Designing Inclusive Immersive Experiences: Intergenerational Codesign of Heritage and Underwater Extended Reality for Older Adults

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Abstract*—Despite rapid advances in immersive Extended Reality technologies, creating inclusive and accessible experiences for older adults remains challenging. Many Extended Reality applications fail to account for the physical, cognitive, and ergonomic needs of older users, resulting in low engagement and digital exclusion. Cultural heritage and underwater environments offer rich contexts for meaningful interaction and wellbeing. This study explored how intergenerational codesign can inform the development of immersive Extended Reality applications for older adults. Two case studies were undertaken within the ICONIC project: a Heritage Extended Reality experience recreating Cotehele, a National Trust heritage site, and an Underwater Telepresence experience simulating marine environments. The objective was to identify design principles supporting accessibility, comfort, and engagement. Sixteen codesign workshops were conducted with 24 older and 12 younger adults across five iterative stages: framing, ideation, prototyping, digital design, and testing. Mixed-methods analysis combined thematic coding of qualitative feedback with non-parametric statistical tests to assess design priorities. Participants prioritised immersion, interactivity, and accessibility. Simplified locomotion and one-button control schemes enhanced usability, while ergonomic modifications to headsets and controllers improved comfort. For Underwater Telepresence, dual "relaxation" and "learning" modes broadened appeal. Social features were consistently ranked lower than immersive and educational elements. Intergenerational codesign offers an effective approach to inclusive Extended Reality development and these insights inform future applications addressing digital exclusion and promoting equitable access to cultural and environmental experiences. In this paper, we showed that simplified controls, ergonomic design, and affordable hardware improve engagement and confidence among older users for immersive heritage and underwater telepresence experiences.

Keywords- extended reality; intergenerational codesign; heritage; underwater; digital exclusion; immersive; telepresence.

I. Introduction

Building on our previous work on immersive cultural heritage experiences [1] presented at the The Second International Conference on Artificial Intelligence and Immersive Virtual Reality (AIVR2025) [2], this paper extends the investigation of how Virtual Reality (VR) can support meaningful engagement across diverse audiences with a special focus on the older adults. In our earlier study, we explored how age-related differences influenced user preferences and modes of interaction within virtual environments, and we discussed how the codesign process shaped the overall experience for both heritage sites and telepresence for underwater environments. The current work expands these findings by presenting quantitative and qualitative evidence collected during the evaluation stage of the codesign process and how this evidence influences future development.

Advances in immersive technology such as Extended Reality (XR) have opened the door to new opportunities creating novel ways of exploring abstract concepts such as the visualisation of a Tadpole spinal cord firing mechanism [3] or representing complex numbers as shapes [4] but also accessing an engaging with museums and heritage sites [5] through recreating real world locations in a Virtual environment. Evidence suggests that younger audiences prefer Virtual Reality (VR) as a learning environment for cultural heritage [6]. This

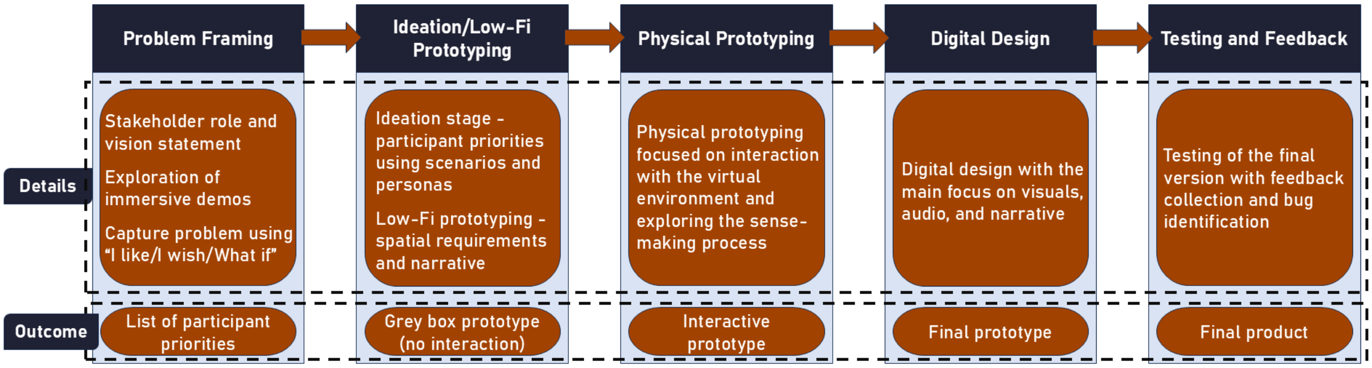

Figure 1. Timeline for the HXR and UT work package. The timeline is split in five distinct stages with an approximate one month duration for each stage. This approach is common to all ICONIC's work packages.

does not imply technological exclusion for older audiences, it highlights the need to go beyond usability testing and consider their interests and requirements for newly created content [7]. Although younger audiences are potentially drawn to the novelty and interactivity of VR, older audiences might engage more deeply with content that resonates with their life experiences and memories.

Through the Intergenerational Codesign of Novel Technologies In Coastal Communities (ICONIC) project, our aim was to give codesign participants (contributors), both young and old, a voice in the creation process and help them integrate their needs, suggestions and requirements into the design of novel technologies. The general aim of the ICONIC project was to develop four novel technologies through intergenerational codesign that would help connect digitally disadvantaged older people to local heritage and the environment. From the expertise of our team and our coastal context, we had nominated four general areas of technology: extended reality for heritage, telepresence for underwater, social games, and voice-AI over the telephone. This paper will focus on the intergenerational codesign approach to develop a Heritage Extended Reality (HXR) application and an Underwater Telepresence (UT) application.

Ijaz et al. [8] highlighted ten categories of design considerations for older adults that focused on users and physical configuration, hardware usage and the design of the immersive application. Through our codesign process we had the opportunity to address the majority of the categories such as: *onboarding and assistance* through supplementary sessions in order to familiarise the contributors with the hardware and the concept of VR; *safety* with support for contributors to explore VR standing or sitting in the presence of a researcher; *visuals* designed and created to capture the sense of being the physical heritage site; *audio* with the implementation of spatial audio; *personalisation* customisation of the VR headset and the controllers to help users with reduced mobility; *usability* with custom interaction metaphors for engaging with the virtual environment; *engagement* adding a gamified experience through interaction with historical artefacts; *minimise side effects* through support and clear instructions especially when testing new control mappings or unique locomotion techniques. *Embodiment* was addressed through the implementation of localised walking complemented by teleportation. In addition, it also includes automatic adjustment of the user's height when they put on the VR headset although we did not use an avatar to represent the user's body. *Realism* was addressed using actual measurements to recreate the heritage site in virtual space combined with ambient sounds. Throughout this paper, we will unpack the elements that contributed to each category in more detail.

This paper demonstrates how intergenerational codesign not only enriches the engagement of older adults with immersive technologies but also crucially informs the development of accessible and intuitive user interfaces in cultural heritage and underwater environments. By integrating extensive user feedback into the design process, we offer novel insights into creating more inclusive and effective immersive experiences.

The remainder of the paper is structured as follows. Section II provides a background and overview of our approach to codesign in the ICONIC project including the exploratory aspect of technology development. Section III describes the methodology and approach in the implementation of the project with a focus on contributors recruitment, partner involvement, and the iterative development process that integrates feedback from the codesign team. Section IV explores the outcome for each package, focusing on the immersive application for each package, and highlighting additional recommendations and findings. Section V unpacks the findings focusing on the HXR and UT rankings based on their respective design priorities. Section VI provides a discussion of common elements in packages and also highlights some of the differences between them. Section VII draws the conclusions of the article and highlights future work.

II. Background

This project approaches codesign from a participatory perspective, accessing the dormant creative potential of intergenerational groups through hands-on creative methods including storytelling and experience design, technology development, and interaction design. Here, the project has followed precedent from prior research [9] suggesting ten principles to codesign XR experiences for health interventions in rural communities [10], allowing end users to envision future and speculative scenarios (in this case, shaped by engaging with a local heritage location), the delivery of a research-in-residence approach [11], and the contextualization of XR design within defined societal groups and geographies, among others. These guidelines stem mainly from the GOALD project [12], which focused on physical activity and reminiscence and included a menu of XR experiences for further evaluation and feedback from older adults groups. In addition to those results emerging from the participation of older adults, we pose the question of whether rural communities can benefit from the creative participation of young people in need of high-value digital skills. Furthermore, the literature [13] [14] indicates that youth disenfranchisement results in more critical social outcomes, e.g., vulnerability, mental health and isolation, and feelings of 'nowhere to go'.

Heritage sites and museums play a vital role in the lives of many individuals, particularly in rural communities across South-West England. A 2018 UK Government report examined the influence of historic sites on wellbeing and one of the highlights is the concept of "Heritage as Place" [15]. The report, emphasises the importance of belonging, where the connection to historic locations contributes to reduced social isolation and strengthens feelings of pride, identity, and community. However, these advantages are not experienced equally across all segments of society, with older generation visitors experiencing accessibility and mobility issues. From a large partner network of 36 organisations [16], we partnered with Cotehele - National Trust to create a digital immersive version of the heritage site. Cotehele is a historic estate located in Cornwall, England, and features a medieval manor house, gardens, and a mill. The Great Hall, a significant architectural point of interest of Cotehele, was constructed in the late 15th century and has been preserved in traditional Georgian style for centuries.

With Ocean Conservation Trust (OCT), Plymouth, England, as a partner for the UT work package, the ICONIC project explores how these immersive tools can bridge physical and financial barriers, providing access to the otherwise inaccessible underwater world. Inspired by the beneficial effects of blue spaces on wellbeing [17], our goal is to simulate an underwater experience, enabling people onshore to explore marine environments that are otherwise out of reach. The codesign workshops centered on designing an interaction with the marine environment to evoke a sense of "being underwater" while addressing the practical challenges associated with such a design. The concept of telepresence — originally introduced in human-computer interaction to describe the illusion of being present in a distant location — has evolved beyond its technical roots. Sheridan [18] describes telepresence as the sensation of being "there" at a remote site. Within the scope of the ICONIC project, we have adopted a broader phenomenological view emphasising the sense of presence in underwater spaces that could include methods such as VR and pre-recorded content, enabling engagement without real-time telecommunication [19].

In line with design thinking, we have started the development from the first principles, by understanding what is it that stands out the most about the heritage sites and underwater spaces to our codesign participants and what are the main barriers to higher levels of engagement with these spaces. The goal of the project was to allow contributors to explore different modalities of immersion and interaction and to allow them to define what it means to experience a heritage or underwater spaces in an immersive environment. The technical solutions differ in a way they are delivered and in the resulting level of accessibility, interactivity and immersion for both packages.

Figure 2. During the codesign session, participants prototyped immersive interactions by annotating paper templates of 360° environments, taking snapshots, and instantly exploring their work in Google Cardboard VR. This iterative approach promoted deeper understanding and collaboration.

III. Methods

The ICONIC project recruited twelve Digitally Excluded Older People (DEOP) aged 50+ for the HXR workshop group, and a further twelve DEOP for the UT workshop group. Six Young People (YP) were recruited for the HXR, and an additional six YP were recruited for the UT group. Attendance amongst the younger cohort for both groups was more inconsistent than amongst DEOP contributors. To support asynchronous codesign an additional group of 20 YP were recruited through a higher education partner of the ICONIC project. The project received approval from the Ethics Committee of the University of Plymouth and each contributor received an information sheet and offered the option to withdraw from the study at any time. After each workshop, the contributors were encouraged to raise any issues or provide feedback in person and anonymously through a suggestion box. For analysis, data was anonymised and kept secure on the University of Plymouth machine and OneDrive protected by passwords. Access to the data was limited to the ICONIC team. Codesign participants and partner organisations have given permission for the photos used in this article.

The development process was created to reflect the contributors' involvement at different stages of the codesign process. The five main stages are as follows: Problem Framing, Ideation, Physical prototyping, Digital Design and Testing and Feedback, as described in Figure 1.

Each workshop followed a four-step iterative design approach as described by Macklin and Sharp [20]: Conceptualise, Prototype, Playtest and Evaluation. In the Concept phase - The research team will generate the concepts that it wanted to explore next based on the current development stage of the application and the feedback received. Prototype phase - the concepts get transferred into codesign activities and a technical prototype gets created. The playtest phase - during the workshop the codesign team generates feedback and knowledge through testing the prototypes and executing the designated activities. Evaluation phase - after the workshop the research team evaluates the workshop results, both from activities and the prototype feedback, and generates a new set of concepts to explore for the next workshop. This approach was applied to both the HXR package and the UT package as described by Jones et al. [16]. There were similarities in data collection between the two work packages, as the focus of each was understanding contributors' needs and design priorities for the two technologies. Each workshop featured a variety of activities that were designed to produce written or verbal feedback to support the iterative design of the technologies (Figure 2). Workshop materials and audio recordings were cleaned and transcribed verbatim for thematic analysis.

With Cotehele as a partner for the HXR, contributors chose from a set of six possible indoor locations part of the Cotehele's manor by using 360-degree videos captured at each location. The codesign team selected the Great Hall (Figure 3) due to its impressive size and extensive range of historical artefacts on display, although other locations, such as the kitchen, had great potential in exploring novel and immersive interactions.

The immersive nature of a VR experience is not only limited to the content presented to the user but also how the user interacts with the content. Lack of interaction creates a world where the user feels detached with no real connection to the digital environment, a passive experience where the user is "looking at" something as opposed to an active experience where the user feels "being part" of something [21]. In the HXR, the lack of interaction was clear from the feedback received during the early stages of development with participants exploring 360 videos of various rooms in Cotehele. Statements such as "lack of interaction" or "Frustration over lack of interaction" were provided as feedback. In addition, when participants were asked to complete the sentence "What I wish…" the top priority was "Immersive interaction". The single perspective of a 360-video capture affected some of the participants sense of embodiment, especially when the height of the user didn't match the height of the capture point, we received feedback such as "Feeling of floating" or "Disembodiment". And finally

Figure 3. Image taken inside the Great Hall in Cotehele - National Trust UK.

lack of mobility inside the video was another issue highlighted by the participants through statements such as "Lack of movement" and for the question "What I wish…" the answer was "Movement". These early findings highlighted the importance of interaction, movement and multisensory engagement for the older adults and informed us that the historical content is not enough to deliver an immersive experience.

For the UT, as contributors prioritized local marine environments early on, we focused on prototyping the interaction with the footage from two National Marine Aquarium (NMA) Plymouth tanks dedicated to local fauna and flora: Plymouth Sound and Eddystone reef. The prototype leveraged 360-degree camera footage, Oculus Quest headset [22] and artificial intelligence (AI) for interactive species identification (implemented as an OpenAI API placeholder for the time being). A point-and-click interaction method was selected based on contributors' feedback, with the option to scroll through the menu and the collection of species. The features of the prototype make it suitable for deployment in care homes, schools, and even tourism hubs, offering a scalable model for broad outreach and engagement.

Towards the end of the codesign process for both technologies, participants individually ranked design priorities for the HXR and UT technologies. When undertaking the ranking exercise, participants were asked "What features need to be priotisised for future design of this technology?" Design priorities were each derived from qualitative data collected over the course of codesign workshops. For the HXR technology, the eight design priorities comprised:

- Educational: The VR experience provides the user with detailed information about Cotehele's heritage
- Interactive: Lets users engage with artifacts and historical environments hands-on
- Explorable: Allows users to freely explore Cotehele
- Accessible: Designed for users of all abilities and tech-

Figure 4. On the left, HXR - final version of the Cotehele's Great Hall aiming to capture the unique "look and feel" from inside the great hall. On the right, UT. An example of interaction with the 360-degree footage of the underwater environment.

nological expertise

- Entertaining: Uses the history of Cotehele to provide a fun experience for users
- Immersive: Provides the user with a sense of being at Cotehele
- Social: Allows multiple users to explore Cotehele in the same virtual space
- Customisable: Provides the user with options to tweak the experience to suit their needs

The eight design priorities for the UT technology comprised:

- Accessible: Designed for users of all abilities and technological expertise
- Educational: The technology provides the user with information about the underwater enviornment
- Entertaining: Uses the underwater space to provide a fun experience for users
- Explorable: Allows users to freely explore an underwater space
- Immersive: Provides the user with a sense of being underwater
- Interactive: The user can engage hands-on with the underwater environment
- Relaxing: Provides a passive, therapeutic experience for the user
- Social: Allows multiple users to explore the underwater space at the same time

To gain a wider understanding of the design priorities for both technologies, participants that were not in the original HXR and UT codesign groups were asked to rank the design priorities. This would have the potential to validate the codesign observations from both HXR and UT workshop groups, should the rankings reflect the observations described previously. In total, the ranking was conducted by N = 57 participants (13 from the original HXR codesign group, 44 from additional codesign groups recruited for the ICONIC project) for the HXR technology and N = 53 participants (11 from the original UT codesign group, 42 from additional codesign groups recruited for the ICONIC project) for the UT technology.

IV. Codesign Outcomes

Although both packages have an immersive experience as the primary outcome, there are other secondary aspects that emerged as a result of the codesign workshops.

A. Heritage XR

1) Multimodal immersive experience: The main outcome of the HXR package is an immersive VR experience replicating the Cotehele's Great Hall (see the image on the left in Figure 4). The application is a multisensory experience that makes use of visual, audio and haptic feedback. The VR is delivered using the Quest 2 headset developed by Meta [23], which includes two VR controllers. The headset features six degrees of freedom (6DoF) using an inside-out tracking system and is equipped with a set of speakers that allows the delivery of 3-dimensional sound. The tracked controllers support 6DoF and have customisable buttons and haptic feedback capabilities. The virtual space has been created using a combination of local textures, rough measurements, and recreation of the main features of the hall. A set of 4 unique historical artefacts have been scanned using Photogrammetry [24] and due to limited resources and time constraints, the rest of the artefacts in the Great Hall are 3D digital replicas of weapons and items acquired through the Unreal Engine asset store [25].

2) Technical prototype with simplified interactions aimed at older adults: The codesign process revealed the challenges older adults face with various metaphors of interaction, found in most VR applications. Therefore, a set of simplified interactions were created aimed at alleviating some of the issues, such as holding a button pressed for a long time or hard-to-reach buttons. A combination of button mapping and interactive

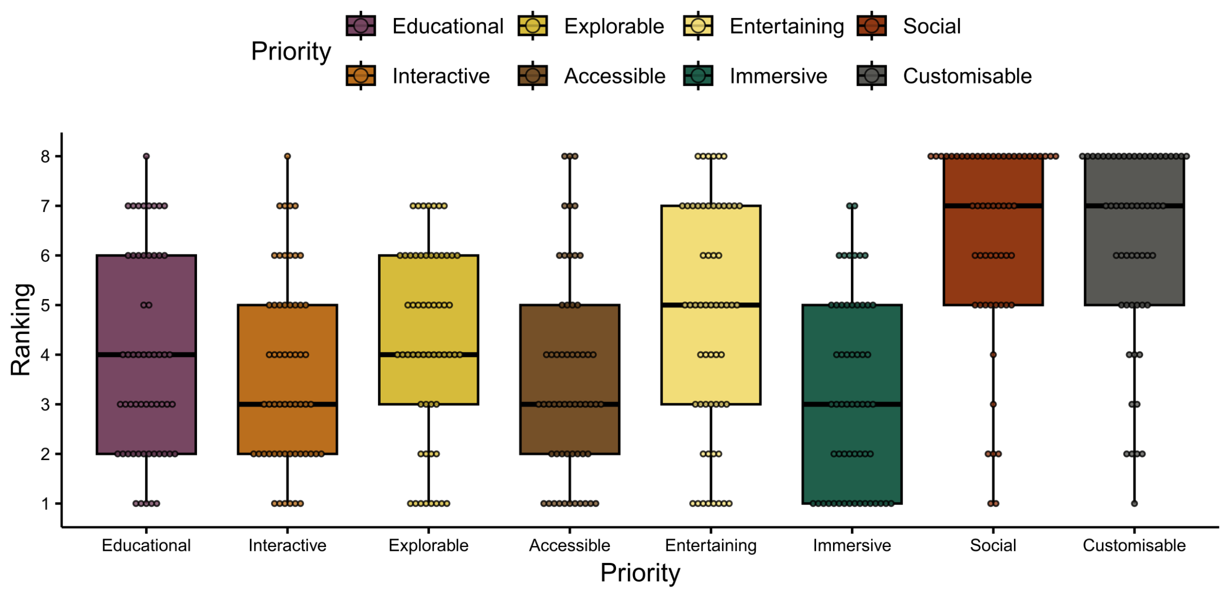

Figure 5. This graph depicts median and interquartile ranges of the HXR rankings for all participants. Each indiivdual point represents one participant's ranking score.

objects was packaged in an example project in Unreal Engine [26]. The interactive elements are modular and flexible, and developers can turn any asset into an interactive object.

3) UX recommendation for the development of VR applications: A set of recommendations for the development of a technical immersive application for older adults through an intergenerational codesign approach. These recommendations are in the process of being published soon in a peer reviewed article.

B. Underwater Telepresence

There are three outcomes from the UT codesign sessions:

1) Immersive Prototype: The main outcome is the immersive VR prototype designed to include most of the features designed by our contributors. There are two modes of interaction: "learning" and "relaxation". Relaxation is designed for users seeking a calming experience; this mode emphasizes the serene beauty of the underwater world with ambient sounds and minimal distractions. The learning (or stimulating) mode enables users to interact and identify marine species within the immersive environment implemented in the prorotype via API calls to a vision enabled LLM system. Features such as "collecting" fish and a virtual agent, designed as a friendly "penguin," engages users with contextual challenges (such as questions about the previously envountered marine species) to encourage users to explore the space more actively. Feedback emphasized the need for realistic, but not necessarily real sound, with ambient underwater sounds enhancing immersion.

2) Design of Alternative Delivery Modes: While there was general agreement about the use of the VR headset, the contributors proposed additional modes of delivery of the experience. The proposed design included a web interface with the ability to interact with 360-degree underwater footage in the same way as before, use of a large interactive screen (that was used to demonstrate the live video in Workshop 2), emphasising the social interaction aspect as an important part of the design. One of the alternative designs to the headset included a portable mini-dome. While the dome enabled shared experiences, it was deemed to be less immersive compared to headsets and limited in scalability due to the infrastructure required. In all design decisions, contributors prioritised accessibility and scalability above most other design properties, thus resulting in the VR headset (Oculus Quest 3) prefered as a final delivery channel.

3) Established Feasibility of Using ROV for Outreach: Remote Operated Vehicles (ROVs) emerged as a promising outreach tool, offering a hands-on, interactive modality to experience underwater environments. We tested the feasibility of the ROV-based telepresence project in an outdoor setting by using BlueROV2, allowing contributors to directly engage in marine exploration. The contributors operated the ROV, navigating an underwater outdoor space in real-time. To improve the comfort of contributors, we have also offered one-to-one ROV teleoperation training sessions in the indoor pool. Throughout the workshop, contributors expressed interest in extending interactivity through robotic arms for activities such as object collection or habitat observation. While not directly related to the immersive prototype, it shows that the ability to control movement in the underwater space can serve as equally engaging immersive modality as high resolution immersive footage. It was decided to continute develop this as an independent thread in the context of Plymouth National Marine Park activities.

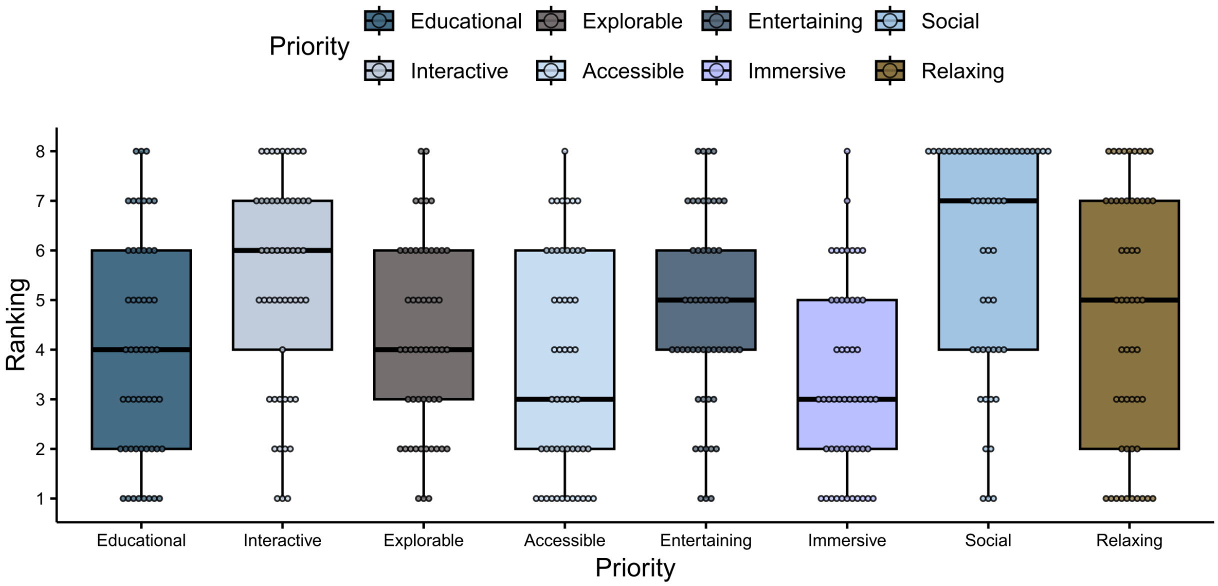

Figure 6. This graph depicts median and interquartile ranges of the UT rankings for all participants. Each indiivdual point represents one participant's ranking score.

C. Analysis

The ranking data for each technology were analysed using R [27] in RStudio [28]. To identify if there were differences in rankings between the main codesign group for each technology and the additional codesign groups that conducted the ranking exercise, Wilcox tests with Bonferroni multiple comparison corrections were conducted between the two groups for each design priority. For both technologies, there were no significant results from the Wilcox tests (all *ps* ¿ .005) so the data from all participants was aggregated into a single dataset. Friedman rank sum tests were conducted on the ranking data to determine if there were differences in how the constructs were ranked. These were followed by Nemenyi post-hoc tests with multiplen comparison corrections to determine if constructs differed in their ranking. Additionally, Kendall's coefficient of concordance W tests were conducted to determine if there was concordance within the rankings across participants.

V. Results

The HXR rankings are visualised in Figure 5. The Friedman rank sum test was significant, $\chi^2(7) = 100.5$, *p* ¡ .001. The Nemenyi post hoc tests indicated that the Social priority was ranked significantly lower than the Educational, *p* ¡ .001, Interactive, *p* ¡ .001, Explorable, *p* ¡ .001, Accessible, *p* ¡ .001, Entertaining, *p* = .004, and Immersive, *p* ¡ .001, design priorities. Similarly, the Customisable design priority was ranked lower than Educational, *p* ¡ .001, Interactive, *p* ¡ .001, Explorable, *p* ¡ .001, Accessible, *p* ¡ .001, Entertaining, *p* = .015, and Immersive, *p* ¡ .001. The only other significant difference was that Immersive was ranked higer than Entertaining, *p* = .023. All other pairwise comparisons were not significant (*ps* ¿ .005)

The Kendall's coefficient of concordance W for the HXR rankings was not significant, $\chi^2(56) = 4.43$, *W* = 0.01, *p* ¿ .005, indicating that participants were not consistently aligned with their rankings.

The UT rankings are visualised in Figure 6. The Friedman rank sum test was significant, $\chi^2(7) = 40.94$, *p* ¡ .001. The Nemenyi post hoc tests indicated that the Social priority was ranked significantly lower than Educational, *p* = .037, Explorable, *p* = .037, Entertaining, *p* ¡ .001, and Immersive, *p* ¡ .001. Additionally, the Immersive priority was ranked significantly higher than Interactive, *p* ¡ .001, and Entertaining, *p* = .037, and the Accessible priority was ranked significantly higher than the Interactive priority, *p* = .006. All other pairwise comparisons were not significant (*ps* ¿ .005)

The Kendall's coefficient of concordance W for the UT rankings was not significant, $\chi^2(52) = 2.3$, *W* = 0.006, *p* ¿ .005, indicating that participants did not all rank the constructs similarly.

VI. Discussion

The generalist approach taken in the development of HXR and UT offered a unique opportunity to explore multiple directions and delivery methods for the experience. Rather than narrowing the scope early, the projects deliberately kept the solution space broad, enabling the team to investigate a variety of technologies and approaches. For HXR, our initial findings identified similar challenges to Wu et al. [29], with older adults experiencing difficulties, such as headset-related neck fatigue and limited field of view leading to extra head movement leading to decreased motor performance. Therefore, the interaction and locomotion were prioritiesed by the codesign team to improve accessibility and direct interaction.

For the UT the focus was on exploring various methods of allowing contributors to experience telepresence through controlled ROVs and recorded underwater environments in VR. By allowing the contributors to interact with a full spectrum of possible telepresence delivery systems (live stream vs pre-recorded, flat vs 3D, simulated va real, etc.) we were able to identify what aspects of the experience users value most with great level of precision. However, this openness also posed challenges, in particular, highlighting the need for diverse expertise and ample resources to deliver multitude of prototypes with required level of functionality.

Accessibility emerged as a decisive factor in nearly every stage of the project. Whether considering the mobility of devices, their cost, or ease of use, the contributors consistently emphasized the importance of making the technology as inclusive as possible. For instance, while immersive dome projections offered an interesting social dynamic, they were ultimately de-prioritized due to their high infrastructure requirements and limited portability. For both packages, the Quest 2 headset (upgraded to Quest 3) was chosen by the contributors for its affordability, accessibility and mobility. These decisions reinforced the need to prioritize technologies that could reach the largest audience, even if it meant compromising certain experiential features.

A. Exploration through technology interaction

The ability to explore through interaction was one of the key factors that the codesign team highlighted early in the process in both the HXR and UT packages. Workshop 1 was dedicated to problem framing, the contributors explored technologies dedicated to each package in order to identify the key elements of an immersive heritage and underwater telepresence experience.

For HXR, some key elements highlighted by the team were: (i) accessing heritage information through novel and unique ways such as a non-player character (NPC) that provides information about the various historical artefacts; (ii) collaboration between two or more users in exploring the digital space; and (iii) education and knowledge through gamified experiences such as an escape-the-room puzzle.

The exploratory aspect of the codesign process combined with the onboarding sessions and equipment support [30] from the researchers provided contributors with a unique opportunity to explore both the limitations and possibilities inherent in technology, leading to a deeper understanding, reduced cognitive load and reducing their initial reluctance to engage. This was evidenced by the preferences for movement in the VR environment. Initially, teleportation as the initial locomotion metaphor, proved challenging for some of the contributors. A combination of controls and the ability to aim towards a landing spot made some contributors uncomfortable. A more simple locomotion, called ”grab-and-drag” was initially preferred, but as the contributors became more experienced with the VR technology, they started to revert to the teleportation metaphor. The contributors increase in confidence in using the VR assembly shifted the focus towards the creative aspects of engaging with the content, especially in the workshops that took place at a later stage in the process. This is consistent with the findings of Zhang [7], who argue that during technology development, the involvement of older users is crucial, especially if the final goal is the adoption of technology [31].

Figure 7. We replaced the original elasticated strap for the headset with a more mechanical strap that distributes the weight of the VR headset equally.

For UT, one of the most striking findings was the evolution of the preferences of the contributors as they interacted with the technology. For example, while live streaming was initially considered a priority, this changed once contributors received live-like footage (footage recorded earlier). The limitations in video quality led to a diminished preference for live streaming in favour of pre-recorded footage. Similarly, in the first workshop, real underwater sounds were thought to be crucial for immersion, but after interacting with the videos with real underwater sounds recorded by hydrophones, participants found that they did not match their expectation of a relaxing ambience. Hence, we have used an ambient underwater sound in the consequent prototypes.

Another example of this evolution occurred during the ROV trials. Initially, contributors viewed interaction with the underwater environment strictly negatively, as disruptive to the environment and in conflict with the environmental preservation motivations of the group. However, ROV’s teleoperation capabilities introduced a new dimension of engagement, and contributors became enthusiastic about more direct interactivity. The session provided suggestions for features such as a robotic arm to “collect samples” or clean up the ocean floor from debri.

B. Accessibility, usability and comfort

A variety of immersive experiences have different levels of immersion based on the technology used to deliver them and the implementation of the experience. Immersion is an objective factor in a system that mirrors the extent of technology can support natural sensorimotor alternatives to perception [32]. The contributing factors are typically related to the real world, mainly the hardware specifications or the design of the system, such as resolution, panoramic view, audio input and generally the number of outside physical realities that are blocked by the system [33]. The importance of this was clear from the beginning, in both packages, with members of the codesign team expressing discomfort with the headset. This is all related to the weight distribution of the headset [34] using the original strap, as it adds pressure on the forehead of the user and strain on the neck. This issue has been solved by purchasing a custom head strap that allows weight distribution, transferring the pressure from the forehead to the rest of the strap (Figure 7). Although the new strap marginally increased the overall weight of the system, the contributors reported increase comfort in wearing the VR headset, which in turn, improved the quality of the experience. The new head strap also reduced the amount of light reaching the user's eyes through an improved light blocker that sat closer to the face. Participant comments, such as appreciating the "adjustable headset," and "The headset was a much better fit than previous ones and made it a more comfortable experience" clearly evidenced the positive impact of these ergonomic improvements.

Figure 8. The controller has a strap attached to it that allows the user to open their hand and the controller will stay attached, minimising the amount of strain on the hand.

The use of the VR controller also presented a challenge early in the codesign process. Although ergonomic in its design, the needs and requirements for older adults present different challenges. For starters, holding the controller in hand for a long time presents a challenge, considering the participants might suffer from frailty or from a limited range of motion in the hand. The solution was to add a strap to the controllers that allowed participants to slide the controller on their hand, and the controller was attached to the hand without having to actually close their hands. This greatly reduced the strain on the hand and one participant actually mentioned that it is "easy to control" (Figure 8).

In addition to the ergonomic aspect of the controller, participants complained about the controllers, "difficult to get used to" or "Not being able to use the controls with confidence" or even "The controls - they were not intuitive". The complexity of using the controller came from various buttons and joysticks that had different actions attached to them such as teleporting, moving, grabbing objects, opening various options and also from the locations of some of the buttons that were difficult to reach by some of the users. In response to that we simplified the controls to use only one button, the trigger button. The button was easy to reach, and we attached additional behaviours to the button depending on the context. All the actions were toggable as participants were able to grab objects close or from a distance by using just one press of the button. On the second press the button disable the grab action and the object fell to the ground. That means the participants didn't have to keep the button pressed in order to hold an object in their hands.

C. Immersive experience for older adults

Focusing on the digital content is paramount to immerse the player in the digital environment and gives the user a sense of presence (SoP), the sensation of leaving their current location, and they transport to a virtual environment where they act as if they are physically there, perceiving virtual objects and individuals as real [33] [35] [36]. For the HXR, in our approach to increase the SoP for our contributors, we introduce multisensory inputs using visual, audio and touch. Many of the historical artefacts are interactable, with the user having the ability to grab them from proximity or from a distance (Figure 9).

In the early stages of the codesign process, after the transition from a 360-video to an immersive interactable version of Cotehele participants expressed their enthusiasm and appreciation for interaction such as "picking things up" and "actually handle things". These early interactions used objects of various shapes such as cubes and a gun that shoots small balls. The goal was to explore the grabbing mechanic involving the hand/controller in VR and the object and also to explore how the objects behave in the environment. The participants used a set of controllers that were replicated in VR to align their real-world sensory inputs to the visuals in the VR environment. The visual representation of the grab mechanic was done through replacing the controller with the grabbed object with positive feedback from the participants "I loved picking up the gun and firing it".

We also explored the realistic behaviour of simple objects such as cubes in order to increase the participant's sense of presence in the virtual environment. We introduced physics-based cubes that mimics the real behaviour of a cube in the real world. Participants had the ability to grab, move, push or throw these cubes with positive comments such as "the cubes are very realistic and fall/move as they should" further supporting the objective factor of Immersion. Of course, in the later codesign stages we introduce actual interactive historic artefacts and elements that contribute to the narrative of the experience but these early stages prototypes played a crucial role in understanding the codesigners preferences and needs.

Figure 9. The interaction works for nearby objects or for objects in the distance. The feedback is in the form of visual highlight, haptic feedback and audio for when the object lands in the user's hand.

Audio textures are used for simple interactions or for impacts between swords and other objects in the environment in order to give user situational awareness [37]. These interactions are accompanied by haptic feedback in the form of small vibrations with different amplitudes and intensities in order to trigger tasks [38] and enhance the level of immersion for the user. Multisensory interaction was one of the codesign group's priorities with an initial discussion about implementing hand tracking in order to simplify the interaction metaphor versus keeping the controllers with a simplified version of the button mapping. The contributors opted for continued use of the controllers as they did not want to lose the haptic feedback.

For the UT, immersion was embodied through a bimodal distribution. Many contributors expressed interest in highly stimulating and relaxing experiences, depending on the context. For example, some valued the calmness and meditative quality of simply observing marine life, while others were drawn to active gamified elements that encouraged exploration and learning. This dual demand for contrasting modes presented a design challenge, but also highlighted the potential versatility of the system by catering to diverse user needs. We have responded by delvering two modes of interaction, and found that both were equally used by the participants. Some participants found it is be uncomfortable to be "inside" of the tank in the VR space, without any visible support underneath them, making them loose balance. It suggests that building some aditional virtual structure around the user could be beneficial to improve this experience.

The codesign exploratory approach of the ICONIC project was aimed at creating a technological base for each of the four technologies, with the intention of one or more social enterprises to take over the development and turn each prototype into a product developed by the local community for the local community. This approach meant that we did not run any simulator sickness tests [reference] with our codesign groups, although we encourage them at each session to report any symptoms.

D. *Future design priorities*

To identify the future design priorities for the two technologies participants from our codesign workshops and from separate evaluation workshops ranked eight design priorities derived qualitatively from codesign data. Between the HXR and UT workshop data, the design priorities were identical, with the only difference being a 'Customisable' design priority for the HXR experience and a 'Relaxing' design priority for the UT technology.

Analyses of the HXR ranking data indicated that participants did not demonstrate concordance in their overall ranking patterns. There were, however, significant differences between the ranking of specific items. Participants significantly prioritised immersion, interaction, and accessibility to a greater extent than social or customisable elements. These reflect observations from the HXR codesign workshops as participants sought to maximise the immersive nature of this technology. The emphasis on accessibility also reflects difficulties some older participants experienced with Quest 3 controllers, highlighting the importance of inclusive design in VR systems and software.

Similarly to the ranking data for the HXR technology, there was no concordance amongst participant rankings for the UT technology, though, again, there were significant differences between specific priorities. Participants ranked the social design priority lower than the educational, explorable, entertaining, and immersive design priorities. As with the HXR codesign process, these data reflect observations from the UT codesign workshops.

While rankings across the two technologies focused on different sets of priorities, both consistently deprioritized social features relative to technology-specific core functionalities, i.e., Immersion, Accessibility, and Interactivity for the HXR technology, and Education, Exploration, and Entertainment for the UT technology. This deprioritisation of social elements of the technology may reflect the stage of the codesign process, as the features that were prioritised reflect the further developmeent of core functionality that is integral to the identity of the two technologies. When the core functionality is well-established, it may be that participants then begin to prioritise elements that were not a clear design priority at this stage. Whilst these data do not demonstrate a concordance for design priorities across the two technologies, it does highlight priority areas of development for the two technologies that should be prioritised, and others that should be deprioritised.

VII. Conclusion and Future Work

In conclusion, the comparative analysis of design priorities across the HXR and UT technologies highlights both shared and technology-specific user expectations that can inform future development of immersive heritage and underwater telepresence experiences. Despite limited concordance in participant rankings, consistent patterns emerged that underscore the centrality of immersion, accessibility, and interactivity as critical design priorities for HXR, and education, exploration, and entertainment for UT. The consistent de-prioritisation of social features across both technologies may reflect the developmental stage of the prototypes, where participants' focus remained on refining core functional elements essential to meaningful engagement before contemplating social engagement.

These findings reinforce the importance of iterative, user-centred design processes in the evolution of immersive technologies for older adults. Through an iterative development process and a series of intergenerational codesign workshops, the research demonstrates that immersive XR technologies hold considerable potential for reconstructing cultural heritage sites and underwater environments in ways that are both engaging and meaningful for older users. Nevertheless, the effective adoption of these technologies remains dependent on addressing key design challenges, including the implementation of intuitive locomotion and interaction mechanisms, the simplification of control schemes, and the incorporation of ergonomic solutions to enhance comfort and mitigate physical strain. Notably, the introduction of simplified locomotion and control systems instilled greater user confidence in operating the VR headset, enabling participants to shift their focus from issues of usability and hardware management toward a more creative and exploratory engagement with heritage artefacts.

Moreover, factors such as accessibility, affordability, and hardware usability emerged as critical priorities for older participants, underscoring the necessity of minimizing barriers to engagement. To address affordability constraints, the codesign team selected a cost-effective headset, though its limited technical capabilities posed challenges in achieving high-fidelity visual representation. In response to usability and accessibility concerns and as a result of collaborative design interventions, simple non-expensive solutions were introduced to enhance comfort and ease of use—these included the integration of adjustable straps to secure the controllers to the users' hands and a redesigned head strap that more evenly distributed the device's weight. Furthermore, a context-sensitive single-button interface was developed to adapt dynamically to user actions within the virtual environment, thereby simplifying interaction and reducing cognitive load. Collectively, the results provide actionable insights for guiding the next phase of design and evaluation, advancing the creation of inclusive, engaging, and contextually resonant XR experiences for diverse audiences.

The value of codesign became particularly evident in the interactions contributors had with multiple version of the technology prototypes. Participants initially articulated preferences and expectations based on their imagined interactions with the technology. Once these ideas were translated into prototypes and participants could directly interact with them, their understanding frequently evolved. Experiencing the designs in a tangible form allowed participants to reassess their assumptions, refine their preferences, and, in some cases, develop entirely new ideas. This iterative process demonstrated that meaningful codesign extends beyond conversation. The designs emerge through engagement, reflection, and learning that occur when participants interact with evolving design artifacts. Such embodied participation grounds the technology's development in lived experience.

Ongoing evaluation sessions with intergenerational user groups and industry partners are currently underway to validate and extend the findings of this study. The insights emerging from these sessions will inform the next phase of development, with a particular focus on designing and testing a simplified controller that enhances usability, supports personalisation, and reduces cognitive load for older adults with limited mobility. This next stage will further advance the project's commitment to inclusive design, aiming to translate user-centred insights into tangible technological solutions that foster broader accessibility and engagement across generations.

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