Antwerp Under Water: The Interdisciplinary Human-Centered Design of an Embodied VR Experience on Climate Change

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Abstract

"Antwerp Under Water" is a work-in-progress VR experience that is being designed to raise climate change awareness by immersing users in a flooded version of the iconic Antwerpen-Centraal railway station. This interdisciplinary, human-centered project combines narrative, technical, and user research insights to foster a sense of urgency through place-based embodiment. Through three immersive time periods, users experience rising sea levels' impacts, moving from a distant future's apocalyptic landscape to the present-day, bridging the psychological gap between climate data and local relevance. Multi-sensory elements like haptics, scents and auditory cues are looked into to intensify embodiment, making climate risks tangible and emotionally resonant. The first prototype of the Antwerp Under Water VR experience is scheduled to be completed in February 2025. Following this, a between-subjects experiment will be planned in February and March 2025 to evaluate the prototype's impact on climate knowledge, emotional engagement, and pro-environmental behavior.

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Virtual Reality, Climate Change Awareness, Human-Centered Design, Multi-Sensory, Embodiment

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1 Introduction

Despite extensive research demonstrating that environmental policy and sustainability have a profound impact on society, effective communication about the risks and solutions related to its challenges remains a significant barrier to policy action [6, 7]. The current paper focuses on how Virtual Reality (VR) can be employed as a persuasive tool to address climate change. The issues surrounding climate and environmental governance are often abstract, invisible, complex, and multilayered, making it difficult to convey their urgency to target audiences, who are frequently not convinced of the immediate need for action [9, 14, 26]. Moreover, encouraging people to take action requires a sense of urgency, which is essential for fostering changes in attitude and behavior [17, 20]. We therefore seek to explore the role VR can play in fostering this sense of urgency and promoting shifts in public attitudes and behaviors regarding climate change, as it has the potential to induce high levels of presence and embodiment and make communication about this issue more tangible, scalable, and relevant to people's everyday lives [15].

To investigate this potential, we are developing "Antwerp Under Water", a location-based VR experience set within the iconic Antwerpen-Centraal railway station. This VR experience is designed to raise awareness of the pressing risks associated with rising sea levels, using the familiarity and prominence of a local landmark to foster a powerful, place-based connection to climate projections. Situated within the railway station, Antwerp Under Water will be presented as a temporary exhibition in a VR booth, allowing the public to engage directly with the experience on-site. By situating the experience in the station, we aim to bridge the gap between abstract climate data and its immediate, tangible impact on a place close to home. Users journey through multiple timelines in the experience's story, descending from a future ravaged by environmental consequences to the present day, fostering a visceral understanding of climate risks and the urgent need for action.

The design and development of Antwerp Under Water are grounded in an interdisciplinary, human-centered approach, combining the expertise of creative, technical, and user research teams. Each team contributes unique insights, from narrative and visual storytelling to immersive technology and audience engagement, and work together toward a cohesive and impactful experience. This collaboration enables us to address both the technical and emotional dimensions of climate change communication, with the goal of ensuring that the experience is scientifically accurate, technically feasible, and emotionally resonant. Our process centers on iterative design cycles, integrating stakeholder feedback (e.g. from experts on climate change, users from the intended target group) to continuously refine usability, emotional impact and immersion. By closely aligning creative and technical efforts, we aim to make climate change not only visible but personally compelling, fostering a sense of urgency and connection among users. Through this integrated, human-centered design approach, we aim to create a VR experience that is both educational and evocative, encouraging audiences to reflect on the local impact of global climate challenges.

In this paper, we detail the design and development process of our work-in-progress VR project Antwerp Under Water thus far, and share our plans for the next stages of development during the months to come. In the following sections, we first provide background on climate change communication challenges and the potential of VR as an immersive medium for fostering environmental awareness, as well as related work on VR applications for climate education. We then detail the design and development process of Antwerp Under Water, highlighting the interdisciplinary collaboration and human-centered design methods that guide each stage. Following this, we describe how we shaped the experience's narrative, concept art, environments and characters. Finally, we discuss future directions in development, including putting a focus on enhancing user embodiment in the VR experience through multi-sensory stimuli.

2 Background and Related Work

The communication of climate change remains a significant challenge, particularly in translating abstract and distant environmental risks into meaningful actions. While public awareness of climate change has grown, its complexity and gradual nature can hinder engagement and behavioral change [9, 14, 26]. Many people perceive climate change as a distant problem, both geographically and temporally, which often reduces the urgency to act [17, 20]. To bridge this gap, innovative communication strategies, including the use of immersive technologies such as Virtual Reality (VR), are being looked into to foster deeper emotional engagement and promote pro-environmental behaviors [15].

VR offers a unique medium for climate change communication due to its vivid, multi-sensory, interactive and immersive nature being able to create a strong sense of presence in users (i.e. the sensation of actually "being there" in the virtual environment [22, 24]. This presence, in turn, can enhance users' emotional involvement and understanding of complex environmental issues, resulting in significant attitudinal and/or behavioral changes. For example, Markowitz et al. [16] found that participants who experienced a VR simulation on ocean acidification displayed positive knowledge gain about the causes and effects of ocean acidification and a change in their pro-environmental attitudes. Further, they demonstrated that these effects were positively and significantly related to participants' sense of presence in VR. Similarly, Behm-Morawitz and Shin [2] found that a VR video (versus a flat-screen video) increased users' presence, which was associated with improved perceptions of the importance of water-issues, pro-environmental attitudes and behavioral intentions. As a final example, Chirico et al. [5] showed that participants who were exposed to a VR experience on biodiversity demonstrated greater knowledge on the topic and more environmentally friendly attitudes and behaviors afterwards, and that these effects were moderated by their feelings of presence [5].

Moreover, VR allows users to experience future scenarios that would otherwise remain abstract, making complex issues feel more immediate and personally relevant. For instance, Mol [19] demonstrated that participants who experienced a VR simulation of a flood invested significantly more in flood risk mitigation in an economic game than those in a control group. Adding to these findings, Calil et al. [4] highlighted the power of VR in creating personalized, location-specific experiences for sea level rise planning and community engagement. In their study, they used VR to simulate flooding scenarios in specific U.S. coastal communities.

Their results demonstrate that the simulations enhanced awareness and increased emotional engagement among participants that were familiar with the depicted locations.

Finally, VR allows for users to embody a virtual character. Embodiment is the subjective experience of having and using a body, involving sensations of ownership, location, and agency [3, 13]. With VR, users can inhabit a virtual body distinct from their own, and research shows they can develop a strong sense of embodiment within the virtual space [13]. Importantly, such a sense of embodiment within VR has been shown to increase emotional engagement and empathy and lead to stronger pro-environmental behavior [1, 21]. Ahn et al. [1] explored this by letting participants inhabit the body of animals like cows or coral (versus watching the experience on video), which fostered a sense of interconnectedness with the environment and resulted in greater perceived imminence of the environmental risk and involvement with nature.

Building on these insights, the goal of the Antwerp Under Water VR project is to spatially and narratively immerse users in a future where the city of Antwerp is flooded due to climate change. By situating the experience in the iconic and familiar setting of the Antwerpen-Centraal railway station, the project wants to reduce the psychological distance of climate change, making the risks feel more immediate, tangible and personally relevant to the local audience. This approach draws inspiration from the described related work, combining future scenario immersion with personalized, familiar environments (i.e. placing users in a flooded version of a well-known local landmark) and the embodiment of a virtual character that sees and feels the consequences of climate change, heightening the emotional stakes. We hypothesize that the VR experience will make users feel a strong sense of place-based embodiment, where users not only feel physically present in the virtual world but also experience an emotional and cognitive attachment due to the recognizability of the setting. By doing so, the Antwerp Under Water project aims to make climate change tangible and urgent, increasing users' engagement and their willingness to take action.

3 Interdisciplinary Collaboration in Human-Centered Design

Building on the insights from previous studies, the Antwerp Under Water project aims to leverage VR's strengths in presence and embodiment to create an immersive experience that highlights the urgent reality of climate change. To be able to achieve this, we set up an interdisciplinary collaboration [25] across the three teams within our research group, specializing in technical development, creative storytelling and user research, respectively. Although each team worked within their own expertise, collective brainstorming and co-creation sessions warranted that each team contributed their unique insights every step of the way, integrating realistic simulations, narrative depth and stakeholder feedback into the development of the VR experience.

To ensure that the experience will resonate with users, we furthermore employ an iterative, human-centered design approach [11] that emphasizes continuous stakeholder feedback. Stakeholders — including climate experts, engineers, and members of the target audience — have been consulted throughout each design phase. This approach allows us to align the experience closely with users' needs and preferences. Initial concept discussions and prototype stages were enriched by feedback on usability, emotional impact, and immersion, creating a design cycle that refined visual, narrative, and interactive elements iteratively.

At the project's outset, we developed a synopsis envisioning a future where rising sea levels flood the Antwerpen-Centraal railway station. To achieve a credible and immersive experience, we wanted to ground our narrative in scientific research on climate change and informed by expert advice from various fields. We therefore met with a series of environmental experts (ranging from marine biologists and geologists to civil engineers and architects, from organizations such as VLIZ, Sweco Belgium, MOW, IMEC), whose input led us to further improve our synopsis in several stages, reflecting realistic and location-specific impacts. For instance, we consulted with the Hydraulics Laboratory to explore scenarios in which the Antwerpen-Centraal railway station could be submerged due to rising sea levels, assuming no further government intervention. Additionally, a structural engineer provided insights into the impact prolonged submersion would have on the building, such as the erosion and eventual collapse of its steel frameworks. Biologists also helped us understand the ecological changes in the abandoned station, explaining that the confluence of salt water from the sea with fresh water from the Scheldt river would create brackish water within the station. This environment would limit the presence of many flora and fauna, though organisms like sea lettuce (Ulva lactuca) would thrive in such conditions. The brackish water could also foster the proliferation of disease-carrying mosquitoes. This feedback resulted in us incorporating tidal effects, brackish water and progressive structural corrosion in our narrative, adding tangible layers to the future climate impacts. The evolving synopsis was then presented to target users in 12 interviews. The interviewees were generally positive about the envisioned experience but advised to simplify the storyline and structure the timeline more clearly into distinct "eras" of the station's degradation.

In subsequent prototyping phases, we developed the three different levels (time periods) of the Antwerp Under Water VR experience one by one, with two levels completed so far. User tests on these levels (5-6 participants each, using think-aloud and interview protocols) gathered insights on users' perceptions of the visual environment, navigation, and emotional atmosphere. Feedback highlighted the intuitive nature of the controls and the immersive quality of the design, while also pointing out elements that affected users' sense of agency. The user tests showed that most participants understood the storyline of nature reclaiming the space, with a mix of curiosity, mystery and awe, though some felt the need for more environmental decay to enhance the post-apocalyptic feel. Users appreciated the visuals, especially lighting and water reflections, though some found the water level unclear and noted minor texture issues. The trolley car interaction, while intuitive, kept users focused on movement rather than exploration, suggesting areas for refinement to improve narrative clarity and immersion in the climate change theme.

4 Crafting the VR Experience

Through our interdisciplinary, human-centered approach, each phase of Antwerp Under Water has evolved to more deeply resonate

Figure 1: Concept art of the Antwerpen-Centraal railway station, the suit and the fever dream.

with audiences, bridging technical precision, narrative depth, and user feedback. In the following section, we will detail the final synopsis of the VR experience, the development of its concept art, environments and characters.

4.1 Synopsis

Antwerp Under Water is an immersive VR experience that explores the potential impacts of climate change by projecting future scenarios based on scientific climate models. As time is a central theme in these climate models, we decided to conceptualize it spatially, with the iconic Antwerpen-Centraal railway station serving as the setting. As such, the experience takes place across three different time periods, with the upper floors of the station (+1 and 0) representing the distant future, floor -1 representing an intermediate time level, and floor -2 depicting the present day or the memories of the present. Users begin on the top floor, set in the distant future, and gradually descend through time, eventually reaching the present in the catacombs of the train station. As we descend through the various layers, we evolve from well-defined, figurative design to more abstract, unfinished forms.

The experience begins in the year 3456. The user enters Antwerpen-Centraal railway station on the tracks of the first floor, navigating through an apocalyptic yet strangely beautiful world via a trolley car. This world is marked by decisions made centuries earlier when, after several catastrophic storms linked to climate change, people decided to stop raising the city's flood defenses. This abandonment allowed nature to reclaim the city: rains eroded barriers, and ground-level areas transformed into basements, while the underground infrastructure became storage basins for spring tides and storm surges. Sunlight streams through an open, damaged roof, intensifying the oppressive heat and making it necessary for the user to wear a protective suit.

The station is now an unrecognizable ecosystem, overtaken by new vegetation, stagnant water, and the remains of human habitation. On the ground floor, water levels have risen above the floor, littered with floating plastic and other non-biodegradable waste. Mosquitoes and other disease-carrying insects thrive in this environment. As the user explores this transformed station, controlling the trolley with a pumping motion, a piece of the deteriorated roof crashes onto the tracks, creating a hole. A pebble strikes the user's helmet, creating a small crack through which a mosquito enters and stings them, causing the user to lose control of the trolley and fall through the hole into the water below (on floor -1).

Because of the mosquito's sting, the user enters a kind of fever dream. This dream takes the user into the year 2121, where a 1000-year storm caused the flooding of the Antwerp city center. The water finds its way through the pre-metro tunnels to Antwerpen-Centraal where floor -2 (including the north-south tunnel) is flooded. Excessive amounts of water render underground railway transport unusable, and people use the underground corridors as water basins. As we float through space below the water level, we enter a misty afterlife. We see vague shadows with plastic wrapped around them. As we get closer, we see that they are human statues wrapped in plastic. Some of these statues move, like real people wrapped in plastic. Dead fish float around in the water. The fever dream intensifies, showing the effects of the 1000-year storm: traffic disrupted, train and metro accommodation unusable, basements/houses under water, chaos,... The visions come in flashes. We hear a thundering sound coming from the distance. A large underwater wave breaks several scenographic elements. An underwater robot emerges and leads the user further down, guiding them toward floor -2.

As the experience progresses to the present, users reach the "catacombs of memory", where fragmented 3D scans of people, trains, and objects symbolize incomplete memories of the past. The visions remain longer and feel more real. Attention is drawn to the illuminated carriages. The user steps (floats) into a wagon and finds him/her-self in the present. He/she sits opposite a character who is reading a newspaper. In the newspaper, the user sees articles showing the danger of global warming (e.g. heatwaves), but also articles with absurd headlines such as "It was a peak season for the hospitality industry". After the experience concludes, the user is free to continue with their day. Since the experience is location-based, the VR booth will be placed directly in the station. This setup allows users to step out of the immersive virtual world and continue walking through the station as it exists today, encouraging them to reflect on the future they have just witnessed.

4.2 Concept art

AI tools like Stable Diffusion and Midjourney were utilized to develop concept art based on this research (see Figure 1). We trained these models on datasets related to eroded structures, sea lettuce, and flood scenarios to create highly realistic future environments. This process allowed us to generate highly realistic depictions of the future world, offering precise references for our 3D modelers and developers. Additional concept art was created for the protective suit and the fever dream sequence, in which users encounter human-like statues wrapped in plastic, symbolizing victims who are held in place by the very waste that we have created and discarded.

4.3 Environments and characters

All these elements were carefully integrated into the world and story. Since Antwerpen-Centraal railway station is a highly recognizable building, we aimed to preserve its identity in our future vision. Using architectural plans, photographs, and 3D scans, we recreated the station as faithfully as possible, incorporating future elements like eroded walls, abundant sea lettuce, and rising water levels (see Figure 2). Additionally, for the underwater robot

Figure 2: Screenshots of different environments of the Antwerp Under Water VR experience, in development.

that guides the user through the submerged world, we used scans of a real robot from the VLIZ (Flanders Marine Institute) to enhance realism. This robot helps the user navigate the underwater environment, making them more aware of their surroundings. By creating such a realistic world, we aim to heighten presence and place-based embodiment, allowing users to feel more connected and emotionally engaged as they recognize familiar elements of the station.

5 Next Steps in Development and Fostering Embodiment through Multi-Sensory Stimuli

Currently, two of the three levels in the Antwerp Under Water VR experience are complete. The third level — floor -2, representing the submerged "catacombs of memory" and featuring a train that transports the user back to the present — is in active development. Once this final level is completed, additional storytelling elements will be integrated, including the fever dream sequence and an underwater robot that guides users through the submerged environment. The user's virtual character - an avatar wearing a protective suit, ensuring that everyone can identify with the embodied character - will also be designed and modeled. Timely user tests will be conducted to assess the usability, emotional impact and immersion of these additions to the experience.

Moreover, we aim to further enhance user embodiment in the VR experience in future iterations. Achieving a strong sense of embodiment is crucial for making users feel that their virtual body is a natural extension of themselves, thereby deepening their connection to the virtual environment and the unfolding narrative. A key component in enhancing embodiment in VR lies in the use of multi-sensory stimuli, which can significantly deepen users' sense of presence and connection to the virtual body. Research highlights that embodiment is strengthened when multiple sensory modalities are engaged, creating an "implied body": an inferred sense of physical presence derived from sensory correlations [10]. For example, correlations between head movements and visual scene adjustments contribute to this sense of an implied body, as do other multi-sensory feedback systems, as long as they align with users' actions and expectations in the virtual environment [8, 12, 13].

To heighten embodiment within our VR environment, we therefore plan to incorporate multi-sensory elements like haptic, olfactory and auditory feedback. For instance, we hypothesize that using a bHaptics TactSuit - a wearable feedback suit by bHaptics Inc. that delivers tactile sensations in sync with virtual events - can simulate physical experiences, such as the pressure of water in a flooding scenario or the prick of a mosquito. Studies show that this kind of congruent visuo-tactile feedback enhances embodiment by reinforcing the illusion that the virtual body is a natural extension of the user's own body [10].

Similarly, olfactory stimuli - although technically challenging - offer a promising avenue to increase immersion and embodiment. Research suggests that olfactory cues, when integrated seamlessly, can boost presence and enhance the connection to the virtual environment, as users associate specific scents with their real-world counterparts [18]. For example, introducing scents like damp earth or sea air during particular scenes could further immerse users and evoke stronger emotional responses, making the experience feel tangible and lifelike.

Finally, sound plays an integral role in creating a multi-sensory experience as well. Auditory stimuli are essential in shaping users' emotional and spatial awareness within the VR world. In Antwerp Under Water, we plan to make extensive use of both diegetic and non-diegetic sounds to enhance immersion. Diegetic sounds are those that both the participant and characters within the virtual world can hear, such as mosquitoes buzzing and water dripping; sounds that are part of the environment itself. In contrast, non-diegetic sounds are audible only to the participant, such as a musical score that underscores the mood but does not exist within the world itself [23]. In Antwerp Under Water, the soundscape evolves as users descend through different layers of the experience, with clear, diegetic sounds such as the rustling of new life and birdsong in the upper levels transitioning to abstract, non-diegetic soundscapes in the lower levels. This shift reflects the transition from figurative environments to more surreal, chaotic ones, enhancing the emotional and sensory engagement. The use of both diegetic and non-diegetic sound helps ground users in the virtual world while also guiding their emotional journey.

We hypothesize that these enhancements will not only make the virtual world feel more tangible but also heighten the emotional resonance of the experience, motivating users to connect more deeply with the message of climate change urgency. Our target is to complete a first prototype of the entire VR experience by February 2025. When it is finished, a between-subjects experiment will be conducted in February and March 20215 to evaluate the impact of the prototype on target users. This study will compare responses from participants who engage with the VR experience against a control group exposed to similar climate information through a non-immersive medium, such as video or text. Key metrics will include usability, emotional impact, presence, embodiment, perceived urgency and knowledge of climate-related information, as well as attitudes toward climate change and behavioral intentions to take action. By analyzing differences between the experimental groups, we aim to assess how the immersive and embodied qualities of Antwerp Under Water influence its persuasiveness regarding climate issues, offering insights into VR's potential as an effective tool for promoting climate change awareness and encouraging proactive behavior.

6 Conclusion

In conclusion, Antwerp Under Water aims to harness VR's immersive potential to bridge the gap between abstract climate data and its tangible impact on familiar locations, using the iconic Antwerpen-Centraal railway station as a vivid setting to evoke urgency about climate change. Through an interdisciplinary collaboration that integrates insights from technical, creative, and user research teams, we are creating a scientifically accurate and emotionally resonant experience that immerses users in a multi-layered, location-based journey. Our iterative, human-centered design approach is refining the VR experience to be both compelling and accessible, engaging users through narrative depth, visual fidelity, and interactivity.

With two of the three levels completed, we are in the final stages of prototype development, focusing on enhancing user embodiment through multi-sensory stimuli. Upon completion, our planned between-subjects experiment will assess the impact of the VR experience on usability and user experience (e.g. emotional engagement, presence, embodiment), climate change awareness, attitudes and behavioral intentions. With the results, we hope to offer valuable insights into VR's effectiveness as a tool for climate change awareness and education, and inform the further polishing of the VR experience. Ultimately, we aim to demonstrate VR's unique capacity to evoke place-based embodiment and inspire action, making climate change a more immediate, personal issue for users.

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