Virtual Reality for Maritime Archaeology in 2.5D: A virtual dive on a flute wreck of 1659 in Iceland

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***Abstract*— Public engagement with underwater cultural heritage presents a number of special challenges, particularly with regards to realism, authenticity and education. Digital archaeology specialists working in Adelaide, Australia have undertaken a collaboration with maritime archaeologists and museums in Reykjavik, Iceland to create a Virtual Reality (VR) diving experience based on Iceland's oldest identified shipwreck, *Melckmeyt*, a Dutch flute which sank in 1659. The experience was designed using a fully animated 2.5D VR environment, taking participants on a guided tour with a set time limit rather than offering an interactive experience. This approach maximises the sense of immersion in the underwater environment and replicates as closely as possible the experience of diving for the non-diver. This chapter considers the benefits of 2.5D VR compared to the more commonly applied 3D or interactive VR and argues that 2.5D VR offers significant potential benefits for museum use and *ad hoc* use for public engagement.[1]**

***Keywords*— Iceland; 3D reconstruction; Shipwrecks; Virtual Reality; Maritime Archaeology**

I. Introduction

The wreck at the centre of the project was a Dutch merchant ship named *Melckmeyt* (Milkmaid). It was discovered in 1992 by local divers Erlendur Guðmundsson and Sævar Árnason, close to a tiny isolated island called Flatey in Breiðafjörður, off the west coast of Iceland. A preliminary investigation was carried out in 1993 [1] on behalf of the National Museum of Iceland. The significance of this wreck is enormous for Iceland. Despite a maritime past stretching back to the Vikings, this 17th century wreck represents the earliest physical remnant of an ocean-going vessel for this maritime nation. It is also a rare piece of evidence of an important period of Icelandic history, when Denmark ruled the island and had a monopoly over trade there for a period of 185 years [2]. Archival sources recently uncovered in the Netherlands show that the ship was built in the Netherlands and was then purchased or hired by a Danish merchant who sent it to Iceland as part of a small fleet of seven merchant ships to trade with Iceland 360 years ago. Entries in the Icelandic Annals record the loss of the *Melckmeyt* and its full cargo of fish while at anchor during a fierce October storm. Fourteen of the crew members managed to make it to the shore but one of their fellow crew lost his life in the escape. The surviving crew members over wintered on Flatey island and were they were greatly helped by the locals, before they could attempt a return to their homeland. They managed to do so the following summer in 1660. Some of the crew made a statement on the loss of the ship to a notary in Amsterdam and this statement survives today in the city archives complete with signatures of many of the original crew members.

This wreck also has a particular significance as one of the only known well-preserved Dutch flutes with significant archaeological hull preservation, with the potential to throw light on the entire vessel type. The flute ship underpinned Dutch maritime dominance in the 17th century, and this little ship is often referred to as the 'workhorse of the Dutch merchant trade' [3, p. 17]. *Melckmeyt* was wrecked in 1659, just as Dutch power was at its height, a period remembered as the *Gouden Eeuw* (Golden Age). Investigations at the site restarted in 2016, when a team of divers from the University of Iceland decided to carry out a more detailed survey [2]. This team was led by Kevin Martin, a maritime archaeologist and PhD student in archaeology at the University of Iceland, with the assistance of maritime archaeologists from the Dutch Cultural Heritage Agency who were interested in the ship as it was believed to have been built in the Netherlands and represents one of the world's most northerly historical Dutch shipwrecks. Subsequently, through a collaboration with the Maritime Archaeology Program of Flinders University in South Australia, the data from this survey was combined with scans of a contemporary ship model held in a museum in the Netherlands and used to build a virtual reality experience.

II. Virtual Reality for Maritime Archaeology

A. Background

Virtual reality has been an area of particular interest to maritime archaeologists, as shipwrecks and other submerged cultural heritage sites are inaccessible to most members of the public. As early as 1998, there was discussion of the potential for 'virtual museums' and how websites had the power to transmit a sense of the experiences of underwater archaeological excavation in ways that traditional museums could not [4, p. 27]. At that stage, immersive virtual reality was still within the realm of science fiction, but within less

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than a decade the technique of underwater photogrammetry began to emerge and was rapidly adopted by the discipline of maritime archaeology [5]. This technique offers a chance to change this, allowing users not only to view underwater archaeological sites but to know that what they are viewing derives a certain level of authenticity from the original site, as the wreck is not something that has been created but which is raw survey data. Maritime archaeologists quickly realised that they could use this data to 'immerse archaeologists inside a virtual universe depicting a reconstructed archaeological site, for example a shipwreck' [6].

The first VR experiences for maritime archaeology using tracked Head Mounted Displays (HMD) followed soon after and even at this early stage the emphasis was placed on interactivity, with users able to move freely around the site and to pick up and examine objects [7]. Somewhat surprisingly, there have been relatively few VR applications for underwater and maritime archaeology since then, but the focus has remained on increasingly capable and complex interactive experiences [8]–[13]. Most of these experiences are created with game engines such as Unreal or Unity. This interactive approach facilitates complex and extended interactive experiences with a lot of educational potential but which have some drawbacks in public engagement scenarios. Interactive experiences are user-driven, and this can cause them to take a long time, greatly limiting the numbers of users who can share in the experience. Each user must also learn the controls for the interactive experience during their limited time and this can easily distract from the subject matter. *Titanic VR*[2] is an excellent example of a scientifically credible VR experience that has been successfully launched as a popular game, but its six-hours of gameplay makes it impractical for use in public places and less accessible to those with less computer-literacy. Some of the other problems of a complex interactive and user-navigable VR approach for wrecks have been described by a team in Finland [14] where it was found that users were sometimes confused by the controls, or got lost or stuck inside the ship, with user-experiences lasting ten minutes or more.

For these reasons, it can be more effective to create VR experiences with limited or no interactivity, allowing a defined time limit for the experience. 2.5D VR is a form of virtual reality that is not fully 3D and interactive but is an animated 360° panoramic video. Such videos can be captured using a 360° panoramic camera which can later be viewed in a VR headset. From around 2010, submersible 360° or omnidirectional cameras have used to create underwater tours, often for scientific purposes such as coral monitoring [15]. More recently, consumer grade 360° cameras have become widely available and underwater videos have proven to be some of the most popular content on VR content platforms, particularly for encounters with marine animals such as sharks. 3D animation software can also be used to create 2.5D content. This can be achieved by rendering two adjacent 360° panoramic views of a 3D scene, with two virtual cameras positioned at approximately eye distance apart. The paired cameras can be animated to create a virtual 2.5D tour of a simulated environment. In preparing these files for use in a viewer, both frames are combined into a single still image with one placed above the other and this video is then given appropriate metadata so video playback devices can recognise this format and divide the images for playback. One of the best current examples is *Dare to Discover – a VR journey*, a permanent exhibit at the Scheepvaartmuseum in Amsterdam. This is a 2.5D VR experience where members of the public fly around a photo-realistic recreation of 17th century Amsterdam. A 2.5D design and an entire room full of synchronised headsets allows 15 users to share this experience simultaneously and for large numbers to pass through each day.

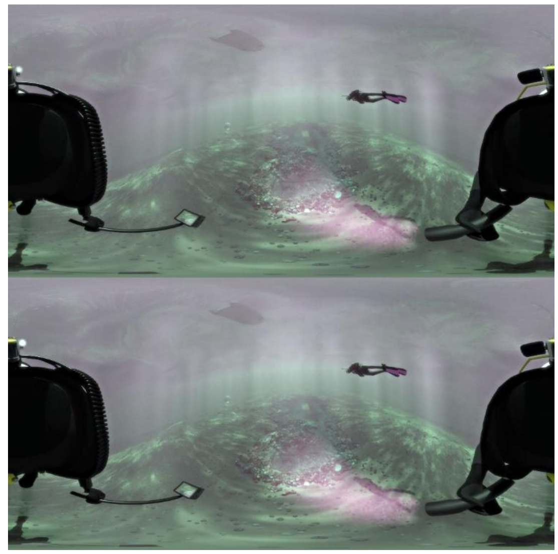

Fig. 1. A single frame of the Melckmeyt virtual dive, showing the top-bottom configuration of the format. The two parts are separated and projected to each eye in a VR headset (image by John McCarthy).

2.5D VR

There are two major advantages to a 2.5D approach. Firstly, the experience can be more easily directed by the archaeologist to ensure that the key information is transmitted within a set time limit. The movement of the user through the virtual environment and the appearance of features along the way is entirely defined by the completed animation. The user has limited interactivity with the scene and can control only their viewing direction. Rather than detracting from the experience, this arguably allows a greater focus on the experience and content, and prevents the technology itself becoming the focus, as is often the case with interactive VR. Real dive trails are often controlled in this way with a sequentially numbered trail of tags for divers to follow in a pre-defined order. Many shipwrecks are long and linear, meaning that all key features can be seen on a controlled path. This 'directed tour' is particularly useful for museum use, where user engagement time is limited, allowing for greater numbers to participate in the experience and where levels of previous user experience with VR are likely to be low.

Secondly, a sense of immersion or realism is a key goal for both historical and underwater VR experiences. Haydar et al [7, p. 147] noted the importance of environmental factors such as caustics and volumetric lighting to the sense of immersion, as well as the challenge of presenting contextual background information about both the site and

[2] http://titanicvr.io/ Accessed 15/5/2019

artefacts in a way that did not detract from that carefully constructed sense of immersion. Complex interactive VR experiences based on game engines can be limited in visual quality as the virtual environment must be generated in real time, limiting the number and quality of objects within a scene and limiting the use of computationally expensive environmental effects such as volumetric lighting and reflections. For an interactive 3D experience, the VR hardware must be capable of rendering the scenes at a sufficiently high frame rate to prevent lag, which is distracting and often results in nausea. One solution is to run interactive VR from a tethered computer, but this comes with a high price in terms of the cost, complexity and portability of the VR system. While the performance of VR implementations of all types is increasing rapidly, the current performance of portable game-engine-based VR solutions is relatively low, limiting the number of objects and the resolution of textures. The 2.5D approach allows the creator essentially unlimited freedom to design features for inclusion in a way that would not be possible for a fully 3D interactive experience, because of the limitations of computing power. In a 2.5D approach, everything is rendered beforehand and output into a simple video file, playable by even the most basic and low-cost viewing devices. there is essentially no limit on the number of objects or the level of detail that can be included as well as the use of process-intensive effects. Instead, all of the burden of rendering the animation takes place beforehand, during the creation of the video file. While this can be a rapid process, for the *Melckmeyt* project, the archaeologists aimed for a realistic and detailed underwater scene and the level of detail used required a large amount of rendering time on powerful computers. Underwater scenes are a unique environment resulting from a complex combination of visual factors, including differential absorption of the visible light spectrum over distance, light scattering, ‘God rays’ emanating down through the water column, caustics visible on the seabed, particulate suspended in the current and complex reflections, particularly from the sea surface above. All of these effects can be approximated in real time in interactive game engines but for a physically realistic effect that maximises the sense of immersion, a far superior result is achieved by rendering in advance, as all of these are computationally expensive effects.

III. Methodology

The animation was created by the lead author over several months during 2018. The most important factor considered in designing the VR experience was portability, for use in museums and at public engagement events. A Samsung Gear VR was chosen as the preferred device and the animation was tailored to its specifications. At the time of selection in 2018, this headset offered the best resolution for a mobile headset that did not need to be run from a tethered PC (as with contemporary solutions, such as the HTC Vive). Two full renders of the animation were created, the first as a draft and the second as a final version incorporating feedback from project partners and museum staff. In the final render, a total of 5,774 frames of 2160 by 2160 pixels in a top/bottom format were created. These were combined with a frame rate of 28 frames per second, for a 2.5D VR experience lasting for three minutes and 24 seconds. Although a professional render farm (an online rendering clustered computing service) was used, the use of volumetric and light emission effects meant that each frame took approximately ten minutes to render and the final render animation required a total of 40 days of render time.

The aim of the project was to create an immersive and realistic virtual dive experience, while at the same time exploiting the capabilities of 3D modelling to convey as much information as possible in the time available. No interactivity was built in and users followed a set path through the 3D environment, only able to look around. A timeline of events within the animation was created to encourage the user to look around and explore the environment visually.

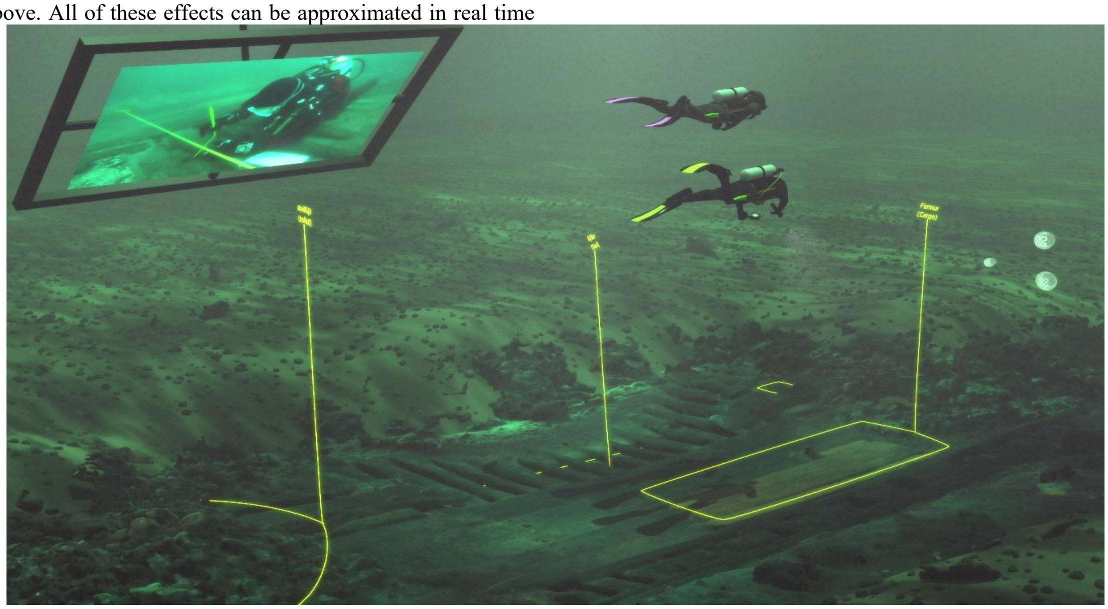

Fig. 2. An outside view of the first part of the animation (image by John McCarthy).

The animation was presented in two parts of equal length. In the first part the user swims over the wreck site as it was exposed during the 2016 3D survey. This environment contains the photogrammetric survey data with seabed added around it and other background environmental features such as kelp and jellyfish. The VR camera position was placed in a first person view atop an animated diver's body. The archaeologists were able to draw on their experience of diving on wrecks to create an experience that other maritime archaeologists understood immediately, and it was assumed that others would too. However, some of the viewers of the first iteration of the 2.5D VR animation reported that they did not recognise that they were a diver and had thought perhaps they were in a submarine. This highlighted an important distinction between the archaeologists who created the animation and the public. To minimise this issue, a second diver swimming alongside provided more visual context and was also more realistic, as recreational diving standards generally require all divers to be accompanied by a 'dive buddy' for safety reasons. This diver also aided in providing an intuitive sense of scale. Other features added to heighten the sense of realism included a dive boat floating on the surface above the diver, a reflective and animated water surface and jellyfish. Non-realistic effects were used for some expository elements, but these were clearly distinguishable from the main scene. They included a video screen showing video clips of the underwater survey process and glowing yellow labels in both Icelandic and English which appear sequentially during the dive, to explain some of the key wreck features (Fig. 2).

At the centre of the scene, the wreck itself is presented as a photogrammetric model. This model was captured using a GoPro camera during the 2016 fieldwork and processed using Agisoft Photoscan (now Metashape). This type of recording has been generally available since around 2009 and has rapidly become a new standard in maritime archaeology in recent years and much current research is focused on ways to effectively exploit this rich new data [5], [16]. The wreck survey is presented as a mesh with photographic texture in the VR experience. Editing of the model was restricted to colour correction and mesh creation and downsampling, so that it presents a photo realistic 3D appearance and is seamlessly integrated with the modelled parts of the scene. This allows the viewer to see the wreck just as an archaeologist would and ensures that a level of authenticity is preserved within the virtual experience. The second part of the virtual dive replaces the wreck survey with a conjectural reconstruction of the ship as it might have appeared just after sinking. The aim of this was to allow the virtual divers make the leap from seeing a wreck on the seabed to understanding it as part of a ship that has largely disappeared. As Adams [17, p. 94] states 'even to experienced eyes the relationship of many wrecks to the complete entity they once were is often far from clear'. *Melckmeyt* is believed to have been a Dutch-built flute but was sailing under a Danish flag at the time of sinking [2]. To create an authentic reconstruction grounded in contemporary material, the lead author travelled to the Netherlands to scan a 17th century model of a *groenlandvaarder*, a sub-type of flute ship specifically designed for heavy North Atlantic seas. One model of this type, dating to approximately the same period as *Melckmeyt* is known to survive. This model is historically very significant but is not on display and is currently in storage at the Maritime Museum in Rotterdam (inventory number M211). With the help of the curators, the model was scanned using photogrammetry and the resulting scan was then subtly changed to match the interpreted details of the *Melckmeyt* wreck. The marks of age acquired by the ship model over approximately 350 years fit very well with the expected wear and tear that a real ship sailing in the North Atlantic might have received in the decade or so of its working life. Changes were limited to repainting the model's Dutch flag to a Danish one and changing the painting on the stern to one that matched the name of the ship, as was typical for Dutch ships of this period. By happy coincidence, 'The Milkmaid', one of the Netherland's most famous paintings by the artist Vermeer, was painted just a year or two before this ship met its fate in 1659. Although there is no direct connection between the two, the painting was an obvious choice for replacement of the stern painting, albeit to a standard that is probably somewhat finer than the original.

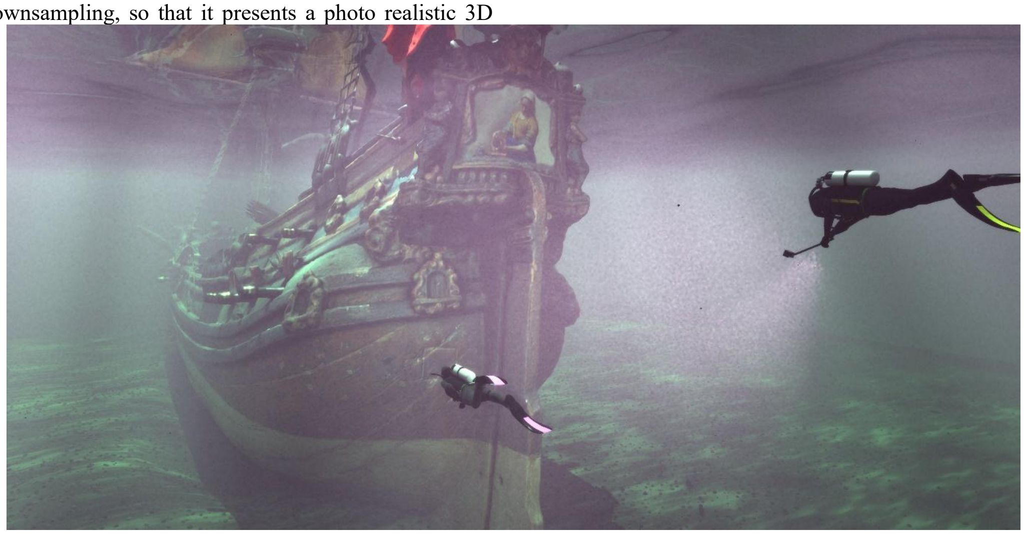

Fig. 3. A scan of a 17th century ship model was used as the basis of the reconstruction, with small alterations such as Vermeer's Milkmaid added to the stern (image by John McCarthy).

IV. Results and Public engagement

The principal location for deployment of the virtual dive experience was the Reykjavik Maritime Museum in Iceland. The 2D animations and VR experience formed central elements of an 18 month-long exhibition (June 2018 - December 2019) on the ground floor of the museum entitled *Melckmeyt 1659*. The museum purchased ten Samsung Gear VR headsets to allow for large groups to undertake a virtual dive simultaneously. In addition to the display in the museum, the portable nature of the VR experience greatly facilitated its use for public dissemination. One of the best outcomes from this was the sharing of the virtual dive with the local residents of Flatey where the wreck is located. Flatey (flat island) is an isolated island about two kilometres long and one kilometre wide in the bay of Breiðafjörður, lying approximately 16 km from the nearest point on the mainland. Although an important trading centre in the medieval and post-medieval periods, Flatey's permanent population has now reduced to five permanent long-term residents, with sheep farming and fishing as its main industries along with tourism which has been on the rise in recent years. Although the residents know the basic history and location of the wreck, none of them had ever seen the wreck as none are divers and the wreck has been covered by geotextile to prevent decay. It was felt important that these key stakeholders in the site should be offered the chance to virtually ´dive on the wreck´ and this was achieved during fieldwork in 2018 by visiting them in their homes and places of work (Fig. 4).

Fig. 4. Project leader Kevin Martin takes local residents working in the slaughterhouse directly opposite the wreck site on a virtual dive during archaeological fieldwork in 2018.

The virtual dive has been taken to many public events, conferences and exhibitions in Europe and further afield, including gatherings of the recreational dive community in Iceland and shown to maritime archaeology specialists in Iceland, the Netherlands and Denmark who were able to comment on features of the wreck. It was also felt to be important to gather formal feedback on the experience. Formal evaluation is a critical component of any public dissemination project, particularly when using novel and experimental approaches and although it is often overlooked, it is vital to establish the success or failure of the work undertaken and to provide lessons for future work. A feedback day was arranged with curators of the South Australian Maritime Museum in September of 2018. Over the course of a single day 20 visitors to the museum were invited to undertake the virtual dive and answer a series of questions, as well as providing comments. Responses are shown in Table 1 below.

TABLE I. Survey responses on the Melckmeyt VR

Survey responses on the *Melckmeyt* VR taken at the South Australian Maritime Museum, September 2018				
	Yes	***Maybe***	***No***	***Blank***
Have you used VR before?	4		16	
Feeling of nausea?	1		19	
Did you recognise the timbers in P.1 as a shipwreck?	17		3	
Was the reconstruction in P.2 highly accurate or made up?	13	2	4	1
Were any elements confusing or distracting?	3		17	
Did you understand you were a diver?	17	1	2	
Have you ever been diving?	2		18	
Does this give a good sense of diving?	16	3		1

Feedback was enthusiastic, and all comments were positive. For 80% of the virtual divers, this was their first VR experience. This highlights the importance, particularly in short museum experiences, of simple VR interfaces that do not allow complex controls and other features to distract the user's attention from the archaeological subject matter. Only one respondent reported mild nausea, suggesting this is not a major barrier to implementation of this format.

Most survey respondents believed that the reconstruction was highly accurate and for the most part did not question its veracity. Maritime archaeologists have begun to consider the potential pitfalls of presenting 3D survey data and reconstructions based upon it [18, p. 67] acknowledging the risk that photo-realistic scans and reconstructions can obscure gaps in the underlying data and archaeological interpretation. While the archaeology of the wreck shown in Part 1 is comprehensively surveyed, some uncertainty remains about some features of the reconstruction. Any differences between the model and the real ship are likely to be minor, although the model is slightly less elongated than a typical flute [19, p. 38]. If there is any risk that the historical experience of the user may be impacted by this, it is offset to some extent by the use of authentic contemporary material throughout, so that while some small details of the exact design of *Melckmeyt* are not yet known, the viewer does experience a virtual dive on a real mid-17th century Dutch flute of the type that sailed in the North Atlantic, albeit a scaled-up ship model rather than an intact preserved wreck. Even the minor alterations made to the stern of the model are made using Vermeer's painting, which also constitutes contemporary Dutch material. This reliance on 3D scanning with minimal intervention has important implications for the overall authenticity of the experience, promoting a sense of connecting with history in a way that objects created by artists in 3D modelling software cannot.

Accessibility is also a key issue. Neither the wreck site nor the ship model are accessible to the general public, and this also applies to a large extent to the act of diving itself. The power of VR to break down accessibility barriers is very clear in this case. Only 10% of the museum goers had any experience of scuba diving. Half the number that had tried VR, although VR is very recent and recreational scuba diving has been available for decades. Most respondents felt that the VR gave a good impression of real diving and this included all these with real experience of diving. Although formal feedback was limited to 20 people, the results of the survey are very much in line with the experiences of the authors in taking many other people on the virtual dive.

V. Conclusion

Virtual reality offers major benefits for the field of maritime archaeology and much of the work carried out in this area has focused explored the potential to make the most of this new technology through complex interactive implementations. While these have been effective in terms of research and for solo use or for small numbers of participants where time is not a factor, there are significant drawbacks for practical public engagement. We have demonstrated that 2.5D VR can be a practical and highly effective approach for immersive and authentic virtual dives on maritime archaeological sites such as shipwrecks. This approach offers a low cost solution for portable high-quality VR experiences, requiring only a smartphone and lightweight headset that can be easily deployed at short notice and in remote locations. The 2.5D video files can be easily disseminated through VR-capable online platforms such as YouTube and viewed in any of the standard consumer VR headsets such as Google Cardboard, Oculus Rift or HTC Vive.

This project has made it possible for a wide segment of the public to share in the experience of diving on one of the most archaeologically significant maritime heritage sites in the North Atlantic. While complex and interactive VR experiences will continue to be an important part of maritime archaeological dissemination, curators and archaeologists should be willing to embrace directed or controlled virtual dives in order to effectively convey information about the past to as wide as possible a segment of the public.

Acknowledgments

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