Intergenerational Codesign of Immersive Technology for a Heritage Site and Underwater VR Experience

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***Abstract*—The development of immersive Extended Reality (XR) applications tailored for older adults remains a significant challenge, even amidst rapid technological advancements. Neglecting to account for the specific needs and requirements of end-users in the design process can result in reduced adoption rates or a total lack of engagement. We present findings and recommendations for building immersive experiences for older adults by exploring the similarities and differences encountered during the development of two immersive XR applications, with a specific focus on cultural heritage and underwater telepresence. The application development followed a monthly, iterative approach, integrating rapid prototyping for a total of 16 intergenerational codesign workshops, with 24 older adults and 12 younger adults codesign participants. The findings indicate that immersive experiences for older adults have significant potential to effectively recreate cultural heritage sites or underwater environments in XR. However, achieving this requires the implementation of simplified and intuitive locomotion and interaction mechanisms, facilitated through a streamlined and simplified control scheme. In addition, accessibility and affordability together with comfort in using the immersive hardware and minimising hand strain when holding the controllers are priorities for older age codesign participants.**

Keywords-xr; intergenerational codesign; heritage; underwater; digital exclusion.

I. INTRODUCTION

Advances in immersive technology such as Extended Reality (XR) have opened the door to new opportunities creating novel ways of accessing an engaging with museums and heritage sites [1]. Evidence suggests that younger audiences prefer Virtual Reality (VR) as a learning environment for cultural heritage [2]. This 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 [3]. 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, underwater telepresence, 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. In the rest of the paper, we will refer to heritage extended reality as HXR and Underwater Telepresence as UT and any Extended Reality concepts and terms as XR.

Ijaz et al. [4] 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

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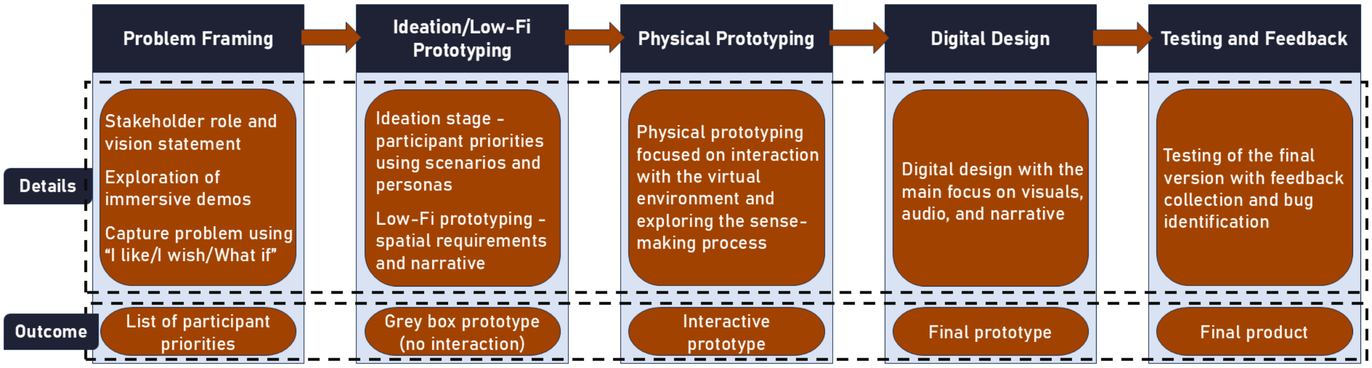

Figure 1. Timeline for the HXR and UT work package. The timeline is split in five distinct stages with an approximate one month duration for each stage. This approach is common to all ICONIC's work packages.

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 provides a discussion of common elements in packages and also highlights some of the differences between them. Section VI draws the conclusions of the article and highlights future work.

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 [5] suggesting ten principles to codesign XR experiences for health interventions in rural communities [6], 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 [7], and the contextualization of XR design within defined societal groups and geographies, among others. These guidelines stem mainly from the GOALD project [8], 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 [9] [10] 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" [11]. 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 [12], 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 well-being [13], 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 [14] 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

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pre-recorded content, enabling engagement without real-time telecommunication [15].

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.

II. METHODOLOGY

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 [16]: 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. [12]. 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.

Figure 2. During the co-design 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.

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.

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 [17] 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.

III. OUTCOME

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.

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

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 [18], 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 [19] 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 [20].

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 objects was packaged in an example project in Unreal Engine [21]. 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. Features such as "collecting" fish and a virtual agent, designed as a friendly "penguin," engage users with contextual challenges 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.

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, 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.

IV. 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. [22], with older adults experiencing difficulties, such as headset-related neck fatigue and limited field of view leading to extra head

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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.

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. This exploratory strategy revealed new possibilities and improved the understanding of what users value in such an experience. However, this openness also posed challenges, highlighting the need for technical expertise and resources, and limiting the final application to a prototype.

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 headset with the lowest price was chosen by the contributors to increase accessibility. 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 [23] 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 [3], who argue that during technology development, the involvement of older users is crucial, especially if the final goal is the adoption of technology. [24].

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 (live streaming 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

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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".

B. Immersive experience for older adults

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 to which technology can support natural sensorimotor alternatives to perception [25]. 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 [26]. 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 [27] 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 5). Although the new strap increased the overall weight of the system, the contributors reported an improvement 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.

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 [26] [28] [29]. 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 6).

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 [30]. These interactions are accompanied by haptic feedback in the form of small vibrations with different amplitudes and intensities in order to trigger tasks [31] 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.

Figure 5. We replaced the original elasticated strap for the headset with a more mechanical strap that distributes the weight of the VR headset equally.

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.

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 motion sickness tests with our codesign groups, although we encourage them at each session to report any symptoms. The only reports we had were about headset comfort and controller usability issues, with some contributors struggling to reach certain buttons or hold a controller in hand for relatively long periods of time. All reported issues were solved or mitigated, for example, we used a strap that distributes the head set weight to make it more comfortable, elasticated straps for controllers that keep the controllers attached and the implementation of all the actions on one, easy-to-reach, button.

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Figure 6. 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.

V. Conclusion and Future Work

The findings of this study underscore the critical need for user-centred design in the development of immersive XR applications tailored for older adults. Through an iterative development process and intergenerational codesign workshops, this research has demonstrated that immersive XR technologies have substantial potential to recreate cultural heritage sites and underwater environments in ways that are engaging and meaningful for older users. However, the successful adoption of these technologies depends on addressing key design challenges that include the creation of intuitive locomotion and interaction mechanisms, simplified control schemes, and ergonomic considerations to enhance comfort and reduce physical strain. The simplified locomotion and controls gave contributors confidence in using the VR headset and as a result they shifted their focus from usability and hardware engagement to a more creative attitude, exploring various ways to engage with heritage artefacts.

Moreover, factors such as accessibility, affordability, and hardware usability emerged as essential priorities for older contributors, emphasizing the importance of reducing barriers to engagement. To address affordability, contributors chose an affordable device, although its limited technical capabilities presented a challenge in creating a rich visual environment. For usability and accessibility, we worked in partnership with the codesign team to increase comfort and accessibility to the controllers by using dedicated straps that keep the controllers attached to the hand and for the headset, we used dedicated strap that distributes the weight equally around the user's head. In addition, we designed and implemented one button that adapts to the user's actions in the virtual world, simplifies the interaction process and reduces cognitive load. These insights provide a foundation for designing inclusive and effective XR applications, not only for older adults but for broader intergenerational audiences.

Although we had a large codesign group with over 90 people recruited and 36 attendances for the combined HXR and UT work packages, we need to evaluate the developed technologies with a wider group of participants. We are currently in the process of conducting evaluation sessions with intergenerational groups of young and old adults and industry partners to evaluate the findings. The outcome of these evaluation sessions will inform the next stages of the project with one of the key elements to be explored is the development of a simplified controller focused on increased usability, personalisation and to reduce cognitive load that is aimed at older adults with limited mobility.

Future research should explore adaptive design approaches that further refine these experiences, as well as investigate strategies to improve long-term engagement and accessibility. By addressing these challenges, immersive XR applications can become powerful tools to enhance cultural engagement and expand the possibilities of virtual exploration for older adults.

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