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Intergenerational Technology Co-Design Process: Reflections from Underwater Telepresence and XR Workshops

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Abstract. Within the Intergenerational Co-design of Novel Technologies In Coastal Communities (ICONIC) project we aim to create technologies aimed at enhancing the wellbeing of older adults through co-design workshops with both older adults (aged 50+) and younger participants (aged 16-30). This is an intermediate report summarising our reflections on the co-design of extended reality and underwater telepresence technologies. For the two technologies' core development track, we held thirteen intergenerational workshops in total, that took place between August 2023 and July 2024, with 24 older and 12 younger participants. As a result of the co-design, we are developing prototypes, including live video streaming from an underwater 360° camera, augmented with interactive elements, and an extended reality experience based on a historical landmark. In this report, we examine key factors affecting intergenerational technology co-design workshops, focusing on participant motivations, recruitment, group dynamics, time management, and methodology. Participants were mainly motivated by the chance to learn about unfamiliar technologies. Recruitment proved challenging, especially with digitally excluded individuals and younger participants. Intergenerational interactions revealed a positive and productive dynamic, with younger participants often assisting older adults in understanding technology and taking the lead in hands-on activities. Effective time management, regular breaks, and flexible workshop activities were crucial for keeping participants involved, as well as focusing on simple tasks, clear instructions, and the incorporation of ongoing feedback. Progressive building of technology awareness and balancing creativity with realistic constraints is key to an inclusive design process. This report summarises our experience to inform and encourage researchers and practitioners that aim to use co-design methodology for technology development.

Keywords: Digital inclusion, older adults, co-design, co-creation, participatory design, intergenerational.

1 Introduction

Modern technology often overlooks older adults as users [4, 7], despite its capacity to enhance various aspects of healthy ageing, such as enhancing connections with the local community and environment, as well as providing entertainment. Designing technologies that ensure digital equality is essential, especially as older adults encounter obstacles to digital inclusion and ageing populations continue to grow. In response to these challenges, the Intergenerational Co-design of Novel Technologies In Coastal Communities (ICONIC) project adopts an intergenerational co-creation approach to develop technologies like extended reality, underwater telepresence, social games, and interactive voice interfaces [14]. This method acknowledges that relying solely on empathy within a design thinking framework can exclude end users from the design process, potentially resulting in solutions that fail to address their actual needs and preferences [4]. By actively engaging both older and younger generations in the design process, the ICONIC project seeks to create technologies that are inclusive, empathetic, and truly responsive to the diverse needs of local communities.

This paper offers insights from co-design workshops on underwater telepresence (UT) and extended reality (XR), expanding on [11]. Here we provide more detailed reflections of the technology co-design process by including a thematic analysis of the post-workshop facilitators' debrief session recordings and their notes. Our findings demonstrate the viability of the approach and suggest key considerations for utilizing technology co-design. We aim to inform the future researchers and designers by demonstrating the potential of using co-design and the process of technology organising and holding co-design workshops.

2 Methodology

Our approach aligns with Participatory Inquiry methods, blending research and action through an iterative development process. We employ a Research through Design approach [2], which extends Participatory Inquiry by ensuring continuous stakeholder involvement from the initial problem framing to the interaction design phase [25]. The overall steps of our co-design process are outlined in Figure 1 and are divided into three distinct stages.

The *preliminary steps* focus on building relationships with partners, recruiting participants, cross-disciplinary planning, reviewing relevant literature and technologies, and conducting mock workshops to test the co-design methodology and logistics. The second stage, *co-design workshops*, follows an iterative process in which the team explores and addresses a series of problems and challenges. The key steps in this stage include preparation, workshop activities, data collection, data analysis, knowledge generation, and the implementation of the technology or design approach.

The final *wrap-up stage* is dedicated to validating the technology and refining both the approach and the technological solution through further co-design workshops. During this stage, we aim to share the findings as academic contributions and develop an open-source framework. This framework has the potential

Stage 1: Preliminary steps		Stage 2: Co-design workshops (iterative)	Stage 3: Wrap-up
Planning	Partner engagement	1. Preparation	Prototype validation with a wider audience
Recruitment	Mock workshops	2. Workshop and data collection	
		3. Data analysis	Design recommendations for a legacy social enterprise
Literature and tech toolkit review		4. Implementations/ prototypes/ tech demo preparation	

Fig. 1. A visual representation of the co-design process, divided into three distinct stages: the Preliminary Stage, which focuses on preparatory activities conducted before the workshops begin; the Iterative Co-design Workshops, centered on hands-on design methods; and the Wrap-up Phase, which focuses on validation, data dissemination, and the potential creation of a social enterprise. Reproduced from [11].

to be used by social enterprises to create new business ventures with a social focus that further the co-design of the novel technologies.

2.1 Workshops

The co-design workshops were conducted on a monthly basis to allow sufficient time for data analysis and technology development, with each technology allocated between 7 to 10 workshops. This long-term engagement of participants helped maintain consistency in the design direction throughout the process. The structure supported effective planning, development, workshop execution, and knowledge generation. From a development perspective, this approach is similar to agile methodology, featuring iterative cycles of product development and evaluation [5]. Two to four facilitators were present at each workshop, managing the activities, timing, data recording and otherwise helping the participants engage with the design process. This ensured the smooth running of the workshops, while also providing a diversity of perspectives.

2.2 Recruitment

We partnered with 35 local organisations to recruit 55 older adults (aged 50+) and 42 younger individuals (aged 16-30). Ethical approval for the project was granted by the University of Plymouth Arts, Humanities, and Business Research Ethics and Integrity Committee (09/05/23; project ID 3941). Recruitment efforts were partially driven by partner organisations [14], which distributed project advertisements to potential participants, but also through organic engagement with social media posts and outreach efforts. Participants received vouchers as reimbursement for their time spent both in the workshop and travelling. Before attending the workshops, participants were interviewed to assess their levels of

digital engagement, revealing great variety in the nature of their digital inclusion. Common barriers included lack of digital skills, high costs, and infrastructure limitations, particularly in coastal and rural areas [23, 12, 16].

2.3 Data collection and analysis

Data used for extracting knowledge about the technology co-design was gathered during the workshops through various means, including voice recordings, videos, feedback forms, questionnaires, facilitator notes, and physical materials from prototyping activities. These data were then analysed using a combination of thematic coding and content analysis to identify user preferences and priorities, similar to the use of "user stories" in guiding prototype development. Participants' identities were protected through anonymisation throughout the entire process.

Additionally, for the purpose of the reflection of the process of co-design, facilitators took notes, and short debrief meetings were held and recorded immediately after each of the workshops. We used thematic analysis to extract the themes from these notes and transcripts across the core set of the XR and UT workshops held between September 2023 and July 2024 to identify the main immediate take-aways from the co-design process.

3 TECHNOLOGY CO-DESIGN PROCESS

Although both technologies share the common goal of enhancing digital inclusion and well-being, they address different themes: UT focuses on developing a deeper connection with the natural environment, while XR workpackage aims to create immersive experiences to facilitate interaction with sites of local heritage. While, the design process for each technology has naturally generated unique insights, we have identified multiple common themes when it comes to both technology development and co-design process.

3.1 Underwater telepresence

Guided by the positive effects of blue spaces on well-being [8] and the project's focus on coastal communities, the goal of UT technology development is to recreate an underwater experience for people onshore, allowing them to explore marine environments that would otherwise be inaccessible. The workshops centered around designing an optimal interaction with the marine space to evoke the "feeling of being underwater" while addressing practical challenges inherent in such a design.

In the initial co-design workshops, several barriers to engaging with the underwater world emerged, including financial constraints, time limitations, physical limitations, and discomfort in cold water. Although the team initially considered creating a remotely operated vehicle for this experience, a scoping review prompted us to not limit immersion to only this aspect and explore a wider

range of technological approaches to underwater telepresence [10], each with its own implications for accessibility, interactivity, installation complexity, and maintenance.

Co-design process From September 2023 to July 2024, in collaboration with the National Marine Aquarium in Plymouth, UK, we held six workshops involving 12 older and 6 younger participants — the first set of workshops aimed at developing the UT technology within the ICONIC project. The activities of all the workshops are summarised in the Table 1.

Through focus groups, prototyping activities, and demonstrations of related technologies — including a virtual reality (VR) headset experience ("Ocean Rift"), 360° underwater videos, and large language model demonstrations — a consensus emerged. Participants expressed a preference for an immersive, real-time experience of the local underwater environment, with interactive access to information about marine life. This feedback shaped the development of a conceptual prototype, which includes live video streaming from a stationary 360° camera, supported by a marine life classification engine and a user-friendly interface accessible via a head-mounted display and interactive controllers.

Design insights Throughout the workshops, we discovered that two contrasting modes of interaction appealed to participants: stimulation and relaxation. The stimulating mode involved dynamic and engaging experiences, incorporating gamification and interactive features, such as learning about marine life. In contrast, the relaxing mode focused on providing a calming and soothing environment, highlighting the well-being benefits associated with blue spaces [8].

A major and consistent theme across all workshops was the desire to learn about marine fauna and flora. To meet this need, we integrated machine learning elements and connected the prototype to a remote large language model API, allowing it to generate explanations about marine life.

The value of live streaming as a tool for fostering long-term engagement emerged through interactions with publicly available underwater camera streams. Participants emphasised that the content must be diverse and varied to sustain long-term interest, also noting the unique appeal of "*observing it as it happens.*" This focus on long-term engagement contrasts with the short-term interactions typically designed for similar applications.

3.2 Extended Reality

This work package aims to enable individuals with mobility impairments to access culturally and historically significant sites by addressing the limitations of commercially available VR systems. In doing so, it strengthens connections with specific places and communities while supporting user well-being [1, 18, 3]. Building on previous work in VR system development for digital heritage sites—focused on locations like Powderham Castle and the Higher Uppacott

Table 1. Underwater telepresence (UT) design process overview

Workshop	Stage of the Design Process	Date	Activities
W1	Problem definition, understanding stakeholder perspectives, team introduction	Sep 2023	Focus groups on prior experiences with the sea and barriers to engaging with marine environments; tour of the NMA with a qualified ranger; collecting feedback sheets to gather insights on the tour experience.
W2	Technology familiarisation, further conceptualisation of the problem, prioritisation of features	Oct 2023	Technology demonstrations based on focus group priorities: live camera feed from underwater, 360° footage of underwater scenes, interactive underwater VR experience, ChatGPT; prioritising features, conceptualising the problem within the group.
W3	Ideation session, interaction with first elements of the digital prototype	Nov 2023	Design studio activity where participants propose underwater telepresence applications. Group work to develop proposals; demonstration of fish detection development, live streaming footage from NMA tank, immersive VR footage from NMA tank.
W4	Paper prototyping of the immersive interaction scenarios and features	Jan 2024	Using VR paper prototyping templates and Cardboard VR headsets to prototype interactions in immersive space. Participants design interactions based on scenes and scenarios from 360-degree NMA tank footage.
W5	Digital prototype presentation, exploration of different immersive modalities	Feb 2024	Introduction to the full version of the prototype; feedback session; evaluation of different immersive experiences: VR headset vs VR Dome.
W6	Digital prototype interaction and feedback session	Jul 2024	Prototype interaction and feedback session. Participants interact with the immersive VR prototype featuring fish species recognition, game elements, and two interaction modes: relaxing and stimulating.

medieval site in Dartmoor National Park [26, 27] — our current focus is Cotehele. Managed by the National Trust, Cotehele consists of a collection of medieval buildings and historic gardens in Cornwall, deeply connected to the local community. Despite efforts to improve access to the site which includes digital solutions [24], the original construction of the site poses accessibility challenges such as narrow corridors, steep steps, and limited access via public transport.

Co-design process From August to July 2024, we held 7 workshops with 12 older and 6 younger participants, as described in the Table 2. Participants engaged in immersive VR experiences, participating in activities that explored, documented, and speculated on historical sites and their potential to promote well-being principles, such as social cohesion and intergenerational interactions. These activities included 360° video demonstrations, persona-based experience design sessions, and ergonomic testing of VR hardware for older users, leading to customised control and handling features for the Meta Quest 2 headset. We also collaborated with the Cotehele team to 3D scan and document artefacts, which will be incorporated later in the XR work package as part of further developments to develop storytelling content within the immersive environments. Further VR workshop activities are focusing on integrating locomotion and interaction capabilities, along with narrative and storytelling elements, into the final co-designed VR experience.

Design insights A VR experience involves metaphorically transporting the user to a digitally created reality, distancing them from their current physical location. This usually requires more than just the depth perception offered by a stereoscopic view in a head-mounted display. The more the user’s senses are engaged by stimuli from the digital environment, the deeper their immersion, ultimately creating a sense of place illusion or presence [21]. Moreover, prior work on VR development for heritage sites has highlighted the need to acknowledge place-based conditions of engagement, memory and storytelling, creating compelling and engaging environments that promote user engagement [27]. This became evident during the first VR experience that the intergenerational co-design group participated in. The session centered on exploring the sense of scale and space from a participant’s egocentric perspective using 360° videos filmed at various locations within the Cotehele Heritage site (Figure 2). The primary feedback revolved around the lack of interactivity and frustration with the inability to move within the virtual environment. Participants’ senses were engaged solely by the visual stimuli, while their other senses remained grounded in reality, ultimately disrupting the immersive experience.

With the addition of interactivity and navigation, immersion levels increased, but two key challenges emerged. First, unfamiliarity with VR controllers led some participants to prefer more intuitive interaction methods like hand tracking, though this came at the expense of losing haptic feedback. The second challenge was more physical, as some older participants experienced limited thumb dexterity or difficulty gripping the controller, making simple tasks — such as pressing

Table 2. Extended reality (XR) design process overview

Workshop	Stage of the Design Process	Date	Activities
W1	Problem definition, stakeholders perspective and team bonding	Aug 2023	Team bonding through a "question and answer" activity; Two parallel activities: 360° videos of a historical location; digital heritage - pros and cons.
W2	Technology familiarisation, identifying interactive elements for the experience	Sep 2023	Technology demonstrations of objects interaction and locomotion in VR and in parallel an activity of prioritising features for the VR experience using images from the Great Hall in Cotehele, conceptualising the problem within the group.
W3	Historical facts ideation, interaction with elements of the digital prototype	Oct 2023	Trip to Cotehele for participants to experience the visual, audio and feel for Cotehele's Great hall; ideation session based on facts and information presented to participants by local history experts at Cotehele; demonstration of interaction and locomotion in VR using a basic recreation of Cotehele's Great Hall.
W4	Identifying personas, Wizard of Oz prototyping of the interaction and locomotion scenarios	Nov 2023	Participants develop personas that represent the identity of the group with a focus on a primary persona, secondary persona and negative persona. Second activity was focused on exploring low level prototypes of interaction and locomotion scenarios using techniques such as Wizard of Oz.
W5	Interaction with the elements of the digital prototype, refining persona's characteristics	Dec 2023	Participants explore persona's characteristics; explore 6 unique types of locomotions in VR in order to identify the most representative for the group.
W6	Digital prototype testing, ideation activity to identify interactive historical elements in VR	Jun 2024	The participants explore a custom-developed locomotion system in VR based on their previous workshop choices; Participants explore interactive elements inside the Cotehele's Great Hall through an ideation activity.
W7	Digital prototype testing and feedback	Jul 2024	Participants interact with a custom-build interaction prototype, inside a virtual Great Hall and provide through a feedback session. Through a focus group, participants discuss the custom-locomotion implementation and identify a representative locomotion for the group.



Fig. 2. Screenshot from an early digital model of Cotehele, showcasing the interior of the Great Hall. Participants explored the environment and interaction options to understand the spatial dynamics and test different locomotion methods suited to the setting. Reproduced from [11].

the side button or using the thumbstick — more challenging. As a result, for the upcoming sessions for the XR work package, we plan to introduce a series of workshops dedicated to the co-design and integration of a custom controller — whether through unique control mapping or a specially designed controller — that accommodates the participants’ varying mobility needs while preserving the immersive quality of the experience.

3.3 Cross-track themes

Participants in both workshop tracks remained conscious of cost considerations and the accessibility of the final design. For instance, during the XR work package workshops, when the idea of adding an extra haptic sensor was raised, participants voiced concerns that it could drive up the overall cost of the design.

In both technologies, participants’ feedback highlighted the appeal of immersive spaces; however, there was a recurring tension between the desire for immersion in the virtual environment and the discomfort of feeling disconnected from the real world. In the UT track, this was addressed by allowing participants to interact with a 360° immersive portable dome (Figure 2), providing a comparison with the experience of using a headset. Similarly, participants in both

work packages consistently emphasised the importance of incorporating a social interaction component into the technology design.



Fig. 3. Participants in the UT workshop assess their interaction experience with underwater footage using a semi-portable immersive dome provided by Fulldome.pro. Reproduced from [11].

4 CO-DESIGN PROCESS CONSIDERATIONS

Throughout the co-design process duration we have collected facilitators notes and post-workshop recording reflecting, primarily, on the process of the co-design. This data was analysed using thematic analysis to extract common themes emerging throughout the workshops. These themes indicate diverse set of considerations, such as organisational challenges, as well as observations about how to improve collaboration and help participants generate and express their ideas, as summarised in Table 3.

Our analysis of the workshop facilitators' reflections following the co-design sessions provides some useful insights for developers and researchers seeking to employ similar co-design methodologies for technology development in the

future. While the methods employed were successful in engagement and co-design input and feedback, we seek here to inform future best practice through our learning.

4.1 Participant motivations

One factor that was noted were the types of motivation for participants. Understanding participant motivation has implications for recruitment and marketing strategies. The nature of the participant's engagement is also important to understand, when considering the applicability of the design to the wider population. While financial incentives did appear influential, the primary motivator was the opportunity to learn. It was noted throughout the recorded debriefs over multiple workshops, that *"there's definitely an interest in learning about technology,"* understanding that participants attended to receive this *"opportunity to learn more [...] and maybe get a bit of practical experience."*

4.2 Recruitment considerations

The reflections additionally provided useful learning points on recruitment. One such challenge was including those who are digitally excluded, who *"might just not have the freedom to engage in workshops like this because they might be working [...] it might be an access issue."* Facilitators identified *"there might be a financial [...] the costs might be too prohibitive for them to be able to commit to monthly Internet payments"* or *"it might be kind of a social components. [...] they're socially excluded and they might not see our adverts."* Some challenges were noted on recruiting younger people, who on occasion *"didn't turn up"* but were needed *"in order to have true intergenerational co-design."* One method of overcoming this issue proposed by the team was to introduce asynchronous co-design, where younger people were engaged at their college or community group, rather than expecting them to join the older people. This allowed us to work around the limited availability of the younger people by engaging with them during working hours as a part of their academic activities. Inconsistent group numbers due to fluctuating attendance were also felt to impair group dynamics for co-design discussions as *"higher numbers of people would have been useful"* *"they [...] feed on each other."*

4.3 Intergenerational group dynamic

Some interesting intergenerational dynamics were noted. While the value of older participants as representatives of the user group was apparent in the co-design setting, younger people contributed to helping to explain technologies to older adults, such as *"sensors functionality,"* and also appeared to lead on hands on activities where *"you see a lot of young people taking charge"* and presenting ideas *"to the entire room, young people kind of took it."* This demonstrates areas of value where young people can support older adults in understanding the technology or taking charge. It did appear, however, that there were natural leaders,

Table 3. Thematic analysis of researcher reflections following workshops

Theme	Codes
Motivations for participation	Opportunity to learn; Incentives
Intergenerational dynamics	Young people led hands on activities; Young people present on behalf of the group; Awareness of natural leaders; Younger people bring technology knowledge; Younger people explain technology to older adults; Some younger people harder to engage
Methods supporting ideation	Swapping groups around; Be specific in establishing groups
Methods were successful	Methods were engaging; Methods were enjoyable; Methods promoted collaboration; Methods sparked creativity; Methods promoted discussion
Methods promote useful technology feedback	Feature improvement feedback; Prototype iterations; Technology challenges; Methods allow prioritisation of technology design changes; Methods promote accessibility input
Learning points on timing	Regular sessions, momentum lost after long break; Weekend sessions and incentives for intergenerational contact; Be flexible; Less activities; Participants disengage without interaction; Older adults can get tired; Refreshments for longer sessions; Provide breaks; Shorter activities
Learning points on recruitment	Challenges recruiting digitally excluded; Challenges in recruiting younger people; Inconsistent group numbers impairs dynamic
Learning points on methods	Poor engagement with forms; Forms directed engagement; Comparison of tasks, forms preferred to templates, limited engagement with drawing; Ensure replicability; Simple tasks; ‘Empty canvas’ too difficult; Provide adequate context; Summarise previous sessions; Reduce distractions for technology interaction; Supporting understanding of tasks; Researcher involvement or demonstration to support understanding; Some people have negative reactions to technology; Teach technology use before interactive sessions; Technology bugs can cause challenges in sessions; Older adults can struggle with some aspects of the technology; More interactive introductions; Use digital feedback means as well as physical; Generic images for personas create stereotypes

who were “*very active, very knowledgeable*” and “*took charge,*”, regardless of the age. Despite mostly taking on a proactive position within the workshops, the engagement was not uniform across all the younger participants - based on researcher reflections some disengaged younger people were “[*working*] on their laptop, which may have presented a barrier to interacting with the other participants.”

4.4 Time management and duration

The reflections demonstrate some learning points on co-design workshop timing. This includes hosting sessions regularly. Within our sessions, we have allowed for two separate design sprints with a break in between (see Tables 1 and 2). This led to facilitators noting how “*momentum [...] lost a little bit*” as “*the time has passed.*”

It was also noted that future projects could consider workshops “*on Saturdays and Sundays*” “*if you want to do proper intergenerational stuff*” as “*you just can’t do it during working hours or school hours.*” This is a useful consideration to help overcome the identified challenge in recruiting younger people. Flexibility and “*wiggle room*” in the structure of the workshops was felt to “*work well*” with fewer activities also favoured, as too many activities were reported to be “*quite intensive.*”

Within the reflections, the facilitators suggested having “*1 main activity [...] rather than 3 or 4.*” A further challenge was noted around engaging participants with VR demonstrations, as we only had “*2 headsets*” meaning other participants had to wait, resulting in “*them being bored*” and “*anyone who’s sitting there because there’s no interaction, it’s like, I’m done.*” Solutions to this involved introducing additional tasks while waiting to use technologies or more providing more devices for demonstrations.

A challenge perhaps more unique to working with older adults was also tiredness, as some participants “*lost interest or they just got tired*” and “*shut off*” making the timing considerations even more important. As such, researchers noted the importance of “*refreshments*” and “*breaks in between*” to avoid “*energy kind of dropping.*” The maximum length of continuous activity session was felt to be “*20 minutes*” or up to “*45 minutes*” with “*5-10 minutes to ease them out.*”

4.5 Reflections about co-design methodology

Co-design sessions included a range of forms, templates, and tasks. There were mixed reactions to the forms that required writing, with some noting “*there wasn’t great engagement*” but others finding the forms promoted more “*discussion*” with “*less iterations*” seen on the templates. The consensus demonstrated participants did not engage well with drawing tasks at all, so these could potentially be avoided in future.

Simple tasks that were “*easy to replicate*” were advantageous and also better suited participants, as “*simpler and she understands it, and she enjoys it a bit more.*” There was interesting discussion around providing “*context*” as an “*empty*

canvas” is “*very difficult with be creative with.*” Ideas to help with context included “*demos*” and “*lineage from the previous workshops*” through summaries. It was also felt better clarity on tasks could have been useful, such as “*duplicating instructions on presentation and handouts*” and providing “*additional information*” on how to use the forms provided. A further solution was noted in using researcher as a “*facilitator,*” actually “*being involved in the design process*” to help older adults “*acting it out*”, for example, as applied to WoZ prototyping of interaction in VR space.

While efficient data collection is an important factor for co-design, keeping participant engagement high was also considered carefully, when designing the activities. Overall, the reflections demonstrate that methods employed were ultimately successful, being engaging, with some of them described as “*the most interesting workshop,*” and enjoyable, with “*personal feedback [...] that they really, really enjoyed the session.*” The methods used also sparked “*collaboration*” and “*interaction*” further to “*really creative*” ideas and “*discussion.*” As such, a wealth of useful feedback on the technologies for the co-design process was generated, including “*accessibility things that people raised*” and “*priorities.*”

There were some factors that felt particularly useful in supporting participants to ideate. One was interaction between groups, including swapping groups around and “*seeing [...] within [a] reconfigured group interaction around what the idea was.*” This allowed “*cross pollination*” and sharing of ideas from “*their previous table.*” However, it was important groups were established with sense and order, otherwise it proved “*disruptive*” when the “*movement was not organised.*”

5 DISCUSSION

Throughout the co-design process, we encountered several trade-offs that require careful balancing to ensure the success of the technology development.

5.1 Building technology awareness

Given the ICONIC project’s target audience of digitally excluded individuals, it is crucial to raise knowledge and awareness of technological possibilities among our participants to empower them to generate ideas in a more informed way [15, 23]. With each workshop, participants gained greater knowledge and confidence, allowing them to focus more deeply on co-creation. As a result, later workshops required fewer technical explanations and details.

Striking the right balance between the educational aspect of the workshops and co-creation was essential. For instance, participants needed to be comfortable using VR headsets in order to express their preferences for interaction elements. Given that many participants had no prior experience with VR, we organised additional one-on-one training sessions to familiarise them with the technology.

However, there is a risk of introducing specific technological solutions too early, which could limit creativity and exploration [20]. To avoid this, in the UT

track, the first session was dedicated entirely to participants' previous experiences with the marine environment and included a tour of the National Marine Aquarium, without engaging any technology. Including additional elements of technology later in the co-design process also supported discussions focusing on the platforms employed by the technology, with users highlighting how the use of an immersive dome could support a more social experience than the use of a VR headset.

5.2 Co-design methodology

The methods employed in the UT and XR co-design workshops have provided valuable insight into the priorities and preferences of our participants, who each have varying levels of digital expertise and familiarity. The iterative approach to co-design has been beneficial in the development of both technologies, as this method engaged participants and allowed them to track the technology development from the early ideation stages through to more refined iterations of the technology, which provided greater insight into technology design. Iteration is a core element of co-design as it enables a continuous dialogue between participants and developers, ensuring that co-design participants feel ownership over the product and that their contributions have a direct impact on its development [22]. For example, during our workshops, participants were presented with early versions of the technologies, which they were then able to critique and modify. By recording their feedback across a range of modalities, we ensured that the evolving technologies were aligned more closely with user preferences and needs expressed during workshop activities.

Additionally, building flexibility into co-design workshops has been extremely beneficial, allowing workshop facilitators to respond to participant needs. This has been particularly important given the variation in digital experience and familiarity across our participants, which has required workshop facilitators to adapt activities to meet the needs of participants. For example, when participants in both the UT and XR workshops highlighted the difficulties that they experienced using the VR headsets, we provided supplementary one-on-one sessions for participants to provide further opportunities to become familiar with the VR systems at their own pace. In addition to upskilling participants, these sessions may have supported participant confidence in the co-design process [19], and ensured that participants could contribute meaningfully to the design process, irrespective of their prior experience with digital tools.

The flexibility of approaches in co-design workshops also proved beneficial in tailoring activities to participant engagement. Some activities involved repetitive form-filling which led to disengagement from some participants, so it remained important for the facilitators to remain aware of this and respond accordingly by introducing more varied activities in subsequent workshops. Incorporating varied activities, such as hands-on interaction with prototypes, storytelling sessions, and collaborative sketching exercises, helped mitigate these challenges and catered to differing learning styles across participants [20].

5.3 Balancing the practical limitations

While it is ideal for participants to contribute imaginative ideas during the ideation phase of the co-design process, practical constraints inevitably arise during development [20]. In our case, the primary constraint was development time, as each technology was being developed by a single researcher. We found that participants were open to discussing the project’s limitations and the defined scope for the initial prototype, while maintaining their creativity and imaginative thinking. Indeed research has shown the benefits of constraints in the co-design process, as the limitations may lead to more creative solutions to design problems [17]. Furthermore, it is often possible to identify the underlying motivation behind suggested features and explore alternative ways to implement them. For example, in one of the UT workshops, participants proposed the idea of social interaction in the marine environment using avatars. While we were unable to implement this feature directly, it highlighted a clear interest in incorporating social interaction into the design.

5.4 Representation and recruitment

The representation of our target population — older, digitally excluded individuals — is somewhat limited within our cohort of participants, as our sample consists of participants who volunteered for the workshops and therefore had some level of motivation for engaging with technology [23, 12]. While their participation offers valuable insights from those actively engaged and interested in the project, it may not fully capture the perspectives of individuals less inclined to take part. This may in part be due to motivation, as models of digital exclusion suggest that digital engagement is closely tied to an individual’s attitudes and motivation towards technology use [23, 12]. To address this, we plan to hold additional co-design sessions to ensure the design aligns with the preferences of a broader audience.

Additionally, despite focused outreach efforts, we have encountered challenges in engaging certain groups, particularly younger individuals who have limited availability due to work or educational commitments. To address this, we are extending outreach to more local educational organisations and organizing separate sessions for younger participants, experimenting with an asynchronous intergenerational co-design approach [6], which would support the inclusion of participants that might otherwise be unavailable to join current workshop sessions.

5.5 Intergenerational interaction

Whilst we were unable to maintain a strong, consistent intergenerational presence within the workshops, the intergenerational interactions that did take place were valuable. This included younger people sharing their knowledge about relevant technologies with older participants to educate them, providing younger

participants with the opportunity to demonstrate their expertise. These intergenerational group dynamics generated valuable contributions for the co-design process, and often involved younger participants taking the lead in workshop activities [9]. Despite the trend of proactive younger participants, participants of all ages contributed to group leadership within workshop activities, ensuring intergenerational.

The inconsistency of the intergenerational component did present some difficulties, shown by varied engagement during workshops and attendance by younger participants. In some instances there were few younger participants within the workshop, meaning there was an imbalance in intergenerational contact for participants. It is therefore important to find the right approaches for engaging both generations [13] in order to facilitate constructive intergenerational interaction within our workshops, supporting inclusive technology co-design.

6 Conclusion

Technology co-design is a complex but highly promising approach to developing effective technological solutions. Our participants, both young and old, bring unique and invaluable perspectives, drawn from their own life experiences. Their differing preferences and limitations are crucial at all stages of the design process from the problem definition to the final evaluation. The main challenge of technology co-design, especially when designing with digitally excluded or vulnerable communities, is that the participants are not experts in digital technology. However, by addressing key challenges and trade-offs of the co-design process — such as ensuring participants grasp both the possibilities and practical limitations of technological solutions — we can effectively involve the general public, especially older adults, in creating digital technologies.

In the ICONIC project, the next steps involve further more formal evaluation of the technology prototype to evaluate the success of the co-design, as well as deeper analysis of the collected data, to, for instance, identify the patterns of the intergenerational group interaction and establish their impact of the technology co-design. This will allow us to offer even more comprehensive view of the technology co-design methodology.

Though the co-design process within the ICONIC project is still ongoing, we have already gained significant insights. Over time, the workshops have become more efficient as we identified what methods work best, how to keep participants engaged, and how to empower them to take an active role in the design process. These lessons not only inform our current project but also offer valuable guidance for future co-design initiatives, particularly for those targeting digitally excluded and underserved populations. We hope that our findings will help researchers and practitioners involve users meaningfully in technology design, regardless of the technology’s complexity or the levels of participants’ digital exclusion.

7 Appendix: Full table of themes, codes and example evidence

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
Motivations for participation	Opportunity to learn	<i>“as an opportunity to learn more about these things that they’re seeing about and maybe get a bit of practical experience.” “There’s definitely an interest in learning about technology.”</i>
	Incentives	<i>“they get quite a lot”</i>
Intergenerational dynamics	Young people lead hands on activities	<i>“interesting [...] to see patterns through workshops, anything that’s hand related where they need to do some sort of activity with creating something paper prototyping [...] You see a lot of young people taking charge of them”</i>
	Young people present on behalf of the group	<i>“when it came to presenting to the entire room, young people kind of took it.”</i>
	Awareness of natural leaders	<i>“He’s very active, very knowledgeable [...] he took charge.”</i>
	Younger people bring technology knowledge	<i>“Younger people why know a lot about technology [...] they [bring] confidence.”</i>
	Younger people explain technology to older adults	<i>“The young person explains sensors functionality in a VR headset.”</i>
	Some younger people harder to engage	<i>“We need to find ways to facilitate intergenerational interaction – the younger participant in this workshop worked on their laptop, which may have presented a barrier to interacting with the other participants”</i>
Methods supporting ideation	Swapping groups around	<i>“Seeing that within kind of reconfigured group interaction around what the idea was” “I overheard people bringing their ideas from their previous table across and discussing them.” “Cross pollination.”</i>

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
	Be specific in establishing groups	<p><i>“The process of that was disruptive. I think we could’ve been more systematic with just saying you, you, you move, everyone else stays where you are.”</i></p> <p><i>“because movement was not organised, we ended up with like half the table there half the table there”</i></p>
Methods were successful	Methods were engaging	<p><i>“I told you about one of the participants when we went for coffee halfway through they said is the most interesting workshop they’ve done.”</i></p> <p><i>“Good workshop attendance and engagement.” “enthusiastic engagement”</i></p>
	Methods were enjoyable	<p><i>“I got personal feedback from people saying that they really, really enjoyed the session.” “she was quite enthusiastic about it.” “They really love the format”</i></p>
	Methods promoted collaboration	<p><i>“I’ve seen collaboration” “I really like seeing the interaction between like the tables”</i></p>
	Methods sparked creativity	<p><i>“I have to say that some suggestions were really creative.”</i></p>
	Methods promoted discussion	<p><i>“you could see that they’re talking” “focusing on the form quite a bit through discussion,”</i></p>
Methods promote useful technology feedback	Feature improvement feedback,	<p><i>“I think we can safely say with the music, if no one specifically wanted it, we can chop it.”</i></p>
	Prototype iterations	<p><i>“Obviously they’re well aware that there’s further progress to be made, and I hope in the feedback forms they’ve given us some direction for that.”</i></p>

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
	Technology challenges	<i>“That idea from them, because it always comes up, options, [...] but the more options you have, the more clunky application is” “It’s not at all the good design for what we’re trying to do. I don’t think there’s a VR headset that doesn’t have that kind of menu button”</i>
	Methods allow prioritisation of technology design changes	<i>“I can trawl through the workshops, pick out all the priorities preferences. And get people to do card sorting type thing getting referenced onto cards. Give each get about two or three groups, give them a set each and then they rank.” “Prioritize how they want it.” “See what features we don’t have in there”</i>
	Methods promote accessibility input	<i>“A few other accessibility things that people raised”</i>
Learning points on timing	Regular sessions, momentum lost after long break	<i>“This momentum we lost a little bit” “I think they’re already out of this mind space [...] it’s the time has passed.”</i>
	Weekend sessions and incentives for intergenerational contact	<i>“if you want to do proper intergenerational stuff with did you excluded people, I think you’re just going to have to do it on Saturdays and Sundays, give proper incentives and so on and so forth. You just can’t do it during working hours or school hours, so.”</i>
	Be flexible	<i>“Build in a little flexibility.” “Timings worked really well as well, just having that little bit of wiggle room really helped.”</i>
	Less activities	<i>“try to be a slightly less optimistic with what we’re trying to fit in” “it was quite intensive” “1 main activity that was gone rather than having maybe 3 or 4 [...] It was the right level” “even just scaling down the amount of sort of demos”</i>

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
	Participants disengage without interaction	<i>“So we do 2 headsets and they just going to sit down and just going to take their time like 15 minutes.” “But funny enough, anybody who’s sitting there because there’s no interaction, it’s like I’m done.” “The risk of them being bored.”</i>
	Older adults can get tired	<i>“They lost interest or they just got tired” “Got really stress and then she kind of shut off.”</i>
	Refreshments for longer sessions	<i>“two hours sounds like a lot of goes in the blink. If we just have stuff like refreshments just ongoing”</i>
	Provide breaks	<i>“Activities we still need to break them with a break in between” “they’re sitting for too long” “activities [...] 45 minutes with [...] 5-10 minutes to ease them out” “problem was its energy kind of dropped”</i>
	Shorter activities	<i>“That needs to be like 20 minutes Max, half an hour Max. Not more than that. And that if you have two activities like that.”</i>
Learning points on recruitment	Challenges recruiting digitally excluded	<i>“Generally speaking, they’ve not been fully digitally excluded. They’ve had elements of digital exclusion, but [...] they all have computers, they all have the Internet and they know how to use them.” “people that are digitally excluded might just not have the freedom to engage in workshops like this because they might be working stupid hours because they can’t because it might be an access issue” “There might be a financial the costs might be too prohibitive for them to be able to commit to monthly Internet payments and so on and so forth.” “so it might be kind of a social components. [...] they’re socially excluded and they might not see our adverts.”</i>

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
	Challenges in recruiting younger people	<i>“It’s very frustrating with our younger participants didn’t turn up.” “We need an additional young participant in order to have a true intergenerational co-design.”</i>
	Inconsistent group numbers impairs dynamic	<i>“I think higher numbers of people would be would have been useful to have a better” “They will feed on each other.”</i>
Learning points on methods	Poor engagement with forms	<i>“There wasn’t great engagement with those forms.”</i>
	Forms directed engagement	<i>“And they focus on that quite a bit and then they switch to trying different things with the headset. [...] interesting to see because there are kind of two different Avenues, 1 focusing on form and then focusing on the on the headset itself.”</i>
	Comparison of tasks, forms preferred to templates, limited engagement with drawing	<i>“I’ve seen them focusing on the form quite a bit through discussion, so it was less iterations on using the 360 template and you know putting it on and trying things and then talking about it was all more about the process thinking process” “they didn’t draw on the forms.” “they didn’t really do iterative process at all.”</i>
	Ensure replicability	<i>“It’s again a process that might be a little bit more easy to replicate.”</i>
	Simple tasks	<i>“simple activities will help them a bit more.” “But this is simpler and she understands it. And she enjoys it a bit more”</i>
	‘Empty canvas’ too difficult	<i>“Empty canvas like that. It’s very, very difficult to be creative with that.” “The demos so we can show them how to interact with them. It’s not always working, but I think the context is missing because it’s very difficult for them to be creative with the empty space in front of them.”</i>

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
	Provide adequate context	<i>“probably it would be an interesting thing to give them a bit of context around things because I think maybe that’s one element that was missing either to do an activity”</i>
	Summarise previous sessions	<i>“So one of the ladies, she was saying that she would. She would appreciate more detail about the previous workshops” “put together a quick summary of what happened”</i>
	Reduce distractions for immersive technology	<i>“But you need to have the room quiet so you bring them in one by one”</i>
	Supporting understanding of tasks	<i>“Duplicating instructions on presentation and handouts” “future planning is having like either the activity on it” “We could have more formally ‘announced’ the activities” “Participants need additional information on how to use the persona form.” “participant states that doesn’t understand the point of this exercise, he lost motivation”</i>
	Researcher involvement or demonstration to support understanding	<i>“Do we need the facilitator to be the computer or the persona, perhaps?” “no participants are moving around the room, they prefer it as a mental exercise, rather than acting it out. (Do we (the facilitators) need to be involved in the design process? Do we need to act as the computer in the co-design process?)”</i>
	Some people have negative reactions to technology	<i>“Some people did say about nausea” “some people felt discomfort.”</i>

Table 4: Full table of themes, codes and example evidence

Theme	Codes	Example Evidence
	Teach technology use before interactive sessions	<i>“The manual selection was unintuitive was kind of breaking the interaction bit, so it kind of overshadowed in some parts the whole other experience” “others especially struggling and all that, they had to spend some time like getting there. And I think that explained the huge disparity in what people said.” “so I still found some people were not very fluent with the controllers. This was mitigated when I figured out later that I should show them all controller before and explain them exactly what the direction will be and also bring in the the table and show”</i>
	Technology bugs can cause challenges in sessions	<i>“There was a little bug with it” “some participants highlighting the issues with the perspective (not matching their actual height, giving them a “floaty” feeling).”</i>
	Older adults can struggle with some aspects of the technology	<i>“Some participants couldn’t (literally) grasp the interactions with the Quest controllers; participants” “Yeah, she keeps saying it’s too complicated. It’s too many buttons, so she’s struggling with that bit.”</i>
	More interactive introductions	<i>“We could have made the introduction talk more interactive” “But they still want some sort of their activity. They want activities”</i>
	Use digital feedback means as well as physical	<i>“And maybe a different thing to vote, because these stars are very difficult. I’ve got chubby fingers, like probably do that online, on screen”</i>
	Generic images for personas create stereotypes	<i>“one participant mentioned stereotypes in the use of generic images for the personas. He believes that using a particular image leads to stereotypes.”</i>

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