago, the UK's only Marine and Dual UNESCO World Heritage Site that is part of Scotland's Outer Hebrides isles [4]. This was installed in Taigh Cearsabagh museum in North Uist. The objective of this exhibition was to highlight the natural and cultural heritage of this once inhabited islands. The exhibit comprised of a virtual tour of St Kilda as it looked like in 1810. This is both engaging and exploratory, enabling visitors to interact with the subject in an immersive way. However, this is complemented with an archive of local stories and songs, local biodiversity, and current views of St Kilda. These seamlessly connect to other elements of the exhibit that address the biggest climate threats to the archipelago: a VR simulation of an extreme storm in St Kilda, and an interactive digital poster that educates on these threats and promotes climate actions that visitors can take. In this context, the information about climate threats is not presented as a pessimistic account of adversity, but rather as motivation for the safeguarding of precious and unique biodiversity.

We also developed a simulation of flooding in the Isle of North Uist (Fig. 3). This experience was not showcased as a stand-alone exhibition, but as an activity at the aforementioned digital festival we hosted on the island. In order to better represent the issues and threats, the flooding simulation was shown alongside virtual walk experiences exploring the archaeology and history of the island. The virtual walks are further discussed in [36]. The addition of the flooding simulation enabled visitors to appreciate the context of the climate change discussion that was present in the exhibit. Through the combination of these exhibits, visitors could visualise the effects of climate change within the context of their own community and heritage, which in turn could reduce the psychological distance

Fig. 2. Simulation of Future Flooding in Glasgow

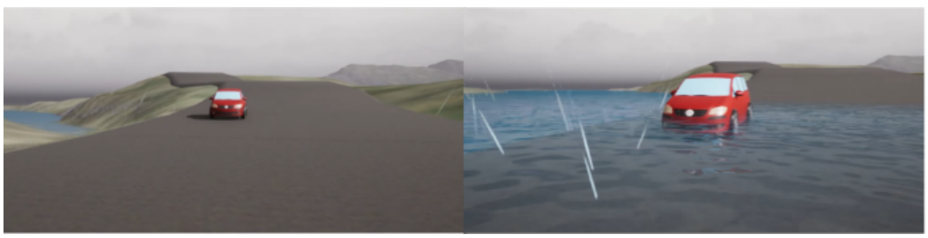

Fig. 3. Simulation of future flooding in the Isle of North Uist

driven by both the temporal and identity separation between the perceived 'self' of the individual and the effects of climate change. A place name activity was also carried out. This was based on a desire by the community to record local place names, as communicated through the survey discussed in section 3.2. Through an online digital map, visitors contributed the Gaelic names of places that are at the risk of being lost. Again, whilst the discussion on climate change in this activity was not a direct one (visitors were not asked to write places that have been affected by climate change alone), participants still engaged with the climate change discussion, and were naturally putting in names that they believed will be lost soon, either due to erosion or abandonment as a consequence of harsher conditions. This simulation was evaluated by 19 participants, nine who joined the festival and ten who assessed the simulation at a subsequent workshop at our institution. This was achieved through the same feedback survey used with the other climate simulations which was available on paper and online, and shared with the users during the events. Six participants responded that the immersion was their favourite element of the simulation, with some mentioning that it allowed them to relate more strongly with the topic of the exhibits. Others stated that *"VR is a great way to visualise the effects of climate change"*, *"it helps to make the impacts of climate change hit home"*, and that *"it really shed light into how impactful climate change is beyond abstract data"*. All participants agreed that VR will help climate communication. Perhaps the most interesting part of the feedback was that over half of the users said that they wanted to learn more about the topic, and that they were likely to research it after interacting with the simulation. This indicates how immersive climate education experiences are likely to drive action beyond the user's interaction with the exhibit.

4.3 Applying Methods to Global Landscapes

To explore the use of VR in climate communication, we developed a series of immersive climate educational experiences. The simulations address various effects of climate change, such as rising temperatures alongside China's Silk Road, Icelandic melting glaciers, and the bleaching of the Great Barrier Reef. Users can explore the virtual environments and visualise them through throughout different time periods, from how these landscapes looked like in the past to how they are expected to change in the future because of climate change. The VR experience regarding Icelandic glaciers leveraged the concept of virtual museums, which redefines engaging with heritage - the user is able to virtually explore a gallery of 3D exhibits and displays on glacial melt in Iceland. For each case study, an accompanying web gallery was built for accessibility that incorporated panoramic photos and videos of the VR experiences amongst other digital artefacts, such as photography, videos and infographics [3]. These were evaluated by an average of ten participants per project through individual workshops to test if the immersive technology enhanced the learning experience through usability and user satisfaction. The online questionnaire was built in Qualtrics and shared with the participants after the interaction with the exhibit. It contained a mix of open-ended ended questions and Likert statements on a 5-point scale ranging from "Strongly agree" to "Strongly disagree", addressing both the simulations and web gallery. Some of the statements were "I thought the system was easy to use" and "I enjoyed this way of learning". The feedback was predominantly positive, with users stating that the VR simulations fostered a more engaging and interactive learning experience, whilst simplifying a complex phenomenon like climate change. Most participants answered that they were more likely to engage with ecological action after visualising climate change in VR, indicating that immersive technology has the potential of being an effective communication tool. However, a small number of participants stated that the simulation was not an interesting learning experience, with some mentioning that they would have preferred more gaming elements. This holistic approach is one key element that can help museums talk about climate change in their exhibits whilst addressing the challenge of climate fatigue. This refers to a phenomenon that is yet to be widely researched in museums, where people disassociate with the climate change discussion due to its negative or depressing effects [28]. This is reflective of the museum fatigue phenomenon which demonstrates that users often lose interest after engaging with an exhibit for a while [19]. However, it has been shown that using more positive narratives can promote action and engagement in visitors [19]. Thus, this is what aims to be addressed through climate learning exhibits.

5 Challenges

Although VR has great potential as an effective climate communication tool implemented by the heritage sector, it also poses several limitations. Building climate simulations is resource and skills intensive, and some groups of people might not want to engage with it, or might physically be unable to do so. Furthermore, it is an ongoing challenge within research to measure behaviour change effectively, especially over longer periods. If this is not addressed, we might not be able to attest the effect of immersive technology on psychological distance and human action. To address these limitations and support the heritage sector in halting climate change, we are proposing a holistic approach to heritage that integrates digital engagement, including VR. This includes exploring cultural landscapes and the relations between cultural and natural heritage, both tangible and intangible.

6 Future Work

Fig. 4. Planned case studies for climate projects

This holistic approach will be further developed through a global strategy, as we aim to showcase climate effects in various landscapes, ranging from polar environments to islands (Fig. 4). This will include building, to our knowledge, the first immersive climate simulations of the Western Antarctic Peninsula in collaboration with the Discovery Point in Scotland, which will be integrated with the climate simulations of Scotland during the development of the museum's upcoming Antarctic climate gallery. This will allow us to expand our evaluation methods and investigate more in depth how perceptions of climate change are impacted through VR experiences that display both global and local impacts. We are further collaborating with Heritage Malta to develop a hub for multi-sensory experiences about the local heritage and the effects of climate change to help visitors engage with Maltese history and identity through Virtual and Augmented Reality.

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