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KEYNOTE PAPER: VIRTUAL & AUGMENTED REALITY TECHNOLOGIES FOR APPLICATIONS IN CULTURAL HERITAGE: A HUMAN FACTORS PERSPECTIVE

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ABSTRACT:

After three decades of "technology push", Human Factors design techniques and processes are finally being applied to applications of Virtual Reality and Augmented Reality (VR, AR) in such sectors as defence, engineering, transportation, medicine and scientific visualisation. However, the importance of Human Factors, or human-centred design, is yet to impact significantly on the Virtual Heritage sector, especially given the recent emergence of new VR and AR technologies, where a preoccupation with unproven and often unreliable examples of "immersive" technologies is already resulting in costly, unusable "interactive" systems. This is unsatisfactory, especially as Virtual Heritage must, out of necessity, engage with individuals from all walks of life, especially those who possess valuable personal recollections or material resources. Furthermore, these are also individuals whose knowledge, skills and abilities must be taken into account from the outset, as these factors are of fundamental importance to the design of usable and meaningful interactive media. Using three recent examples involving VR and AR technologies, this paper sets out to emphasise just some of the key human issues involved in the Human Factors life cycle, from concept to delivery, underpinning the delivery of future interactive systems for Virtual Heritage, including the importance of what may be termed "Heritage on my Doorstep" in overcoming end user anxiety or low self-efficacy in using "high-tech" human interfaces.

KEYWORDS: Augmented Reality, Virtual Reality, Virtual Heritage, Drones, Human Factors

INTRODUCTION

Over the past decade, there has been a wide range of publications and conference presentations describing the potential contributions of new and innovative interactive digital technologies to the preservation, understanding and interpretation of sites, artefacts and events that come under the banner of "industrial heritage". Digital, or Virtual Heritage applications are as diverse as the recreation of Spanish windmills and watermills (Rojas-Sola and Amezcua-Ogayar 2005), the operation of lighthouses (Gabellone and Monte 2005), the mechanical functioning of historic salt-washing machinery (Laroche *et al*., 2008), and the visualisation and exploration of artificial subsea reefs and shipwrecks (Flack & Rowland, 2008; Stone *et al*., 2009). Just as diverse as the applications are the technologies that have been or are currently being exploited to support the display of information and interaction with it. These include smartphones and palmtops (Michaelis *et al*., 2012; Benini *et al*. 2002), tablet computers (Rubono 2011), custom-built "museum kiosks" (Karoulis *et al*. 2006), and so-called "immersive" Virtual, Augmented Reality and Mixed Reality (VR/AR/MxR) techniques – head-mounted displays, theatres and CAVEs ("Cave Automatic Virtual Environments"; Rousso 2002; Noh *et al*., 2009). The delivery of rich multisensory worlds to a technology-hungry population of end users now exploits familiar media platforms, from "serious games" (DeLeon and Berr, 2000; Stone *et al*., 2009), to online communities (Harrison 2009).

However, whilst many of the publications appear to concentrate on the exploitation of new technologies in "enhancing" end users' "experiences" (be they for entertainment or educational applications of virtual heritage), there are very few that focus on the challenges faced by developers active in the more human-centred activities associated with the field – the acquisition and presentation of meaningful interactive Virtual Heritage content to a diverse and sometimes technology-averse audience (Laroche 1980), be it made up of members of the general public or historical subject matter experts (SMEs). The aim of this paper is to highlight the importance of considering Human Factors and human-centred design processes early on in the development of interactive technologies, especially those that "target" a diverse end user population, and to illustrate the key issues using three recent VR and AR Heritage projects.

Human Factors

> "Human Factors is the study of the relationship between the human and his or her working environment. It makes no difference if the working environment is real or virtual" (Stone 2012a).

The importance of Human Factors in the development of interactive 3D systems has long been the focus of intense research interest, particularly in the industrial domains of aerospace and defence training, and in engineering design and prototyping, with recent guidance documents providing a wealth of case study-related material (Stone 2012a). However, good examples of the application of Human Factors knowledge and techniques to the field Virtual Heritage generally, and Virtual Industrial Heritage specifically, are very few and far between.

The motivation for attempting to address the merits of "cross-feeding" the latest Human Factors principles from the industrial and defence worlds to those more focused on Virtual Heritage pursuits originally arose as a result of two projects that occurred in the 1990s, where a preoccupation with interactive technologies came very close to ruining the experience of the end users, not to mention compromising the quality of otherwise sensorially-rich virtual environments. That same preoccupation is being witnessed yet again today, not just in the Virtual Heritage sector, but in other interactive media pursuits, including so-called "serious games", where the target user populations are often dominated by non-technical specialists, lay users and schoolchildren.

Virtual Stonehenge, a project originally sponsored by English Heritage, set out to deliver a high-fidelity (for the mid-1990s) VR model of the monument and its environs (Figure 1). The original aim of the project was to provide end users not only with a real-time exploration capability, but also with a means of interacting with certain stone features, thereby exposing historical details, such as Christopher Wren's famous graffiti, or axe and dagger marks (Stone, 1998; Stone 1999). However, the focus of the project was changed to some extent by a well-known computer chipset company, keen to provide sponsorship, but only to demonstrate (and, thus, publicise) the real-time graphics power of its latest processor. As a result, the project emphasis changed from one of strong educational potential to one dominated by technology (Burton *et al*., 1997). Indeed the final presentation included a rather distorted display of the VR model using the London Planetarium Dome Theatre, "enhanced" by the use of an inappropriate synthetic odour, allegedly representing "cut grass"!

Fortunately, *Virtual Stonehenge* has, more recently, been recreated using appropriate "serious gaming" software and the original aspiration of using interactive techniques to display the educational potential of a Virtual Heritage recreation is now demonstrable.

Figure 1. *Virtual Stonehenge* (1996).

Figure 2. *Virtual Lowry* (1995).

Virtual Lowry (Stone, 1996; Stone, 1998), one of the most popular examples of VR for heritage of its time, was based on the notion of exploiting technology to allow end users to approach and actually enter a famous L.S. Lowry painting – *Coming From The Mill* (*circa*. 1930). "Reappearing" on the other side of the virtual canvas, the observers would be free to explore a 3D reconstruction of Lowry's townscape, complete with animated "matchstick" figures (Figure 2). This demonstration was commissioned by Salford City Council, as part of their bid for national funding to build the now-established Lowry Centre on Salford Quays in the north of England.

However, a preoccupation with high-tech "gadgets" on the part of some of the council personnel very nearly compromised the final presentation to the bid assessment panel. By providing three of them with relatively low-cost (and, therefore, low-quality) VR head-mounted displays, and then moving them *passively* through the painting transition process and into and around the virtual world, the resultant disorientation effects and dissatisfaction were plain to see. The situation was, fortunately, recovered by a repeat presentation using a projector-based display.

There have been a number of other examples of "near misses" as a result of the use of inappropriate interactive technologies in the delivery of VR application solutions (including the *Virtual Scylla* shipwreck/artificial reef presentation described by Stone *et al*., 2009). Space precludes giving each example a full coverage, but the lessons learned and Human Factors principles established as a result of these and a wider range of applied VR projects have recently been collated under a single cover and published as a freely available guidance booklet (Stone 2012a).

Human Factors Challenges in Virtual Heritage

As emphasised by Rojas-Sola & Castro-Garcia (2011), the two key elements that underpin the generation and acquisition of Virtual Heritage material are "working memory" and "culture". Working memory, a term more familiar perhaps to cognitive psychologists than Virtual Heritage specialists, refers to information drawn from the spoken and written accounts from people who are able and willing to provide their own recollections. Culture, in this context, and again referring to the work of Rojas-Sola & Castro-Garcia (2011), refers to the exploitation of data from ethnographic, anthropological, sociological and historical sources, including historical and modern maps, local authority archives, photographic and film collections, and so on.

Each of these elements brings with it its own unique human challenges – challenges that are not necessarily made easier with the passage of time, nor with the evolution of innovative interactive technologies. The key "research question" facing designers and developers of Virtual Heritage (where there is still a significant likelihood that the end results will be experienced by surviving and, therefore, highly knowledgeable SMEs), can be phrased thus:

How can we present and manipulate the early findings and results of VR or AR recreations in such a way as to engage end users, stakeholders and SMEs and to avoid their alienation, either as a result of errors in historical interpretation, or by compromising their experience by exposing them to inappropriate human interface technologies during design and final presentation?

"Working Memory". Material from Rojas-Sola & Castro-Garcia's (2011) category "working memory" is essential to the execution of an accurate and educational Virtual Heritage experience. Each of the three "case study" projects described later in his paper serves to support this statement. Exposing the owners of "working memories" on a regular basis helps to ensure the accuracy of the virtual sites and artefacts developed. Indeed, early engagement with and iterative exposure of end users or stakeholders are well-established principles in human-centred design processes, as laid down, for example, in International Human Factors standards such as ISO9241-210 (ISO 2008). In addition, exposing stakeholders to the evolving VR or AR deliverables could very well help stimulate memories that were not forthcoming during earlier review or recall sessions. However, as time passes, it is a fact of life that the SMEs will diminish in number, and there is no guarantee that any knowledge they once possessed will be recorded, archived or passed into the hands of the generations they leave behind. The attitudes of those generations to the preservation of such knowledge may also be problematic – there is little doubt that, in the past, valuable heritage material will have been lost as a result of removing the old to make way for the new.

"Culture". In many respects, material from the "culture" category defined by Rojas-Sola & Castro-Garcia (2011) is a much more complex issue. At one end of a very broad "cultural continuum" of issues is the need to engage closely with the owners of these different cultural material assets and to convince them that their material will be treated carefully and sympathetically. Not only does this refer to care in handling assets such as photographic images, maps and the like, it also refers to how they are likely to be transformed when implemented in a digital form and how their distribution will be protected (especially if specific assets contain images of personal significance for the owner).

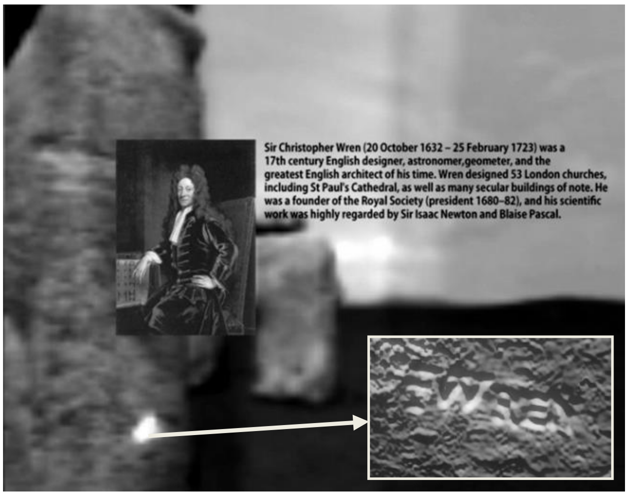

Figure 3. Information "window" on Sir Christopher Wren activated via a highlighted representation of the architect's graffiti (insert) on one of the stones in *Virtual Stonehenge*.

This was demonstrated with the more recent "reincarnation" of *Virtual Stonehenge* mentioned earlier, with its "embedding" of multimedia data into the virtual stones and surrounding terrain (Figure 3). Using hyperlinks or "portals" from the main virtual environment to make archived material such as text, images, video and other virtual objects easily accessible is becoming increasingly popular as an interactive technique in many walks of VR and AR. However, it is important that the digitisation of that material does not compromise the owner's expectations or leads to the owner's disengagement through such practices as image warping, the use of false colour or low resolution, highly pixelated images or video sequences, or the inclusion of annotation that may obscure facial or other personal features or characters important to the owner.

Another example is how images sampled from areas within photographs or paintings could be used as textures in the target VR scenario. The *Virtual Lowry* project was an excellent example of this. The "construction" process of the virtual "dreamscape" (a term used by L.S. Lowry himself to describe some of his work) demonstrated the importance of engaging with the owners and custodians of the artist's unique works to ensure sympathetic treatment of the painted content. For example, early engagement helped to define acceptable and appropriate levels of fidelity when using scanned area samples of different paintings for texturing buildings, roads and terrains, and for skydome and horizon bill-boarding purposes.

As well as the diminishing number of SMEs in the Virtual Heritage arena (and Virtual Industrial Heritage in particular), detailed and accurate cultural assets are also becoming increasingly hard to find. Space does not permit a detailed discussion of the hypothesis that industrial heritage sites and artefacts may be more likely to deteriorate faster than their centuries-old counterparts (due to acts of vandalism, new building projects, accelerated decay of 1990s building materials, etc.). Excellent examples of this particular concern can be seen in books relating to the UK's "subterranean heritage", such as Cold War Era nuclear bunkers (Catford 2010). Even when gaining access to actual physical sites is no longer possible, relevant information and material collections that are temptingly referenced on the Web (such as those held by councils and museums) are – frustratingly – often not accessible directly from any online catalogue. To acquire such information may demand significant expenditure on travel to the host locations and, even then, "hands-on" time with the assets themselves may need to be pre-booked and of limited duration (not to mention the restrictions that may be in place for digitising historical material).

Furthermore, where limited or practically non-existent assets exist (as was the case with the Wembury Commercial Dock project, described later in this paper), it becomes necessary to extrapolate details from other sources and reference texts and, in many cases, to simply make one's best guess as to the appearance and extent of the virtual environment one is attempting to develop.

Figure 4. Virtual recreation of Burrator & Sheepstor Halt on the now-abandoned Yelverton-to-Princetown Railway.

When it comes to the actual process of creating 3D models or scenes, it is often the case that the more unique the site or artefact is, the more one has to expend considerable time and resource in the construction of 3D models that are of the correct design, style and era. In the UK, this has proved to be particularly problematic, and the extent to which 3D content has had to be built from scratch has, on numerous occasions, resulted in the distraction of researchers and students from their primary focus of developing interactive and educational Virtual Heritage applications (although see comments relating to the use of Pix4D towards the end of this paper, under "Project 3"). Recreating a short section of the long-abandoned Yelverton-to-Princetown railway line, close to Burrator Reservoir on Dartmoor National Park, is a particular case in point (Figure 4; Stone 2012b; Stone 2015).

In some cases, it has been possible to acquire 3D content from such online repositories as Turbosquid, 3D Studio, 3D Cafe and the like. However, despite the huge number of 3D models these sites possess, it is often the case that there is little of relevance to the project one happens to be working on at the time. Whilst this situation is slowly improving (with sites such as Trimble/Google SketchUp Warehouse doing much to alleviate the situation), it is still a fact that there are more US-relevant objects and datasets available online than there are for other countries. The temptation is often to download the closest match to the object one requires and to modify the geometry or associated textures. However, this practice runs the risk of attracting significant criticism from, and, potentially, losing the engagement of surviving stakeholders.

Finally, and at the other end of the "cultural continuum" from a Human Factors perspective, is the question of how one defines the nature of one's end user population. What are their informational and educational needs, their current and previous interactive experiences and their knowledge, skills and attitudes, and how does one use this information to ensure that the Virtual Heritage content is delivered using the most appropriate interactive technologies? Again, this is a complex topic that cannot be covered in detail here. However, attention is drawn again to Stone (2012a). The most important message from this guidance document is quite simple. Interactive 3D media has to be designed in conjunction with its end users, identifying the skills that need to be trained or the knowledge that has to be imparted, and then delivering a solution based on appropriate content, fidelity and interactive technologies. Furthermore, the solutions must be packaged in a form that can be delivered to the end users in their own working and living environments, as opposed to expecting them to experience the technology in isolated and restricted laboratory-like environments.

There now follows short reviews of three recent Virtual and Augmented Reality Heritage projects that have prompted the writing of the present paper. Each project has presented its own challenges, not only in terms of the limitations of the technology during data acquisition in the field and at subsequent demonstrations, but also in the collation of relevant historical material and in attempts to engage with a wide range of SMEs, stakeholders and end users. The ultimate aim of these and related projects, as with the contents of Stone (2012a), is to develop a human-centred body of knowledge specifically aimed at the Virtual Heritage community based on real-world experience and lessons learned.

PROJECT 1: THE WEMBURY COMMERCIAL DOCK & RAILWAY PROPOSAL OF 1909

Wembury is located to in the South Hams district of Devon, to the east of Plymouth. Designated as a Special Area of Conservation and a Voluntary Marine Conservation Area (Figure 5), the original rationale for constructing a 3D model of this particular coastal region did not evolve from any Virtual Heritage pursuit. Rather, the coastal topography was developed to support research into *virtual restorative environments* – the exploitation of interactive 3D scenes of natural settings (forests, lakes, coastal paths, etc.) to improve post-surgery recovery of physical and psychological well-being for hospitalised patients (Depledge *et al*., 2011; Stone *et al*., 2014).

Virtual Wembury was "constructed" using commercially available Digital Terrain Model (DTM) data, which represented the undulating scenery of the region in the form of a dense spatial "cloud" of *x*, *y* and *z* points. An area of 3.5km^2 was obtained, covering Wembury Bay itself (including the Great Mewstone Island), the coastal path west to Heybrook Bay and Renney Rocks and an area extending approximately 1km inland. In addition, a digital aerial photograph of 12.5cm resolution was used. Draped as a texture over the DTM data (once converted to a 3D model), the aerial image provided a visual template which was invaluable in helping to locate key natural and man-made features – trees, large plants, meadows, rocks, streams, paths and buildings (including the village church of St Werburgh, from which the image in Figure 5 was taken).

Figure 5. The real Wembury Bay from the tower of St Werburgh's Church (the distant island is the Great Mewstone).

A series of photographic, video and sound surveys were also conducted at the Wembury Bay site. Sounds of birdsong, waves, wind and footsteps have been programmed into the virtual model (the real-time version of which has been created using the *Unity* games engine and toolkit; Figure 6) to create a dynamic "soundscape" which varies depending on the user's location. A 24-hour day-night cycle, synchronised with the actual time of day, together with weather effects have also been implemented. During the early site surveys for this virtual restorative environment, opportunistic contact with Wembury Village residents provided the motivation to undertake what became a rather ambitious Virtual Heritage project.

Figure 6. Virtual Wembury Bay from the base of the tower of St Werburgh's Church.

In 1909, a proposal (HL Deb, 1909) was put before the UK's House of Lords relating to the development of what could have become one of the largest – if not *the* largest – and most successful commercial docks in the country, rivalling other ports at London, Southampton and Liverpool. Had the proposal not failed, then Wembury Bay would have been changed forever, with the docks, railway and workers' houses decimating what is, today, one of the most attractive and popular coastal areas in the south-west of the UK.

The port was to consist of breakwaters extending far out into the Bay. Two layout proposals were considered, one consisting of a large single continuous dock structure with a railway terminus; the second boasting four or five "finger" jetties, dry docks and railway sidings taking passengers directly to and from their ship's berth (Figure 7). The railway would have taken the form of a single-track branch line from the town of Plymstock just to the north (with expansion space for a double track branch in the future), offering disembarking passengers a more rapid service to London than that being offered by the competing ports, and even by Millbay Dock in Plymouth itself. Another key issue emphasised by the proposal owners was that the geological nature of Wembury Bay would be ideal for berthing of large-draught vessels, unlike elsewhere in the UK, where ships had to weigh anchor offshore and then ferry passengers and cargo into the port area.

The proposal failed for a number of reasons, including under-capitalisation, reliance on third parties for significant infrastructure elements, such as railway coaching stock, naïve growth and revenue estimates, and the belief that Southampton's expansion plans were already well developed and moving forward. It is also fair to say that Parliamentary hostility played a key role in the downfall of the proposal, as did opposition from the London & South Western and the Great Western

Railways, for obvious reasons, given their well-developed routes into Plymouth Millbay and Plymouth Friary.

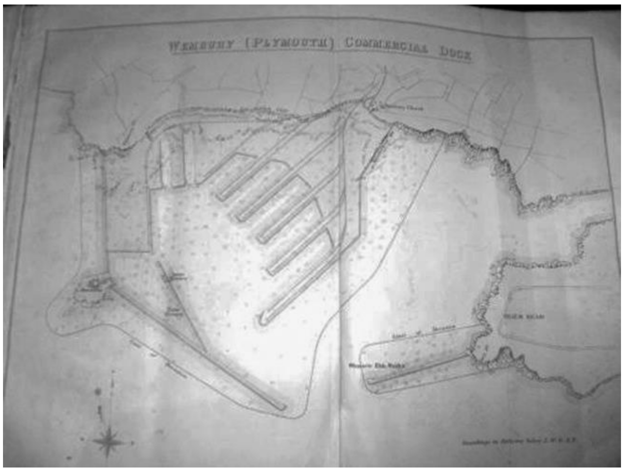

Figure 7. 1909 plan illustrating one ("finger quay") layout concept for the proposed Wembury Dock (HL Deb., 1909).

The Wembury Docks AR and VR Demonstrations

Apart from one article in a History Society newsletter (Broughton, 1995), one or two simple concept illustrations and plans, limited personal reflections by local historians, some newspaper cuttings (Anon., 1908; Anon., 1909) and the 1909 hard-bound proposal itself (only one copy of which has appeared on *eBay* in the recent past), there is nothing to convey the magnitude of this engineering project, nor the impact it would have had on the Wembury environment and local village residents. Consequently, the cultural assets underpinning the actual 3D models were based on extrapolations from historical British railway and maritime publications. In particular, historical research had to be conducted using references to other UK docks, including Liverpool/Birkenhead, Southampton and the Port of London, together with Hull, Cardiff, Falmouth and Bristol, where the current Heritage Dock exhibits proved to be particularly useful.

As well as the topographical model developed for Wembury using DTM data, described earlier, the final Wembury Dock Virtual Heritage demonstrator exploited a wide range of 3D assets, procured both from online sources and built from scratch. For the AR implementation (and bearing in mind the huge size of the dock), a low-fidelity model was used in conjunction with *ARToolkit* and iOS (Apple Inc's mobile operating system) plugins for the *Unity* toolkit, thereby supporting on-site AR visualisations using an *iPad3* with high-contrast fiducial markers (typically printed monochrome patterns, similar to barcodes, recognisable by the AR software via a laptop or tablet's camera) and a customised user interface supporting scaling, positioning and orientation of virtual images (Figure 8).

To develop as much accurate historical content as possible, it was essential that the development team engaged with local villagers from the outset, although in the early stages of the project this proved to be quite difficult, due to the lack of experience with (and suspicion of) computing technology on the part of many of the inhabitants. Members of the Wembury Local History Society provided highly valuable input, although some were unclear as to how a VR or AR reconstruction of the "docks that never were" would appear to the village community. To overcome this, it was decided to stage an evening "Virtual Wembury" event at the Village Hall, initially emphasising how the 3D coastal model was being developed to assist in healthcare pursuits at Birmingham's Queen Elizabeth Hospital, but later introducing the Augmented Reality Docks project (using a virtual model of the Docks to introduce the villagers to the key concepts (see Figure 9)).

The event, which enabled villagers to experience the technologies first-hand (with Virtual Wembury displayed using a 50-inch TV display or a Sony HMZ-T1 Head-Mounted Display, and using an Xbox gamepad for navigation), was a considerable success and demonstrated the power of VR technologies in helping to engage with potential end users from all walks of life, and of all ages. In particular, allowing villagers to explore the VR model freely and capturing their comments, no matter how pedantic (and often unachievable with current technologies) they were, it was felt, an important step in removing any barriers to or fears with computing technologies. It was also noted, given the availability of other VR demonstration projects at the event, how important the location of the virtual scene was too strong engagement on the part of the villagers. A similar VR model, based on Burrator Reservoir (mentioned earlier), was also present at the Wembury event, but attracted less attention from the audience than did its more local counterpart.

This, and more recent observations, particularly with regard to the exposure of senior citizens to VR and AR technologies, has led to the coining of the phrase "Heritage on my Doorstep". It may be that, when presenting VR or AR (or, for that matter, any form of sophisticated computer interactive technologies) to often sceptical, and sometimes highly reticent end users, such as those who inhabit remote communities, or communities of predominantly older individuals (75% attending the Virtual Wembury event were older than 50), the more familiar the content, the more likely they are to focus on that content. In doing so, this may help to overcome any barriers to navigation and interaction, including low computer self-efficacy or high computer anxiety, brought about by the display and input technologies used.

Indeed, some early experimental findings supporting this theory have been found as a result of recent PhD research (Qian, 2015) involving a small sample of Wembury villagers (n = 15 (7 male, 8 female) with a mean age of 68). Participants were invited to roam freely around two virtual scenes: a natural coastal scene (Virtual Wembury) and a natural forest scene with a lake (a modified version of Virtual Burrator). Using both subjective (e.g. presence, realism and satisfaction questionnaires) and objective (navigation data-logging) measures of participants' activities, it was found that their subjective ratings on all three questionnaires were greater for the local coastal scene than for the unfamiliar forest scene. Indeed, the objective results showed that participants spent, on average, 75 seconds longer exploring the familiar coastal scene than the forest scene.

Figure 8. Augmented Reality Wembury Docks using *ARToolkit* on an *iPad3* and a custom-developed image manipulation Graphical User Interface (GUI).

Figure 9. Virtual Reality Wembury Docks using the *Unity* games engine.

PROJECT 2: HMS *AMETHYST*'S "FINAL RESTING PLACE"

While researching the history relating to the railway infrastructure in South Devon and Dartmoor for the Wembury Docks project, another opportunity arose to undertake an evaluation of Augmented Reality technologies that has since generated enormous interest. Interest not only in terms of what it set out to demonstrate, but also in terms of encouraging a new generation of interactive media developers, each with a personal motivation keen to preserve a unique part of British naval history.

Information relating to the rail transit of people and raw moorland materials to the ports in South Devon is available from a number of established publications (e.g. Kingdom, 1982; Kingdom, 1991), but one in particular provides an excellent account of the history of the oldest maritime part of the city of Plymouth, namely Sutton Harbour, within the famous Barbican area. The book *Sutton Harbour*, by Crispin Gill (Gill, 1997) contained an impressive (if somewhat sad) image of a famous Royal Navy vessel, awaiting the breaker's torch. That image was of HMS *Amethyst*, unceremoniously abandoned in the corner of the Harbour, next to the China House – today a popular public house and restaurant (and itself an historic building, dating back to the 1600s),

HMS *Amethyst* was a "modified" *Black Swan*-class "sloop", re-designated as a Frigate, pennant number F116, after World War II. In the late 1940s, the ship and her crew made their mark on history - a mark that was to be immortalised in the film *The Yangtse Incident*. While based at Shanghai in 1949, a Civil War was being fought by the Communists and the Chinese Nationalist Party (the Kuomintang). On 20 April 1949 the *Amethyst* was ordered to relieve HMS *Consort*, a ship that was protecting the British Embassy at Nanking on the River Yangtze, and to make preparations to evacuate all British citizens facing the Communist advance. Whilst transiting the Yangtze, and despite flying numerous Union Jacks, the Communists opened fire, inflicting significant damage and nineteen fatalities (including the ship's Commanding Officer, Lt Cdr Skinner), not to mention causing the ship to run aground on a sandbank, at an angle that rendered the firing capabilities of the two forward turrets useless.

Whilst the politicians and media argued about who was to blame for starting the engagement, *Amethyst* was stranded for months in unbearable conditions of heat and an increasing population of rats and cockroaches. With rapidly dwindling food and fuel supplies, Commander John Kerans, the British Naval Attaché in China arrived from Nanking and took command of the ship. On 30 July 1949, Kerans decided to make a night-time bid for escape. Once again the ship took heavy fire, but at 05:00 on the 31st, the frigate rendezvoused with the destroyer HMS *Concord*. *Amethyst* underwent a refit in the UK in 1950 and, following additional service in the Far East, returned to Plymouth in 1952, was paid off and placed in reserve.

Following her final duty, which was to appear as herself in the *Yangtse Incident* film, on 19 January 1957, *Amethyst* was towed into Sutton Harbour, coming to a final stop on Marrowbone Slip (Figure 10 (Anon., 1957)), next to the China House, where she was broken up by Messrs. Demmelweek & Redding.

Today, the only physical reminder of the ship's demise, and one that is unknown to many, if not most residents of Plymouth (let alone the current owners of the China House) is a diminutive commemorative plaque on the site of Marrowbone Slip with a single, almost unreadable sentence – "HMS *Amethyst*, famed for her role in the Yangtze Incident of 1949 was broken up here".

The Augmented Reality *Amethyst* Demonstrator

The AR Amethyst demonstrator project was designed to visualise the *Amethyst*'s final resting place and to draw attention to what must have been a spectacular sight – a 1350-ton, 283-foot long Frigate laying silent in a harbour which was, at the time, more used to welcoming small fishing trawlers and sailing ships. The 3D model of the ship was constructed from scratch using 3ds max and a variety of data sources – from screen grabs of sail-by sequences from *The Yangtse Incident* film and images from the Web, to not-very-detailed radio control model plans, even old reproduction cardboard construction kits from Micromodels (originally costing one shilling and sixpence). As with the Wembury Docks project, the AR software used was *ARToolkit*, with plug-in features for the *Unity* game development toolkit. The visualisation hardware utilised for the *in situ* demonstration was, again, an *iPad3*.

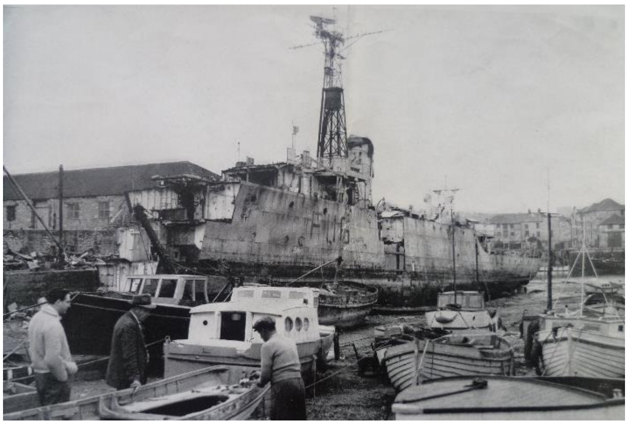

Figure 10. HMS *Amethyst* at Marrowbone Slip in 1957, minus her bow (Anon., 1957).

Figure 11. Marrowbone Slip and the China House in 2012 with the Augmented Reality HMS *Amethyst* visualised via the *iPad3*.

Despite what initially seemed to be a rich collection of data sources, even historical memorabilia relating to the *Amethyst*, the lack of early contact with SME's and, indeed, surviving crewmembers was a major drawback in the development of the 3D vessel. Issues relating to the accuracy of deck materials, the scale of various components, weaponry, the design of the bridge and other key features meant that the resultant 3D model was not as comprehensive as would have been liked. However, as the AR demonstration deadlines were approaching, contact was made with one of the ship's surviving officers, Lt Cdr Stewart Hett, President of the *Amethyst* Association. Not only was he able to provide valuable assistance in clearing up some misconceptions about the ship's make-up, he was also able to ensure that the AR *Amethyst* project (and a VR version, based on the ship moored in Wembury Dock – see Figure 9), would ultimately be presented to a group of highly critical commentators.

The real-world trials of the Augmented Reality system took place in two locations in the Plymouth area. The first was Marrowbone Slip, described above (the present-day context shown in Figure 11). For this demonstration, a revised model of the ship had to be used, whereby all significant deck fittings – guns (large and small), life rafts, depth charge launchers, and so on – were removed (as they would have been, prior to delivering the vessel for breaking up). The second location was on the Cornish side of the River Tamar, just south of Her Majesty's Naval Base at Devonport, where the *Amethyst* made her penultimate journey prior to being paid off and sold to the breakers. Again the main model had to be modified, with the lower hull region (including propellers and rudder) being removed to create a simple waterline effect (Figure 12).

Figure 12. Augmented Reality HMS *Amethyst* visualised on the River Tamar.

Shortly after the *Amethyst* AR exercise in Plymouth was completed, Lt Cdr Hett provided a unique opportunity to present the findings of the early research and field trials. This took the form of an invitation to a reunion event for the surviving crewmembers of the *Amethyst* (including those from the 1949 Yangtze confrontation), together with three generations of family members. A constructively critical audience indeed. However, their acceptance and understanding of the significance of the technologies used, plus their recognition of the potential for future educational development, was both surprising and inspiring. Subsequent to this event, material from crewmembers and families was forthcoming, helping to improve the accuracy of the 3D model.

PROJECT 3: UNMANNED VEHICLES, AR AND RETURN OF THE WARSHIP *ANNE*

A recent "newcomer" to the domain of technologies for field surveys and data collection for digital heritage projects is the small, low-cost unmanned vehicle system (UxV). Typically UxVs are land, water surface/sub-surface and air ("drone") vehicles equipped with remote camera devices or more sophisticated sensors, including LIDAR, thermal imagery and navigational packages. Whilst still in an early stage of development, UxVs have the potential to enable end users to conduct more extensive and informative field surveys than before, in more remote and hazardous areas.

Recent examples where "drones" (or more correctly, small Unmanned Air Vehicles (sUAVs)) have been successfully tested in support of digital heritage projects include Foggintor Quarries and Foxtor Mire within the Dartmoor National Park in the south-west of the UK. Once home to an active quarrying community of some 400 inhabitants (Brewer, 1997), Foggintor was responsible, between 1820 and 1938, for producing high-quality granite for the construction of such famous landmarks as Dartmoor Prison, Nelson's Column and the original London Bridge (today in Lake Havasu City, Arizona). The granite was transported via tramway and the Great Western Railway line between Princetown and Yelverton – the topic of another digital heritage project mentioned earlier in this paper – (and then on to Plymouth, London and elsewhere). By using commercial software (*Pix4D* – a product that automatically triangulates aerial video, frame by frame, based purely on image content), it has been possible to process the digital video to develop highly accurate geo-referenced and fully textured 3D models of this impressive historical site (Figure 13). This technology has the capability to save Virtual Heritage developers enormous amounts of time in the 3D reconstruction process.

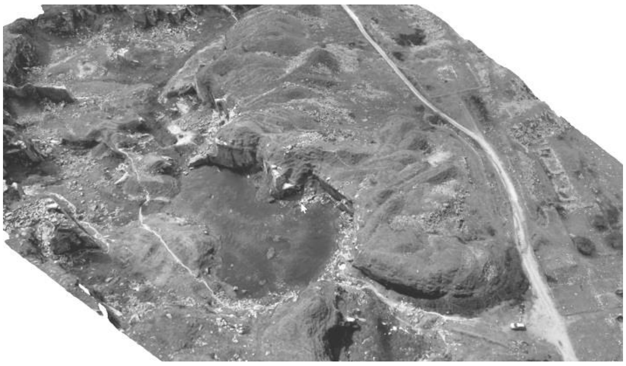

Figure 13. A Pix4D 3D reconstruction of Foggintor Quarry on Dartmoor developed from sUAV aerial digital video images.

Undertaking aerial searches for man-made artefacts in inhospitable regions is another area in which sUAVs can deliver benefits, such as conducting wide area, low-altitude search patterns over short periods of time, not to mention guaranteeing the safety on the part of the investigators. A recent example of a project in this respect is the use of an sUAV to fly over the wreck of a 17th Century warship, where the shifting sands and at-sea-level location demands short-duration and safety-conscious activities. However, during the early flights, an idea for a unique aerial AR demonstration was conceived.

On Pett Level Beach, near Hastings, and only visible at very low tides (especially following periods of stormy coastal-eroding weather), lie the skeletal remains of the *Anne*, a 70-gun third rate ship of the line, built by Phineas Pett at Chatham Dockyard as part of a late 17th century restoration of King Charles II's Royal Navy, overseen by Samuel Pepys (Marsden, 1984). Launched in 1678, the *Anne* was a significant vessel in history and certainly a major component of the Pepys' Restoration Navy (Figure 14). She was one of thirty new standard ships, built under the "Thirty Ship Programme" of 1677. Designed to be highly efficient frontline battleships, the *Anne* and others of her class were to have a significant influence on the Royal Navy, becoming direct ancestors of the ships that ultimately fought at the Battle of Trafalgar in 1805. However, her life as a fighting vessel was cut short twelve years later during the Battle of Beachy Head, in which a combined Anglo-Dutch fleet took on superior French numbers and lost. Having sustained significant damage, the allies attempted to retreat to the relative safety of the Thames, but en route, four Dutch vessels and one British ship were beached on the coast around Hastings. Under the command of John Tyrrell, the heavily damaged *Anne* was beached at Pett Level and was deliberately torched to prevent her from being captured by the French. As much of the ship and her contents as possible were salvaged, but the charred remains were abandoned and left to decay.

Figure 14. Artist's impression of the *Anne* at Malta (reproduced with permission from Richard Endsor)

Over time, the *Anne* sank deeper and deeper into estuarine clay. As a result, the lower part of the ship's hull, which lists slightly towards the west on her port side, is reasonably well preserved, measuring over 44m long, 11m wide and just over 4m high. Contemporary records of the Anne date back to the early 1900s, but significant interest in the wreck was witnessed in the 1970s. Looters using a mechanical excavator caused considerable damage to the wreck site, for the sake of a few cannon balls, grenades and barrel staves (Marsden & Lyon, 1977). Further objects were discovered after this event, but these were put on show at the Shipwreck Museum in Hastings. In 1974, and to prevent further destruction, English Heritage first designated the wreck site of the *Anne* under the Protection of Wrecks Act 1973, and in 1983 the Ministry of Defence and the Nautical Museums Trust jointly created The Warship *Anne* Trust.

In February 2013, following extremely low tides, the Trust reported to English Heritage that the *Anne* wreck site was more exposed than in living memory. Later that year, two months of extensive storms battered the south coast of England, causing widespread flooding across southern England, stretching through Dorset, Hampshire, Surrey and Kent. Despite the destructive nature of the weather, the wreck of the *Anne* was further exposed, and the opportunity was taken by numerous historians to document as much as time would allow.

In 2014, and conscious that the *Anne*'s exposure would be relatively short – 12-18 months at best – an aerial survey of the wreck was conducted, the aim of which was to capture extensive video footage suitable for integrating with a future Virtual Reality model. The video was obtained using a DJI *Phantom 2 Vision* Quadcopter, a small drone of 300m (open space) range and equipped with a GPS auto-pilot system for position holding and altitude lock (Figure 15). The *Phantom 2* is equipped with a 1080p, full High Definition camera, stabilised on an anti-vibration tilt axis (only) and controlled remotely via WiFi using an iOS or Android SmartPhone. During the flight of the Quadcopter, the possibility of developing an aerial Augmented Reality "resurrection" of the *Anne* was discussed, such that a virtual model of the ship could be visualised in real time, in situ, 20m over the wreck site.

Figure 15. DJI *Phantom 2 Vision* over the wreck of the Anne at Pett Level.

Using historical records, extensive illustrations and plans of a sister ship to the *Anne*, the *Lenox* (Endsor, 2009), and collaboration with staff from the Shipwreck Museum in Hastings, the virtual ship was developed by two accomplished intern students visiting the University of Birmingham from Arts et Métiers, ParisTech, Laval in France (Cécile Thevenin and Emilien Bonhomme). Using the 3D modelling toolkit, 3ds max, the detailed VR recreation took nearly ten weeks to complete. Two versions of the model were produced: one of high detail and fidelity, subsequently imported into the Unity3D rendering engine for real-time exploration (Figure 15), and a second of reduced detail, suitable for Web hosting and as the 3D model to be used in the aerial AR trials.

Two successful aerial AR trials were undertaken. The first involved a somewhat crude solution, involving the temporary attachment of a tablet computer to a hexacopter platform (an experimental sUAV, designed to evaluate new control, sensor and display subsystems, including head-mounted displays, panoramic still and video imaging systems, thermal cameras, radiation sensors, and so on). The hexacopter configuration includes six variable thrust, fixed-pitch propellers rotating in alternating clockwise and counter-clockwise directions. This sUAV is capable of fully autonomous flight, GPS waypoint navigation and auto-landing, with stabilisation being governed by a 3-axis gyro, accelerometer, magnetometer and barometer. Auto-heading and altitude hold functions are controlled by an integrated GPS and sonar subsystem. This solution, coupled with the fiducial marker pegged within the centre of the wreck site resulted in a short but nonetheless convincing AR demonstration, visualising the 3D ship as if from the top of the masts, with the real sands as the backdrop.

Figure 15. The Virtual *Anne* moored alongside a small fishing port.

The second AR trial took place seven months later when it was obvious that the sands at Pett Level were, once again, very close to reclaiming the wreck. On this occasion, a commercial sUAV was deployed. The DJI *Inspire 1* (Figure 16) is a very agile quadcopter. As well as reliable geolocation capability using as many GPS satellites as are available at the time of flight, the platform hosts a downward-oriented optical flow camera that feeds data to the quadcopter's rotor control system to keep the aircraft level, regardless of the terrain topography below. The same system controls the raising and lowering of the quadcopter's landing struts, (a) to prevent them appearing within the field of view of the camera whilst in flight and (b) to effect safe, controlled landings.

The *Inspire 1* is remarkably stable, even in winds of up to 30mph. Unlike the earlier hexacopter flight, use was made of the sUAV's 4K video capture and wireless streaming capability, delivered from an onboard proprietary camera with a 94^{o} field of view. This enabled the pilot to see the AR demonstration in real time whilst flying the quadcopter in a first-person viewing mode (Figure 16).

The technical achievements of the Virtual and Augmented *Anne* Project were extensive, but the bigger challenge came in deciding how to engage with residents of Pett Level and other nearby villages. A general invitation event was held at the Pett Level Beach Club, just a few hundred yards away from the Anne's wreck site in December 2015. The event was well attended, with the audience comprising individuals from all walks of life, many in their 60s and 70s. As with the Virtual Wembury Dock demonstrator described earlier, the very fact that the *Anne* was an important and popular part of local maritime heritage meant that engagement was straightforward, even for those older members of the audience who were given the opportunity to visualise the *Anne* using one of the (then) latest head—mounted displays (the Oculus Rift DK2). Again, a good example of "Heritage on my Doorstep" helping to overcome end user anxiety or low self-efficacy in using "high-tech" human interfaces. In addition, the same Augmented Reality marker that was used in the aerial beach trials was laid out on the floor of the Beach Club, enabling the audience to visualise and move around a scaled-down version of the ship using tablet computing technology.

In addition to the Pett Level event, the *Anne* project has been shown extensively elsewhere, including an event dedicated to the history of Ship in Hastings in July 2015, and at the Annual General Meeting of Dartmouth's Museum, where a 92-year-old veteran of the Battle of the Atlantic (1939–1945) confidently donned the Oculus Rift headset to explore the VR reconstruction of the ship (again, a good example of relevancy overcoming hesitancy in using advanced interactive technologies).

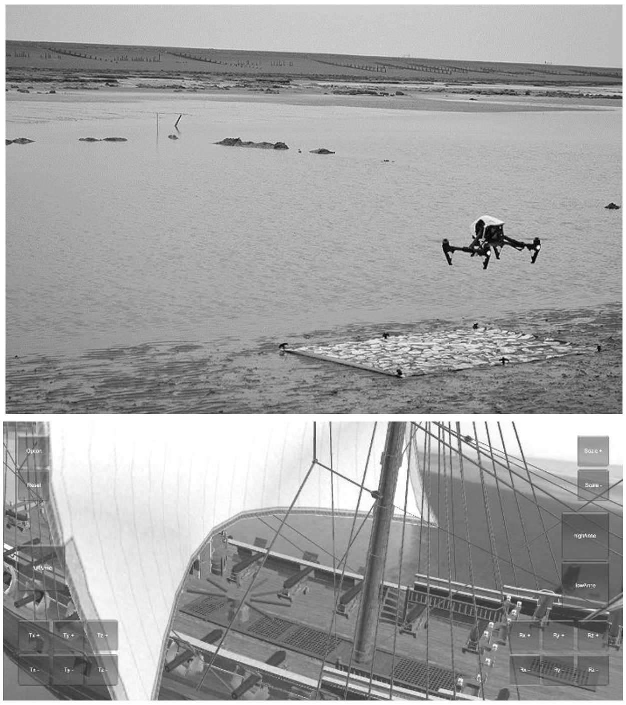

Figure 16. (Upper) DJI *Inspire 1* Quadcopter about to take off over the AR fiducial marker within the *Anne* wreck site; (Lower) *Inspire 1* pilot's view AR screenshot showing the virtual Anne in situ over the real-world wreck location.

CONCLUSIONS

VR and AR, together with the latest variant of high-tech interaction technique known as "Mixed Reality" (or MxR – blending VR, AR with real-world or "tangible" interface objects) continue to demonstrate enormous potential in the delivery of engaging social and educational experiences for cultural heritage. But, despite their prevalence over the past two to three decades or so, their component technologies still have a very long way to go. Even with the significance of the "Heritage on my Doorstep" concept described earlier, where the familiarity of a Virtual Heritage scenario can help overcome early barriers to the use of high-tech interfaces, there is still an important Human Factors "duty of care" that needs to be adopted by Virtual Heritage developers with regard to the safety and comfort of their target users. Only by adopting such a duty of care will those users be able to engage, enjoy and benefit educationally from the rich experiences VR, AR and MxR will bring in the future as more and more novel interactive technologies mature and, thus, become available to the masses.

Of the three variations, VR remains the most mature and has had ample exposure to the heritage arena since the early 1990s, albeit with mixed results in terms of feedback from, and uptake by stakeholders, end-users and the general public. Generating high quality content is not the major issue here, as the VR modelling and rendering toolkits that are available today are more accessible and capable than ever before, and many are actually available free of charge for academia, small businesses and even the general public. The main drawback with VR lies in the delivery and interaction technologies. Despite the hype one reads online and in Internet technology magazines, once one passes the "wow" phase of donning a head-mounted display for the first time, the reality of low-resolution displays, narrow fields of view, discomfort, disorientation and nausea begins to set in, not to mention the fact that one's movement is often restricted by the use of cabling. The same is true of interactive controllers, or data input devices.

It is well known that those who spend much of their free time interacting with first-person action computer games are those who will adapt quickly and efficiently to being presented with a new human interface device. For most of the remaining members of the population, however, it is often the case that requesting them to wear obtrusive head-mounted displays, gloves, hand-held "wands" or other devices has two effects. The first is that they spend more time trying to adapt to the interface – getting to grips with what they need to do with the VR system to explore virtual worlds and interact with its constituent objects – than they do benefit from, or to be educated by the experience. The second is that, during the VR experience, they may experience a range of negative effects on their well-being from being sensorially "confined" within a face-enclosing structure, cut off from the security of the real world (although this is not an effect that is exclusively a problem with head-mounted displays; see also Stone, 2102a). Using head-mounted displays – and particularly face-enclosing units – is, therefore, to be discouraged for long-term (i.e. greater than just a few minutes) general population experiences of Virtual Heritage at this point in time and other VR setups, even involving high-definition screens (as was found by Cheng (2015) require their users to be monitored for early symptoms of malaise.

There is no doubt that this situation will change, but until that time comes, it is very much the case that there are only a very small number of Virtual Heritage demonstrations that truly warrant the use of headset-based VR. Such an example is the Virtual *GLAUCUS* project where, in order to convey the effects of diving down to and entering what was a very claustrophobic early British subsea habitat (Heath, 1967), a head-mounted display solution provided an appropriate vision-limiting experience for the designer of the habitat, Colin Irwin, to revisit his 1965 £1000 subsea experiment once again (Figure 17).

Turning now to Augmented Reality, which has also seen a recent increase in popularity (despite its much earlier entrance onto the interactive 3D stage at the beginning of the century), whilst some recent conceptual papers have painted a range of "what-if" scenarios (e.g. Morrison *et al*., 2012), it is still obvious that applications of AR are quite limited, particularly with regard to real, in-the-field experiences, such as the projects described herein, not to mention subsequent usage of the technology in educational or museum settings. Having explored the potential for AR in museums since 2011, Shelley Mannion, Digital Learning Programmes Manager at The British Museum, summed up the situation quite admirably when she concluded, "As a technology platform and interaction style, AR is still in its infancy. Many applications are mere proof-of-concept rather than robust solutions integrated into museums' existing programmes and interpretative strategies. However, this does not diminish its potential for creating engaging and meaningful experiences for visitors. AR may have been overhyped to begin with, but we are now entering a more serious phase during which its usefulness will become evident" (Mannion 2013).

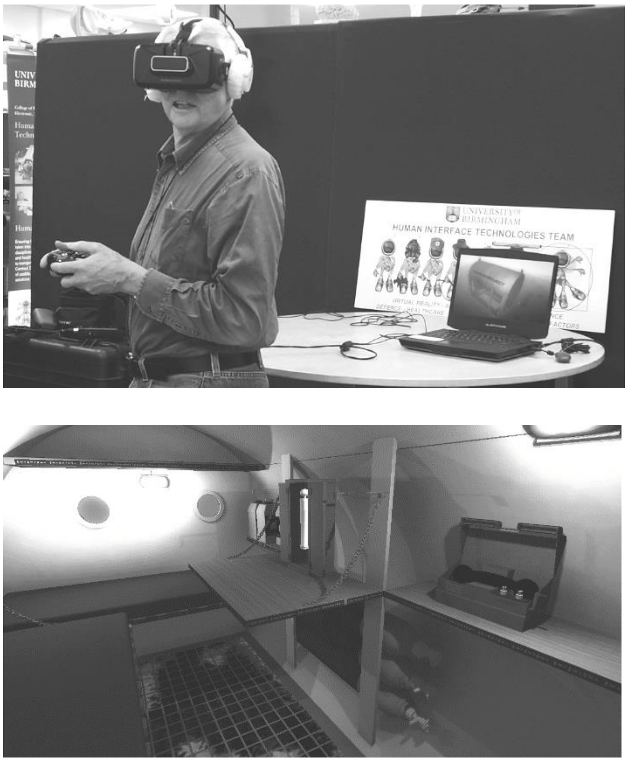

Figure 17. The original designer of the UK *GLAUCUS* subsea habitat uses an *Oculus Rift DK2* head-mounted display and Xbox gamepad explore a VR recreation of his 1960s creation.

External or field exploitation of AR techniques is even more challenging in that the use of head-mounted display technologies, putting to one side the comments raised above, may pose serious problems with end users' safety. Donning a headset that presents rich, attention-grabbing visual information relating to a historical site in an open field, such as the buried Roman City of Wroxeter, is one thing. Using that same technology in already hazardous areas, such as cliff edges (as has been suggested in a West Country coastal path AR application concept), steep hillsides or mountains, or in areas with waterlogged or marshy ground and so on is quite another.

Another particular issue with current AR technologies is that, despite the claims of the developing and vending organisations, using the software in anything but a structured environment with consistent lighting is a major problem. Attempting to use that same technology in a rural location, with (for example) archaeological sites covered in plant growth, seasonal environmental changes and unreliable WiFi or GPS connections can be a very frustrating experience. Furthermore, as anyone who has tried to view a SmartPhone or tablet screen in an outside environment will testify, the on-screen contents of these mobile computing technologies are extremely difficult to view or interact with, despite them being highlighted by many as currently being the interface of choice for "real-world" AR applications. This means that, for the near-term future, the use of high-contrast fiducial markers, as mentioned earlier, is by far the most reliable technique. Even then, setting up such a demonstration in the field brings with it certain challenges, such as moving objects, people and animals causing loss of camera lock, or scaling issues, as was shown during the set-up of an AR recreation of the return of US President Harry Truman's Douglas VC-54C aircraft, the *Sacred Cow*, during a 1940s event staged in 2015 at the long abandoned airfield of RAF Harrowbeer in Devon (Figure 18).

Figure 18. Fiducial marker (bottom left-hand corner of picture) used to "activate" an AR recreation of President Truman's *Sacred Cow* aircraft at RAF Harrowbeer.

Throughout the course of the projects described herein (bearing in mind that many are still ongoing at the time of writing), Human Factors issues have consistently been at the forefront of activities, be they on-site technology-mediated surveys, interacting with subject matter experts, asset holders and, of great importance, members of the public, undertaking exercises to define fidelity levels of Virtual Heritage content, recording usability issues with the VR and AR toolkits, or selecting appropriate display and interaction devices to expose end users to early, interim and mature demonstrator developments. In a very short time, it has become apparent that there are many synergies between the issues covered in international Human Factors standards and in specific VR/interactive media guidelines, but that the unique nature of the Virtual Heritage arena warrants its own attention to human-centered design. If a sector-specific document could capture salient experiences and lessons learned from real-world projects and help make those experiences and lessons openly accessible to future developers, then perhaps many more Virtual Heritage projects could deliver the same impact as was experienced when presenting the projects described herein to those who stood to benefit most from demonstration and engagement.

About the Human Interface Technologies Team

The University of Birmingham's Human Interface Technologies (HIT) Team, based within the School of Electronic, Electrical & Systems Engineering (EESE), has been pioneering the development and uptake of interactive media and robotics technologies in the UK since 2003, building on nearly 3 decades of experience in the domain of Virtual Reality (VR), Augmented Reality (AR), Mixed Reality and Telerobotics/Telepresence. The Team's participation within the UK's Human Factors Integration Defence Technology Centre (HFI DTC) between 2003 and 2012, and, more recently collaborative initiatives addressing future human-system interfaces for command and control in defence, aerospace and unmanned systems, continues to provide excellent opportunities to work closely with stakeholders and end users in the development of methodologies supporting human-centred design for advanced part-task trainers, visualisation techniques and novel human interface concepts for telerobotic systems. In the healthcare domain, the HIT Team has been developing interactive data display and control technologies for the investigation of Virtual Restorative Environments and their impact on patient wellbeing, especially in Intensive Care. More recently, the HIT Team has become involved in projects to recreate sites and artefacts relating to *industrial* and *maritime archaeology*, as these fields are in keeping with the engineering focus of the School in which the Team resides and offer the opportunity to interact with real-world rural and sometimes remote communities (fostering strong public engagemnt and *digital inclusion*). The Team uses a variety of novel technologies to support its heritage site surveys, from small Unmanned Air Vehicles and a mini-submarine, to image processing software capable of converting images captured from aerial video into 3D, fully textured scenes.

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