From Immersion's Bleeding Edge to the Augmented Telegrapher: A Method for Creating Mixed Reality Games for Museum and Heritage Contexts

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Immersive technologies can be used to broaden the possibilities of storytelling in heritage contexts, to enrich the ways in which museum collections are interpreted, and to facilitate more active engagement with history. To this end, as part of the United Kingdom's Industrial Strategy, new models, methods, and workflows are being developed to help realise the value of such technologies across the country. However, prior art shows that immersive technologies present particular challenges with respect to usability, uptake, on-boarding, sustainability, and authenticity. Towards addressing these challenges, a programme of action research has been established across a series of museums in Cornwall. Focusing upon the Augmented Telegrapher at Porthcurno Telegraph Museum, a co-designed social escape room experience that utilises the Microsoft HoloLens to simulate a telegraphy training exercise from World War 2, this article addresses what partnerships with smaller, rural establishments need to effectively realise the value of immersive technologies. Using the work of Erik Champion as a critical lens, the article shows how an iterative constructivist approach leveraging game design principles can underpin success. This is distilled into a set of recommended interaction blueprints and transdisciplinary working practices that will be of interest to curators, researchers, and serious game developers.

CCS Concepts: • **Human-centered computing** → **Interaction design process and methods**; *Mixed / augmented reality*; HCI design and evaluation methods; • **Applied computing** → *Arts and humanities*; • **Software and its engineering** → Software development methods.

Additional Key Words and Phrases: Immersive, Interaction Blueprint, Method, Mixed Reality, Museum, HoloLens, Telegrapher

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1 INTRODUCTION

Across the museum and heritage sector, immersive technologies developed for the creative industries are becoming increasingly useful and accessible tools. They can be used to assist core curatorial tasks such as interpretation and conservation of collections and artefacts. There is also a growing general awareness across the sector that the deployment of creative industries technologies and design expertise will help to meet contemporary audience expectations, making the sector's offer more attractive to 'free choice' learners [14, 15] as well to those looking for an entertaining, engaging experience. Making room for such strategic changes through greater interdisciplinary

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collaboration has clear value for institutions, curators and trustees, not just to engage more effectively with their audiences but also in support of their plans to attract the investment needed to protect and conserve their collections. Engagement with creative industries technologies to assist conservation alongside enriching and diversifying visitor engagement is widely regarded as necessary if the sector is to create the conditions for future sustainability.

Working with far more limited resources, this does however present smaller museums with a significant challenge in both resourcing and internal culture change. In all cases what is required is the development of a body of knowledge based on the critical evaluation of practical design solutions developed for individual museum contexts [7, p. 11]. In addition, through the course of our museum-context design practice, we have developed in discussion with our museum partners a number of prescriptions for workflow methods for co-design and user testing which aim to bridge some of the gaps between game development and the context of museum and heritage. Developed specifically within an interdisciplinary context, such knowledge aims to support the sector in its goal to bring their collections and sites to life for modern audiences through the use of creative industries technologies and interaction design in cost-effective, creative and resourceful ways. Our overarching collective mission for this research is for heritage sites and museums to be valued by the public as cultural providers because they effectively bring the past into the present, using, what Erik Champion calls, 'contextually appropriate interaction' [7, p. 12].

The research reported in this article aims to address the following question: *What methods are needed to effectively realise a social immersive cultural heritage installation in a small, rural museum context*? The case of the *Augmented Telegrapher* approaches this question through three perspectives: (i) the strategies to interpretation representation that are needed to effectively utilise the affordances of immersive technology, (ii) the approaches to design authorship which are needed to address issues surrounding difference in audience expectations and literacy, (iii) the methods needed to mitigate the risks associated with complex technologies, as well as (iv) interdisciplinarity and interprofessionality.

As a group of academics and researcher-practitioners with a collective background in games, computing, interaction design and the humanities, and currently working to support the heritage sector, the authors have found that the co-location of pedagogical theory, experience/game/interaction design and development, alongside curatorial practice has generated sometimes unexpected challenges and affordances. Methodological, discursive and conceptual differences between the various modalities are much in evidence; working together across disciplinary and sectoral divides is nonetheless a rich proving ground for design and user testing of emergent technologies. This context has the additional bonus of providing a comparative means of critical reflection that is challenging some of our basic assumptions. These differences coalesce around: methods and practices of interpretation; the ways in which we understand users (users v. visitors); literacy and technicity; conceptions of authorship; approaches to development (waterfall v. agile); frameworks such as approach to timescales in terms of testing and implementation. We will go on to discuss these nodes of difference in detail throughout the paper. Throughout our collaboration with the sector, we have encountered and found ways (to varying degrees of success) around problems arising from the rapid changes in the support of 'cutting edge' technology and the general skill sets of museum staff and volunteers who must manage any technology used on-site.

The foundation on which this paper's analysis rests is a collaboration between a British Museum, The Telegraph Museum, based in Porthcurno, Cornwall UK, a group of game development specialists working in academia from the Games Academy at Falmouth University, and a regional museum advocacy and development agency, Cornwall Museum Partnership (CMP). Cornwall is a rural area based at the furthest South-West tip of the country and is an area dependent on tourism. These three groups worked together to conceive of and develop an 'escape room' experience based in the 'tunnels' located at the Telegraph Museum (PTM). Thereby we undertook our research through the practical and iterative development of a commercially viable group co-located immersive experience. The project took place over a two-and-half year period and was funded by two grants from the

Arts and Humanities Research Council which were then extended into a further collaboration funded by the Coastal Communities Fund, to which the Local Enterprise Partnership became an additional partner to provide five Cornish museums with immersive content. Based on that collaboration as a form of primary research, this paper evaluates the technical and cultural learning that we gained in designing and developing an immersive game experience using Microsoft's HoloLens, virtual reality and beacon technologies in the context of a museum. Central to this evaluation is our diagnostic examination of the synergies and dissonances that arise when curation, culture, and computing are brought together.

It is therefore the aim of this paper to share what we have learned from our on-going experience of working on a collaborative long-term immersive experience project for the benefit of museum and heritage managers, trustees and curators, academic researchers - museum, cultural, computer and game studies as well as the digital humanities, in addition to designers and technologists, and businesses looking to partner with those in the museum and heritage sector. We hope that our evaluation will help others working to create immersive experiences across sectors.

2 LITERATURE REVIEW

There is a considerable body of prior art, with recently published reviews highlighting the widespread application of immersive technologies in cultural heritage contexts [2, 16]. Existing research on the use of immersive technologies and design in museums fall broadly into two main categories. The first focuses on the development of virtual museums, online collections or on the use of Virtual Reality or Augmented Reality as a means of remotely touring a site [8, 9, 33]. Using augmented reality (AR), Nguyen [31] places the users as witness of a historical battle. The second group shifts concern to the use of game design as a means of creating a more participatory experience for players [1, 4, 35].

The *Augmented Telegrapher* represents a movement into an emergent third group, where game mechanics are integrated into Mixed Reality on location. While guidelines already exist to guide such endeavours, they tend to focus on digital storytelling (e.g., [39]) and seldom make reference to the challenges and opportunities presented by immersive technology. As such we follow Kidd and Neito's [20] research review of immersive experiences, which finds that interaction provides an important tool for immersive experiences in museums. As Barbara [1] demonstrates, VR and AR in museums is rarely leveraged to provide agency for visitors. In support of the development of greater user agency in the immersive context, as game designers, we take up Barbara's provocative challenge to develop strategies to support a model of co-design for interaction that involves not only end-users (visitors) but also museum curators, historians and staff.

It is only recently that it has been possible to create collaborative, multi-user mixed reality experiences, as such there is little research in this area. There has been some research on the technical tools and design for multiplayer collaborative AR-based educational escape rooms, notably the Amelio project at Tilburg University [34]. The project sought to develop team building experiences and evaluate Unity tools. It was not designed for a public museum space.

Haptics have been a feature of some museum installations, including the use of haptics for handling fragile objects at Manchester Museum developed by Touch and Deliver systems. Given the importance placed on the inclusion of both the tangible and intangible as integral to cultural heritage, we have experimented with bringing together character, story, puzzles along with real objects in our escape room design. As such our research question arises out of the gaps left between the different modes of research in the museum space and through mixed reality, we can synthesize elements to produce a step forward in immersive design research.

2.1 Immersion expectations and Museum Contexts

A primary factor that informs the movement towards a more pervasive use of creative industries technologies as interpretative and curatorial tools is found in the now widespread cultural appetite for user-centred immersive experiences. As we will argue, such an appetite leads to a mode of practice that suits very well the milieu of 'free choice learning' that characterises visitor engagement within heritage and museum contexts [14].This expectation is also where game and interaction design can provide the know-how, methodologies and expertise that can help address the nature of the need [7, p. 14] [8] games are after all largely responsible for the creation of this widespread cultural appetite. As Rabbie Hier, founder of the Museum for Tolerance in Los Angeles, noted back in 1993, 'we have to use the medium of the age' (cited in [46, p. 355]). While smaller museums may not have access to such expertise or indeed the resources to make games that 'synthesize narrative, conjecture computer-generated objects, contextually constrained goals, real-time dynamics data, and user-based feedback' [46], one of the conclusions of this paper is the pressing need for an open-source platform alongside a blueprint for working methods that supports diverse forms of immersive development to include those with minimal resources. In addition to which we argue that AR in particular is becoming increasingly within reach across the whole sector and this needs relevant support.

'Immersive' experience development has been high on the Creative Industries agenda in the UK, with the support of the 'Audiences of the Future' Industrial Challenge fund; this sponsored activity reaches across sectors and brings together a range of different disciplines. While this aims high, upwards to showcase technical innovation and design sophistication, it also marks a growing culture of cross-sector and interdisciplinary collaboration in the museum and heritage sector.

2.2 Defining Immersion

The concept of 'immersion' has become common currency in contemporary culture and has been adopted by both creative and heritage industries making use of a term that arose from the latest round of virtual and augmented reality headsets, developed by Oculus, Microsoft and Magic Leap. This idea is now deeply embedded in the arts and humanities, and although there are debates about the rhetorical use of the term, in the main, is commonly used to refer to a sense of being transported by the power of sounds, words and/or images into a fictional world or space. Even in the early days of virtual reality however, distinctions were made between perceptual immersion (fooling the senses), as Howard Rheingold [38] and Alison McMahan [25] noted, as opposed to a more fragile sense of deep emotional engagement with events in the fiction [30]. Games aim to create a multi-levelled sense of immersion for players: often games solicit cognitive engagement through their gameplay mechanics and while a more emotional engagement is developed through the players connection to their game character and through the design of the environment in which the mechanics appear (see [22]). We have sought in our practice to bring such tried and tested methods to our work with museum partners.

Immersion is regularly conflated with 'presence', 'suspension of disbelief' or 'transportation'; these terms are certainly overlapping and in general sense refer to a set of properties that are regarded as synonymous with expectations of contemporary media. It becomes clear when extrapolating from debates around immersion within game studies and the digital humanities [23, 25] that the immersion gains its contemporary rhetorical power not just in relation to the power of a fictional aesthetic experience but also in terms of a powerful perceptual and interactive experience. In this the experience expected is more than simply the use of supplementary interactables in the museum space. As articulated by the blended reality, haptic-based 'escape room' experience that we have created within our collaboration, our working and situated definition of immersion has come to mean: a structured experience that through story and game mechanics enhances a sense of presence in the location and which seeks to transport to some extent users into a historical dimension where they are active participants who gain a palpable sense of the types of activities that were carried out in the location.

Fig. 1. Porthcurno's tunnels, dug and built in just 10 months to withstand a bomb blast.Photo ©The Porthcurno Collections Trust 2019, Telegraph Museum, Porthcurno.

We set out to create an immersive and engaging experience for players using a number of different methods unified by narrative and using the affordances of the HoloLens. We sought to create historical relevance for the players by overlaying computer-generated assets (artefacts such as a ship at sea and a galvanometer device) in the real space of Porthcurno Telegraph Museum's tunnels, built in WWII to house vital global communications technology (see Figure 1). We gave players tasks which required physical and mental dexterity to undertake, placing those players in the shoes of new communications recruits, thereby mimicking the tasks undertaken in the location during World War II but facilitated by a combination of the headsets and real objects. In addition we wove a narrative around a set of puzzles that needed to be solved, with the aim of creating both cognitive and emotional engagement. All of these aspects were deployed to encourage players to enact tasks conducted by those in the past, cast in an adventure game format, thereby augmenting an already strong sense of presence provided by the player's location in the tunnels.

2.3 The Charge of Immersion as Spectacle

The current cultural desire for immersion is however one that has attracted criticism and is often seen by critics in terms of a consumer-focused distraction [36, p. 514] that is far from educational in intention. Museums who deploy interactive and immersive installations can run the risk of appearing to some as wanting to privilege footfall over education. Some critics have regarded the heritage industry as buying too heavily into postmodern spectacle, wherein the heavy complexities of history are cast off in favour of in authentic theme park aesthetics. This is a potential charge that as developers of a blended reality game in a heritage context we take very seriously. The novelty value of augmented technology and its seeming magical ability to put convincing geometry in real space along with the concomitant narrative and game mechanics could very possibly overshadow the everyday realities of what it was like to be working at Porthcurno during World War II. However, unlike the concept of the virtual museum, our design intention was very much to work in the real location and for the players to undertake tasks that while not fully simulated nonetheless gave a real sense through both cognitive and sensory experience of the place and what happened there. Players must work to actuate this experience, work quite hard in fact, so that this is not a case of simply luxuriating in ready-made image. Instead, the player is active emotionally, creatively and cognitively in the construction of meaning. As such we aimed to create a context for meaningful and focused activity, lending to the user a palpable sense of lived reality admittedly couched as a story but one that puts the player in more direct contact with the purpose of the telegraph station as a kinetic means of cutting through what we might call the opaqueness of history and place. That the experience is a mediated one should not in itself be denigrated, mediation providing the nub of postmodern critiques of consumerist culture; it was very important to us as developers that our designs adhered to constructivist notions of learning providing for players the fuel for rich interpretational and improvisionational activity of the type found in role-play formats and a strong sense of problem-solving agency, chiming therefore with the approach demonstrated by many of the telegraph station's staff working at their own time's bleeding edge of communications technology.

Various cultural commentators have drawn our attention to an escalating expectation for an increase in the perceptual fidelity and novelty of computing-based immersive experiences. Simulation has often been a guiding trajectory in graphics and physics modelling, demonstrating what Tom Gunning has noted of early narrative cinema, a tendency towards an aesthetics of what filmmaker Sergei Eisenstein called 'illusory imitativeness' [45, p. 66]. This has certainly driven technological development in games and also the ways in which some games technologies are marketed and indeed recycled (bigger, brighter, more convincing graphical environments). We can therefore trace the cultural appetite for immersion through these channels and this is a key to opening new and under-engaged markets for the heritage sector. As Benardou et al [3, p. 1] identify, a growing number of museums, galleries and libraries are seeking to leverage, 'the capabilities of contemporary technologies in visualizing and representing cultural objects beyond text, and occasionally borrowing ideas from the entertainment industry.'. However, the novelty value of new immersive technologies to the leisure market to which museums that charge want to appeal comes at an additional price – both in terms of support from hardware developers and in terms of reliability. We go on to evaluate our particular encounter with the bleeding edge of immersive technology below in 3.0.

2.4 Authorship versus User-led design

We have changed quite profoundly our approach to the development of immersive experiences within the museum context since we began our work on Augmented Telegrapher Escape Room experience. We've moved away from a more authorial, artist-lead approach to a more community-based approach. This was in part because we needed to work with the practices that museums adhere to as best practice in their strategic approaches to appeal to their audiences. Along the way other benefits emerged, including creating a context where we could fold together more effectively our diverse skills and approaches. We've moved from working in parallel with our museum partners

towards the implementation of a more integrated ecosystem and in so doing we have avoided the bear-trap of a behaviourist model of education and practice that the artist-lead model tends to lead to. As such our approach to user testing and evaluation has also altered (discussed below in 4.0).

Throughout our collaboration, we have continued to ask how it is that we can create more meaningful content with our museum partners. What we aimed to do was create something more than simply a bit of virtual spectacle, instead to develop what Champion calls an 'experiential learning mechanism' [6, p.1]. The aim of which is to bring together the specifics of place, realism and culture, through a deep and highly appropriate form of interaction. Arguing in contrast to the postmodern critique, Mosaker [29] suggests that simulated spaces don't necessarily in their own right create user enjoyment, content might have a realist caste, but in a museum context it is authenticity that matters. As Champion [6, n.p] notes in his consideration of the meaning of culture in digital heritage, 'the purpose of heritage is not just to preserve but also to communicate cultural significance' advocating that realism needs not only to be graphical but must also provide 'contextually appropriate interaction'. Therefore, and building on Champion's diagnosis, the axiom that we conclude that best fits the augmented and immersive bill in a specific museum context is that 'being there' must be located in a specific there (ie spatially) and in a specific then (ie temporally). We would argue that Augmented Reality technology is rapidly becoming the best way to achieve this and therefore is what defines 'immersive' in this context. This does however need a bespoke framework to support its contextual specificity.

3 THE AUGMENTED TELEGRAPHER

3.1 From interactables to a more fully realised experience

Functional head mounted displays (HMD) have been around since the mid 80s. One of the most notable being the NASA VIEW system, a full stereoscopic head-tracked HMD that filled an entire room, required numerous engineers to operate it and achieved reasonable low performance in terms of tracking and display latency. The development of immersive technologies has been comparatively slow compared to other technologies such as personal computers and mobile phones. However, mobile rapid growth in consumer mobile technologies has been instrumental in the recent immersive technologies boom. Many of the modern HMDs could be thought of as mobile phones with novel displays. The advantage of the HMD for delivering augmented content has the advantage of lining up directly with the user's eyes and filling the whole vision, making for a more convincing experience than available with a phone or tablet. This can then be utilised within an Escape Room context to position computer generated imagery and sound directly and convincingly within the space in abeyance to the laws of perspective.

3.2 "The original HoloLens will no longer receive major OS updates": Affordances and limits.

With the introduction of HoloLens version one in early 2016, Microsoft shifted the landscape of augmented reality (AR) by producing the first commercially viable, embedded, inside-out tracking AR HMD. The screen technology was fairly standard and lines up with many other smart glasses style products of the time. The biggest innovation was the tracking system to which the lineage can be traced back to the Microsoft Kinect controller. The tracking system works by combining the data from a depth sensor that has a 120° angle of view with four other environmental sensors. One of our major issues lay in the lack of technical support for the admittedly Beta first HoloLens; while we welcomed the freedoms of the HMD and its incredible potential for museum contexts, there were often hurdles to overcome to get the software working and for the headsets to sync up in group task contexts.

A key advantage is that with inside-out tracking there is little to no setup. Users can place the HMD on their head and immediately begin to move around and interact with holograms in the AR environment. They can move from room to room and the spatial mapping algorithm will ensure that any holograms placed in different

rooms persist for the users next visit to that space. The freedom to move and the ability to create an experience that could potentially map to the whole space of a museum is appealing in terms of interpretational affordances and spatial constraints.

The HoloLens has three modes of user inputs: speech recognition, gaze tracking and basic gesture input. By default, the HoloLens recognises two hand gestures: 'bloom' to open and close the main menus and 'air-tap' to select objects in the centre of the user's gaze. Previous research suggests that these gestures are not intuitive enough for new users to pick up straight away and require some training or practice. The gestures are adequate for general use in a context where there is time to learn the subtle nuances of the interface. For gallery, library, archive and museum(GLAM) spaces, on-boarding is critical and should be immediate. Within the context of a museum, we cannot afford for visitors to struggle with the HMD's complex revolutionary interface. To solve this problem we developed a method of interface that lies with sensors placed on a series of real objects that provide the interface for the users. The value of this was surprisingly important in the context of a museum where a great deal of cultural and meaning value is invested in material objects. The objects pay homage to the museum's existing collection through thematic and aesthetic alignment.

All efforts were made to ensure that players could on-board easily. However, some framing of the escape room theme and overall experience was also deemed necessary. In order to familiarise players, an orientation character was developed who can be seen and heard at the start and end of the experience (see Figure 2). This animated character was designed to have a dynamically realistic size and scale to appear to occupy real space to keep in correct perspective as the player moves around the room. Unlike film, there is no predetermined framing of the character (close-up, mid-shot etc.) but even if the player looks away, they will still hear his voice; this gives players a sense of being a 'free agent' within the space. The character was based broadly on an actor popular in British films of the 1940s, David Niven. However, his face and form were based on data capture from one of the team and is voiced by an actor. His clothing is relevant to the location and date that the experience is set in (1943). The script for the experience was developed as a collaboration with Cornwall Museum Partnership and the curatorial team from Porthcurno, alongside game writing tutors within the Games Academy at Falmouth. The use of the character to directly address to players lends a diegetically cogent means of signposting and context, as well as keeping players focused on relevant tasks. Unlike VR's ability to visually surround the user, the limited window provided by the HoloLens, does however rather break the illusion of this character's presence because, if the character is seen close-up, the limits of the screen become all too apparent (HoloLens 2 promises a solution to this letterboxing). As well as reinforcing a sense of lived history within the tunnels location, this character was designed to act as a narrative device to help deliver the story that wraps around the various puzzles. The character functions as a foundational support to the interaction design and as a method of feeding back to players on their progress. In addition, he helps players connect and empathise with the experiences of those who lived and worked at the Station through the war, tallying with VR filmmaker Chris Milk's claim that the immersive storytelling can aid in sharing the experiences of others outside of our own lives [27].

3.3 Why escape room? Site Specific decision rationale/explain approach.

Real-life escape rooms immerse players in a world of cooperative problem solving. An overarching theme, a coherent narrative and an impending disaster that can with alacrity be averted, drive player motivation while a variety of distinct but related puzzles provide the gameplay (see Figure. 3 for a hologram used for one these puzzles). Despite the cooperative nature of escape-rooms, teams still compete to complete the escape room in the fastest time. The types of puzzle that can be incorporated into a narrative varies greatly and can span the full breadth of the analogue to digital continuum. Big budget experiences may include sophisticated technology, whereas grassroots escape rooms may take a 'hack and tinker' approach. According to Scott Nicholson [32,

Fig. 2. Orientation Character. Digital Artist: Micheal Gray

p. 3], the escape room format has been around since 2007. Real Escape Game, published by SCRAP is the first well-documented escape room and is still very popular today.

The current spike in the popularity of escape room experiences presents an opportunity for museums to appropriate the theory and practice of escape room design and development as a means of engaging audiences with the museum's collections. In addition, it may provide an additional income stream during off peak times and help bring in audiences that are often harder to reach. Experience seekers, as defined by The Audience Agency, are a coveted audience in the heritage sector. Experience seekers are typically digitally savvy, active on social media, searching for things to do and are happy to part with their disposable income in exchange for novel

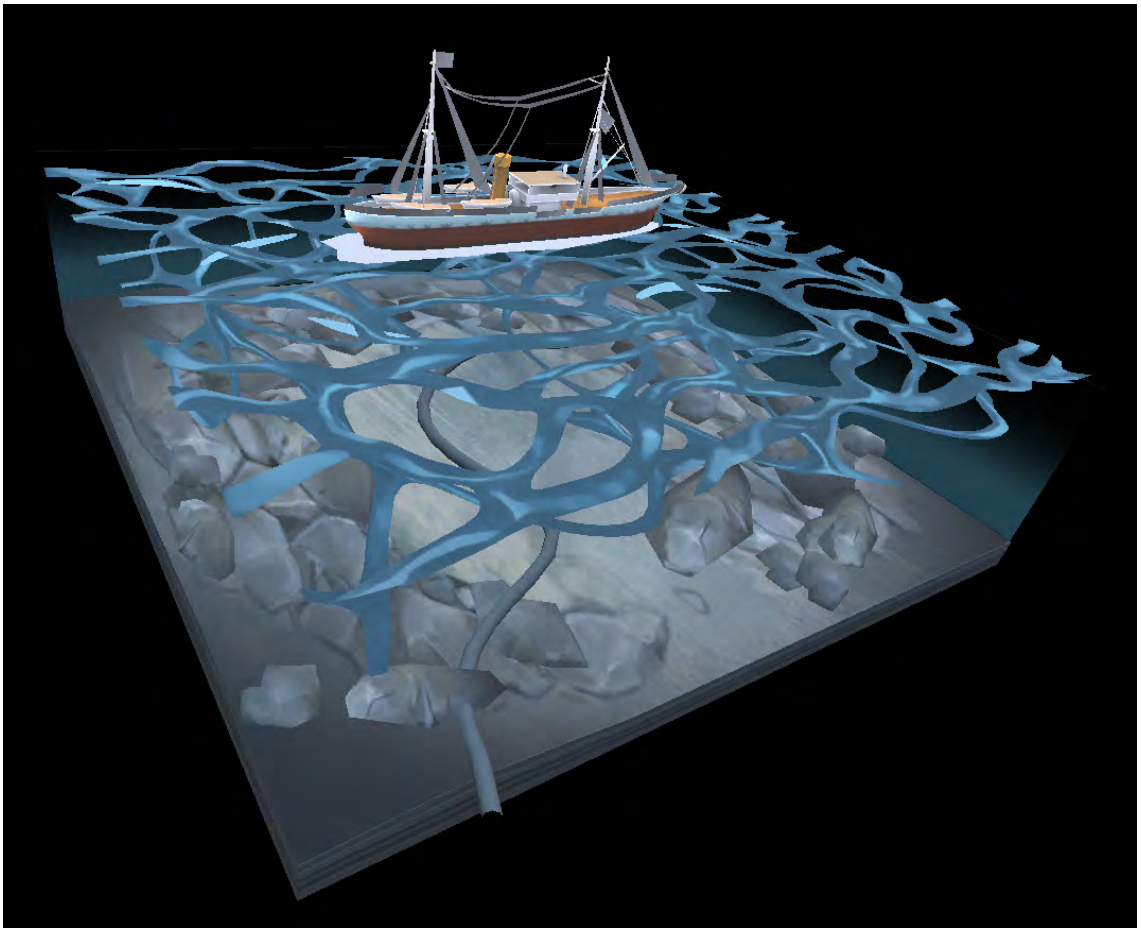

Fig. 3. Puzzle 3 hologram: Grappling the cable from the seabed. Photo © The Games Academy, Falmouth University. Digital Artist: Phoebe Herring.

experiences. Despite high engagement with museums, experience seekers often gravitate towards city centres. This poses a serious challenge for museums situated in more rural areas.

The decision to build a mixed reality escape room in the tunnels of Porthcurno Telegraph Museum was the outcome of several stakeholder meetings. These meetings focused on the question: how can a niche museum in an extremely remote and rural location entice 'experience seekers' to their location. In particular the museum is hard to reach with poor public transport networks and narrow roads. Many of the museum's visitors are families on holiday - rainy days are busy - or outside holiday periods, older people, often couples. Seeking sustainability and increased cultural relevance, the museum is looking therefore to supplement its offer with attractions that appeal to currently under-served visitor groups.

In the 1930s, Porthcurno telegraph station was a vital part of Great Britain's international communication infrastructure. It was deemed so important that within a few weeks of the war starting the decision was made to move the station underground and safe from enemy attack. Two hundred miners were employed to excavate two

large, bomb-proof tunnels in the side of the cliff where the operation of telegraph equipment could be carried out safely. The tunnels remain a key tourist attraction for the museum and provide a captivating setting for a mixed reality escape room. Visitors to the tunnels are confronted by walls of solid concrete and steel doors thick enough to withstand the full force of a bomb blast. They are led down dingey corridors with flickering lights and the strong smell of machine oil. Once in the tunnels, the space opens out and the museum's authentic, fully working automated relay station fills the air with the sound of clicking mechanisms, spinning wheels and the punching of tape. A more fitting *mise en scéne* for a mixed reality escape room would be very hard to find. On a more practical level, the current curated offering in the tunnels includes projected videos on the side of the tunnel walls. The artificial light of the tunnels is dim enough to facilitate projection and therefore, perfect for the holographic displays of the HoloLens. It was clear from very early on in the project that the environment was a very good fit for an escape room experience.

Escape rooms are inherently experiential and provide great affordances for learning. In GLAM contexts, visitors are often presented with glass cases full of untouchable artefacts. By contrast, through their combination of role-play, tactile and cognitive engagement sited within a historically resonant location, a very much more rounded experience enhanced through the use of real and digital props, audio, costume and narrative. This structured and augmented method is therefore more likely to feel more meaningful and personalised as players than simply as visitors. It also lines up with a constructivist model of learning that many museums are now looking to utilise [18]. We are now designing our evaluation of player experience to explore this further through the qualitative use of Personal Meaning Maps [13].

3.4 Game Design Arc

The year is 1942. After receiving their acceptance letters and Id cards (tickets), Four recruits(players), arrive at the Cable and Wireless Cable Station at Porthcurno in Cornwall, UK, where the undersea communications cable that links the UK with other stations across the globe is located. Recruits are to be trained up as Augmented Telegraphers to aid in the British war-time international telecommunication efforts. Clothed in overalls and equipped with state-of-the-art, head-mounted training aids (HoloLens) they are inducted by way of a voice-over from a welcoming character into the day-to-day operation of telegraph equipment.

As recruits, they are responsible for relaying comms to and from the station and our international allies. Having no prior training in Morse code, the headsets use a holographic dichotomic diagram to support the encoding of characters into 'dits' and 'dahs' for transmission as Morse code. The recruits gain a handle on how to use Morse code and then repeat the task confidently (see top-left of Figure 4). However, disaster strikes, a red light flashes, sirens sound, and all communications fail. Dramatic challenge is therefore introduced into the gamic experience.

Assisted by the headsets, the recruits must now use the available equipment to diagnose and support the repair of a break in the undersea intercontinental communications cable. A galvanometer (see top-right of Figure 4) needs to be set up using parts scattered around the tunnels, and, once found and pieced together, the galvanometer is employed to measure the electrical resistance across the cable up to point where the break has occurred. Using a lookup table, the recruits must calculate the conversion from ohms to nautical miles and relay this value to the harbour using the field telephone (see bottom-left of Figure 6). The phone and galvanometer pieces are real object, the phone a genuine object from the era and are each augmented by the headset. Based on the diagnosis, a cable repair ship locates and dredges the cable from the bottom of the ocean; which triggers a new hologram where the ship is seen on the sea and the recruits coordinate the repair using physical equipment supplemented by augmented imagery in the tunnels (see bottom-right of Figure 4)

With the repairs complete, recruits can relay a vital message to Malta alerting them to an imminent danger thus saving the day. As finale and celebration of their contribution to the war effort, a holographic radio appears,

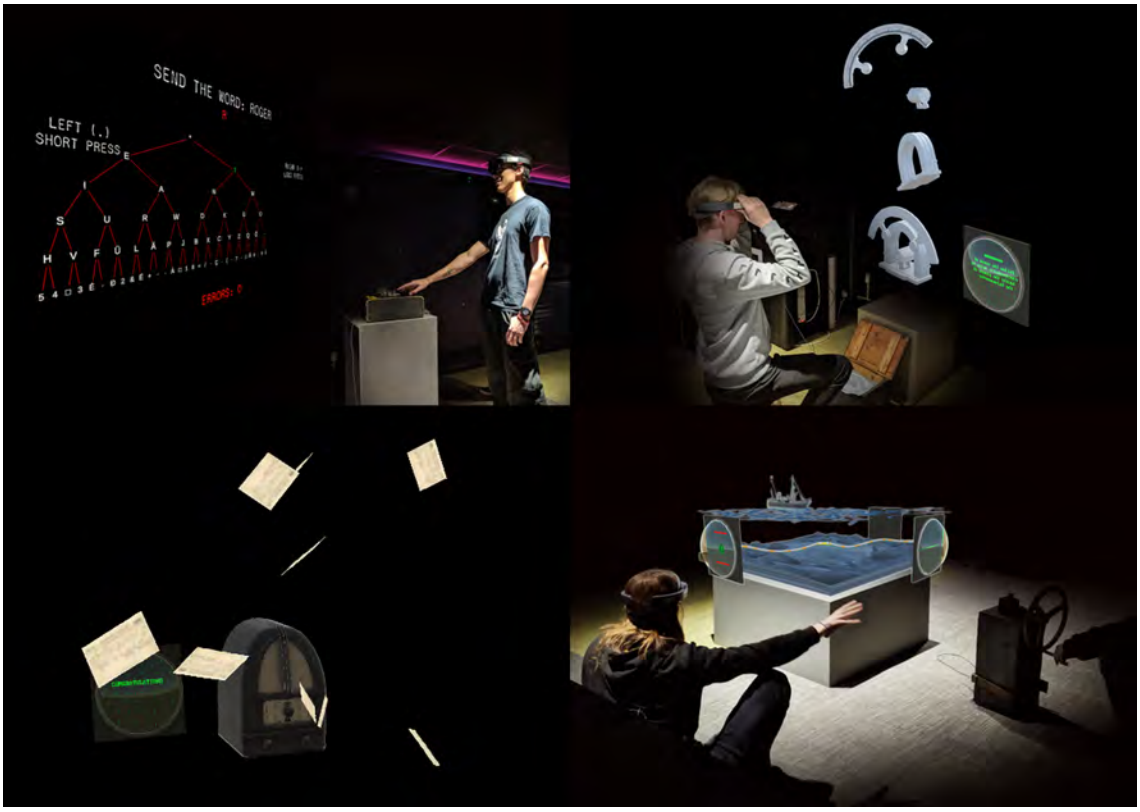

Fig. 4. Description of images from left to right, top to bottom: (1) WiFi enabled physical Morse code key that interacts with the holographic dichotomic chart, (2) physical puzzle box and holographic exploded Galvanometer diagram, (3) holographic radio and falling telegrams, (4) and holographic cable ship with physical hand wheel to control the ship's grapnel. Photo © The Games Academy, Falmouth University.

begins to crackle as if being tuned, and big band jazz tune begins to play while indicating the resumption of communications, telegrams float down from the sky (see bottom-left of Figure 4).

4 RESEARCH METHOD

4.1 Research Programme

The methodology underpinning this work applies a concurrent mixed-method research design. The case of the development and evaluation of the Augmented Telegrapher, reported in this article, forms the first part of a broader programme of *participatory action research* [21, 24, 26, 44]. This broader programme, at its core, applies the Deming-Shewart cycle [11, 43]: the principles of observe-plan-do-check-adjust (i.e., OPDCA). However, embedded within the particular case of the Augmented Telegrapher is a collection of qualitative and quantitative data collection methods which facilitate OPDCA. Namely, methods drawn from Human-Computer Interaction (HCI) including the use of focus groups, experiments, and TAM-style questionnaires assessed the efficacy of the installation from the perspective of end-users. This represents the check that leads to distillation of recommendations upon which the authors can then *act*. However, perhaps equally pertinent to the research question, is evaluating the process

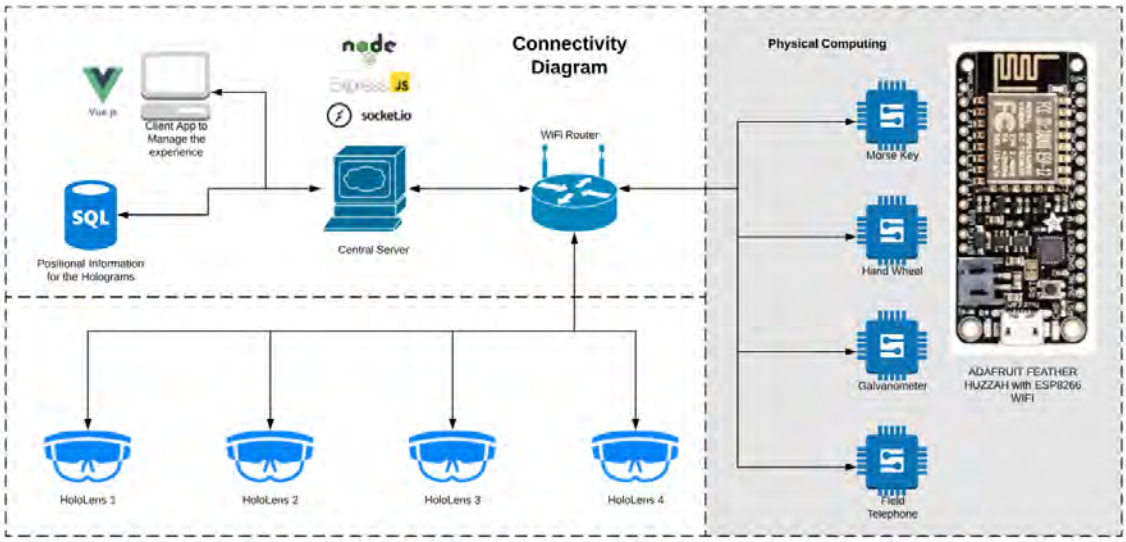

Fig. 5. Diagram depicting the connectivity between the various components of the system.

of *planning* and *doing* in this interdisciplinary cross-sector context. That is, the effectiveness of the means in which the installation has been realised. To this end, autoethnographic reflections on working co-design practice and software engineering methods [12, 40, 42] were collected from researcher-practitioners, developers, curators, and partners. Namely, through observation and discourse.

4.2 Development of the Augmented Telegrapher

Owing to the exploratory nature of the work and its emphasis on participatory and communal approaches, the development of the Augmented Telegrapher followed somewhat fluid set of practices drawing upon the methods the authors brought together from their respective disciplines and the evolving nature of the partnerships with the local museums. However, in order anchor this exploratory strategy, the creative approach to interdisciplinary working advocated by Molyneux [28] was adopted alongside the co-design methods proposed by Sanders and Stappers [41]. Together these methods support collective creativity and sustainable forms of design that were informed through both dialogue and evidence gathering.

The result of initial user testing (reported in [TBC]), provide confirmation that the standard HoloLens One gestures were neither intuitive nor robust and required training and practice to master. To solve this problem, gesture driven input was vetoed in favour of a more tangible, tactile and haptic approach. A network of 'enchanted' and interconnected physical objects provide the core interfaces for interacting with Holograms (see figure 5). Each object is fitted with a wifi enabled microcontroller and sensors. Interaction data from the objects is broadcast in realtime to each headset and the effects are visualised in the holographic world.

4.3 Experimental Pilot of the Augmented Telegrapher

Playtesting was practised throughout the development process (see Figure 6, in keeping with agile practices as used in the games industry (see [19]). Typically, such playtests were designed to calibrate the technology, benchmark the performance of the hardware, and to observe gameplay. However, such playtests often revealed considerable insight into immersive interfaces. Following players reporting difficulty with the head-mounted

Fig. 6. Description of images from left to right, top to bottom: (1) user testing in the Immersive Lab, (2) players collaborating to repair the undersea cable, (3) WWII field telephone with integrated sensors, (4) physical Morse code key in action. Photo © The Games Academy, Falmouth University.

display, an experimental pilot was conducted to compare two different interfaces for the Augmented Telegrapher. The gesture-based interface was compared to a tactile interface embedded into a series of replicas of items in the museum collection. A reversal A|B design was followed [5]. Thirty playtesters attempted to send a message using Morse code. They were randomly allocated to either the tactile interface or the gesture-based interface, eventually swapping over. After a short period of practice, they were tasked with sending the term 'AUGMENT'. Measures such as time required to complete the message and the number of errors made were recorded.

4.4 Private Viewing of the Augmented Telegrapher

To verify the efficacy of the Augmented Telegrapher, a private viewing was arranged. A total of 40 people from the local community (relative to the authors' institution) were invited to engage with the installation. Of these, 39 consented to completing the questionnaire. The questionnaire was interpreted through the lens of the Technology Acceptance Model [10] using methods inspired by prior work in the area of augmented reality for cultural heritage (see [17]). Participants were presented with a shortened questionnaire containing seven 5-point Likert-style questions. There was one question related to behavioural intention (i.e., intention to visit the museum) and two questions for each other factor in the model (i.e., perceived usefulness, perceived ease of use, and perceived

Measure	Agree	Neutral	Disagree	Mean	Standard Deviation
Perceived Usefulness	34	4	1	4.539	.600
Perceived Ease of Use	21	10	8	3.282	.686
Perceived Enjoyment	25	10	4	3.513	.664
Behavioural Intent	30	7	2	4.051	.857

Table 1. Results of an Analysis using the Technology Acceptance Model ($N = 39$)

enjoyment). Factor scores were computed using the mean of the responses. Given the 5-point scale, a response of three was considered neutral, whilst a response above was considered agree and a response below was considered disagree.

5 RESULTS

To validate this approach, a small usability study was carried out to compare task completion times between standard gestures and a custom physical interface. The task in question involved the participant spelling the word 'augmented' by traversing a holographic dichotomic Morse code chart. The findings of the study confirmed what we had observed from informal play testing. The custom tangible interface out performed the gestures considerably. The mean time required to complete the task (including those running out of time at 250 seconds) was 135 seconds ($\sigma = 64.7$) for the gesture-based interface and 92 seconds ($\sigma = 43.1$) for the tangible interface ($p = .001, d = 1.32$). The mean number of data entry errors was 6.97 ($\sigma = 4.0$) for gesture-based interface and 4.1 ($\sigma = 3.1$) for the tangible interface ($p = .002, d = 1.24$).

The results of the private viewing are presented in Table 1. The respondents reflected the target audience identified with the museum and expressed as personae. They were aged between 18 and 38, with a mean of 21.36 and a standard deviation of 5.06. Approximately 18% were women. Based on the analysis of the questionnaire responses, 76.9% of people who engaged with the installation believed it would encourage them to visit the museum. This suggests that such installations can encourage young people to visit museums. The lowest scores were perceived ease of use, which reflect the challenges of working with immersive technologies. The usability and comfort of the head-mounted displays were raised as key concerns by experienced users, with approximately 92% declaring that they used either augmented reality or virtual reality in the past. This raises the question of whether people with no experience have even more concern with these aspects of the technology.

6 DISCUSSION

6.1 Prescriptions for Planning an AR escape room learning experience:

- Complement the museum's existing collections: co-design with the museum will help ensure a good fit;
- Place emphasis on the learning through an experience, minimising mediation and narration (narrative should serve the experience);
- Ensure that the team that has a sufficiently wide range of applied skills - interaction designer, assets creators, programmers and curators;
- Have a good fit between the space available and the content (think of the space as theatre design);
- Design the escape room for 'experience seekers' as they are the group with whom the format is popular;
- Make it clear what is interactable;
- Have a team with experience of creating action-role play and alternate reality games;
- Successful puzzle and problem solving task design demands a lot of testing with users.

There are therefore a range of risks:

- Make it clear to players what is interactable and part of the experience and what is not (example);
- The playspace of escape rooms needs to be clearly demarcated for the player;
- High potential for failure (technology, design or implementation);
- Upkeep maybe high and outside the skills and/or resources of the museum;
- Distracting from the core values of the museum;
- Lacking long term sustainability (novelty value wears thin; technology fails or becomes obsolete);
- High cost of development (outside the reach of many small volunteer-led museums);
- Dissonance arising from conflicting aims of designers and museums (a good co-design workflow is crucial, see below).

6.2 Workflow for Effective Co-Design

Over the course of a three year development period, our workflow methods have become progressively refined. The current workflow that we have arrived at represents a more robust and well-suited structure for managing the co-design, development, and deployment of an innovative exhibit for heritage and museum contexts. The workflow is particularly relevant for projects that involve multiple stakeholders and multidisciplinary teams from differing industrial and institutional backgrounds, not just in terms of deploying technical skills but also in terms of organisation, values, focus, and philosophy.

It is worth noting that the workflow described below, at its core, inherits broad principles from Agile software development; principally, the fact that Agile can be both be tailored and respond to its situational context [37]. By necessity, some elements of our arrived-at structure are direct responses to the situational context, design features, and implementation of the Augmented Telegrapher 'Escape Room' project and another, similar project working across a number of museums. As such, while we believe the workflow offers a solid foundation, we would actively advocate that similar projects remain context sensitive and be ready to adapt their own specificities of collaboration.

6.2.1 Combining Perspectives. The workflow we have developed is divided into three stages: concepting, iteration, and delivery/implementation (see Figure 7 for summary). The first part of the initial phase is the identification of the project's key performance indicators such that suitable, measurable means of data collection can be identified from which to derive that project's impact intentions. It is likely that, in addition to the goals that unite the project's stakeholders, each stakeholder will likely have a distinct lens on what they seek to gain from the project. It will improve project efficiency if all of these goals are made explicit during this first phase and that for each goal a specific data source and means of collection is identified. These methods of data capture can then be built into the project timeline from the start where most efficient and practical. We have found that pre-funding submission planning often sees a different mindset to that when the reality of interdisciplinary co-design delivery kicks in and this should be expected once the work begins in earnest. It is likely that this also recurs in different ways at each of the stages of development. Regular points of contact are crucial - it is tempting to get your head down as a developer into technical and design problems and paper-writing, but regular co-design meetings are key to sustaining effective co-design.

In support of this, throughout the entire design and development process we found workshops and focus groups to be invaluable means of guiding elements of the co-design process in a semi-structured and agile way. The concepting stage should include a number of workshops that operate as tools for arriving at agreements between stakeholder groups while also allowing each to have input in the process. During this initial Concept phase it is important to 'onboard' (meaning to integrate and familiarise team members) each stakeholder such that they get a deeper understanding of the others' focal framework, organisational structure and culture, and methods of working. It is likely that the onboarding process may need to be tailored somewhat for each stakeholder to

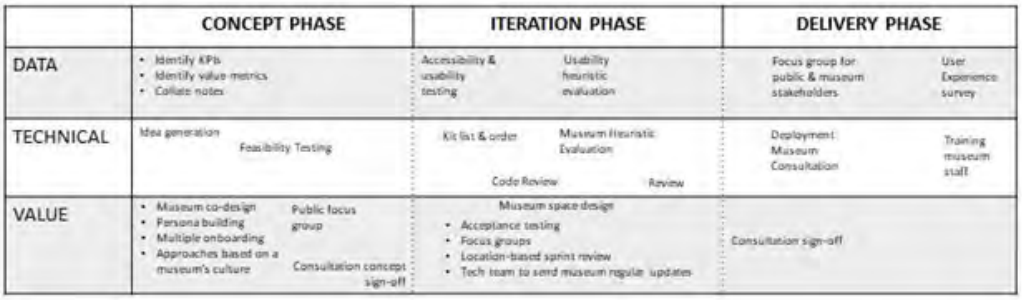

Fig. 7. Outline of workflow

take into account differences in culture. We strongly recommend that onboarding is built into the timeline of the project, as it will save precious resources of time and energy later.

6.2.2 Sharing Contexts. As an example of this, we found there was some anxiety in some members of museum staff, particularly those who are public facing, around the adoption of, and working with, new technology with which they were unfamiliar and from which they felt excluded. It was therefore useful in our case to include a process of technology showcasing in our initial workshops with museum staff. This served multiple purposes, first allowing museum and partner staff to familiarize themselves with the devices that may be used in the final installation. This process of demystifying the technology and indeed demonstrating that the developers in the team were approachable helped somewhat to reduce their anxiety and gently introduce them to new skills and possibilities for their museums. Additionally, by showcasing experiences similar to that which could be achieved during the lifetime of the project, this process served an important role in expectation setting. We found wildly diverse expectations of what we were able to do technically and in the time available in the museums, particularly those which are staffed often exclusively by volunteers. In order that the co-design process runs smoothly, it is vitally important that all stakeholder groups have their expectations calibrated early on in terms of what is realistic and possible within the project constraints. This will help to minimise confusion, frustration, and disappointment while helping to provide fruitful ongoing conversations around the physical exhibit space, visitor flow, and manning by staff.

The museum teams response to exploring the technological possibilities is a guided tour around their offering and museum context. The museum team will talk through their exhibits, highlighting any areas they feel are under served or particular stories they would like to tell. Attention should be paid to the current audience that the museum attracts and the audience they with to attract with the experience to be designed. Ideally, a focus group made up of members of this target demographic would be convened and asked about what interests them in the current museum offering. They would also be asked about their thoughts on the potential stories and initial concepts for the experience. After this process, we found it helpful to formulate 'personas' (a fictional character made to represent a typical user) which will then go on to inform the design process.

Moving from concepting to iteration also has some pitfalls that can be avoided. For example, issues arose where a clear sign off from the museum was not in place; it is easy to assume that through the co-design concepting that there is agreement when, in fact, not all museum staff are involved are present. As such it is important that

the concept is agreed by stakeholders, with the caveat that emergence will arise through iteration and testing. This is where differences in culture become apparent most sharply - our iterative process was not fully clear to busy museum managers who often wanted certainty about the end product. We therefore developed a model whereby the museums 'sign-off' on a design so that the design trajectory retains some aspects of emergence relevant to the testing process but which also checked museum curators boxes around knowing what they will get. In this regard, we are not signing off a final design so much as an intended direction. It is important that all stakeholders understand that the design process is more akin to an image becoming less blurry over time than producing a detailed blueprint and sending it to be manufactured.

6.2.3 Maintaining Communication. The second, iteration phase is the longest phase in the workflow owing to the utility in giving as much time as possible to iterative cycles. The basic structure of this phase should absolutely follow an agile sprint structure of code, test, review. During this phase, the form of the artifact under development can change rapidly: as a result it becomes essential to build in regular points at which other stakeholders can be updated on the current state of development. Stakeholders should also be able to feedback on changes so as to have some purchase on the ongoing development. Without sufficient means of updating and receiving feedback from stakeholders, anxiety can develop as they begin to feel as though they have no control. It is convenient to place these points of feedback gathering at the end of sprints. Ideally feedback would be sought not just from museum staff and partners but also from representative samples of the target audience and the current museum audience (so as to manage any potential shifts in perception and behaviour from the existing user demographics). The lengths and number of sprints will be determined by the overall project timeline, but we recommend that stakeholders be able to feedback on development after major changes and that at least two user testing sessions be held from the midway point in the project. Users are often not used to seeing things in a prototype state and can be very led by visuals and confused by unclear interfaces. As such, early testing and feedback can be sought internally via heuristic evaluation by experts who are familiar with the technology and design process. There should also be room for some polishing in this phase after all the major features of the experience have been implemented and are functional. What remains to do in this phase is concerned mostly with making the experience as user friendly as possible and fixing any undiscovered bugs. User testing with the target audience takes a priority during this phase, with the aim of a new user being able to encounter the installation with as much knowledge as they would have in the real setting and being able to successfully navigate the entire experience. User testing should take place in situ if possible and feedback gathered with mixed methodologies.

The final phase is the delivery phase in which the experience is deployed in place. A means, or multiple means of gathering user feedback should be implemented such that the impact of the experience can be measured, ideally over a long period of time. During this phase the experience will get more user testing than at any time to date and this is likely and expected to reveal some issues. Users may report difficulties of understanding or interaction which can be addressed by changes in any part of the total user experience; in other words it is just as likely that the museum staff may need to address the flow of users through the space as it is that the technical team will need to add or change digital instructions or control schemes. As such, each team should keep in close communication when dealing with issues that arise; sometimes there may be multiple practical solutions to issues which would involve different teams and contain different costs. For example, it may be easier and cheaper to alter physical signage than to add a new tutorial to the digital experience.

7 CONCLUSION

The results suggest the following:

(1) placing the user at the centre of the design process, considering what immersive might mean to them in a museum context;

(2) actively adopt a constructivist model of education into the experiential, participatory/game design proposition (the goal is a heuristic, play-based understanding rather than a fact-based one);
(3) remember that audiences in museums and heritage sites are heterogeneous, however museums might want to develop attractions that reach out to new or difficult to reach audiences;
(4) employ game loops and narrative as methods to involve audiences and help span the gap between entertainment and education;
(5) use methods that support interdisciplinarity and co-design across the divide between the heritage and creative industries sectors, rather than each working in parallel;

This article has set out some of the lessons learned across working as an interdisciplinary research team applying computing-based immersive design in the museum sector. Our aim is to support innovation, sustainability and increased visitor engagement in the sector and we hope our evaluation of our learning will help in that aim. To summarise, our prescriptions and the concerns that arise from our work coalesce around three main areas: 1. strategies and approaches to interpretation representation. 2. issues arising from approaches to design authorship. 3. The high risk of working with complex technologies. The first of these coincides with ideological and hermeneutic concerns about who represents what and to whom: we can call this out as interpretational bias and it is inherent in all meaning-making. In experience design we cannot avoid this issue as interpreting history is always partial. Virtual and Augmented Reality is in this sense no different to other media and yet it can be regarded as even more problematic because its formal and medial properties places the user perceptually in a pre-structured point of view. Such strong interpretational placement may also go against constructivist modalities of education, unless the content is conceptualised to mitigate against this. This is however balanced against the medium's ability to place the user in a place at a given time to create a strong sense of being there. If is therefore up to designers and curators to be aware of this.

Second, because in a museum context, practice-based researchers must by necessity co-design with partners, there is always a risk that a concept can be diluted and dulled. However, much as is the case with anyone working in a commercial context, there are multiple drivers in play which work against both a single-minded authorial vision or a 'waterfall' approach (even if museums might desire a clear vision of the 'product' from the get go). It is therefore important for everyone to go into the relationship knowing that any new permanent feature of a collection will have to be sanctioned and signed off by both curators and their visitors. This does make the design and technical work risky as agendas may differ. Differences in ways of working and culture between software developers and the heritage sector are highly likely to come to the fore and are best planned for. Variations in literacies and technicities does however mean that everyone involved gets a new perspective on their practices and this interdisciplinarity, particularly where trust is high, can lead to both innovation and a strong bridge across the divides.

Third, and finally, small museums may not have the resources to mobilise new immersive technologies that are expensive and which present a high-risk of failure. As such we argue that it is vital that new platforms and pipelines are developed to support such museums to enter the digital immersive economy. For this to happen there must be collaboration and partnership with universities who have the skills and experience with the design and development of immersive experiences and we hope to have helped facilitate this through this evaluation and development of this collaborative methodology.

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