"Holographic Archaeology": Mixed Reality implementations in archaeological field- and laboratory work: New perspectives and challenges

Leitourgakis, Andreas

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New perspectives and challenges

Student name: Andreas Leitourgakis

Cover Page Image: Adding measurements to drawn features using the DATCH software. View of the western side of the northern Mytikas tower, indicating drawings of stones and their measurements. A) Drawings and measurements on the actual wall. B) The same section viewed in an indoor setting. (Photograph: Andreas Leitourgakis).

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Student name: Andreas Leitourgakis

Student number: s4146654

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Thesis supervisor: Dr. Kalaycı

Leiden University, Faculty of Archaeology

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Chapter 1. Introduction

Context and Relevance

Archaeologists today have access to a large number of digital tools that assist them in their daily tasks and help them interpret the past in more meaningful and nuanced ways. Immersive technologies, that is the whole spectrum of Augmented, Mixed and Virtual Realities, have had a constant and rising presence in archaeological discourse when designing visualizations of the past during the last few decades. Their main advantage is that they display 3D data integrated in the surrounding environment the user is in, whether that is completely digital or the real world (Fogliaroni, 2018, p. 15). With the rise of post-processualism in archaeology came also the need for more dynamic reconstructions of the past, so that the person immersed in a past landscape would have an experience as close to the original as possible (Landeschi & Betts, 2023, pp. 3-4). The integration of the senses is crucial in this endeavor, as reconstructions used to emphasize only on the aspect of vision. As Eve (2012, p. 583) succinctly states "an experience is not limited to what can simply be seen from a point in the landscape, but includes what can be felt, heard, smelt, tasted, and touched…".

This is the major factor behind such immersive technologies becoming more and more influential in archaeology. These advancements have been enabled by the rapid development of reliable hardware options for displaying and processing computer graphics (Dilena & Soressi, 2020, p. 2). Immersive reality tools have been implemented successfully for educational purposes, whether they are enriching a tour in an archaeological site or a museum exhibition as it will be demonstrated below. Bekele et al.'s (2018, p. 18) informative Venn diagram (Figure 1) visualizes how these above-mentioned applications are the most well represented ones of this technology in archaeology and cultural heritage.

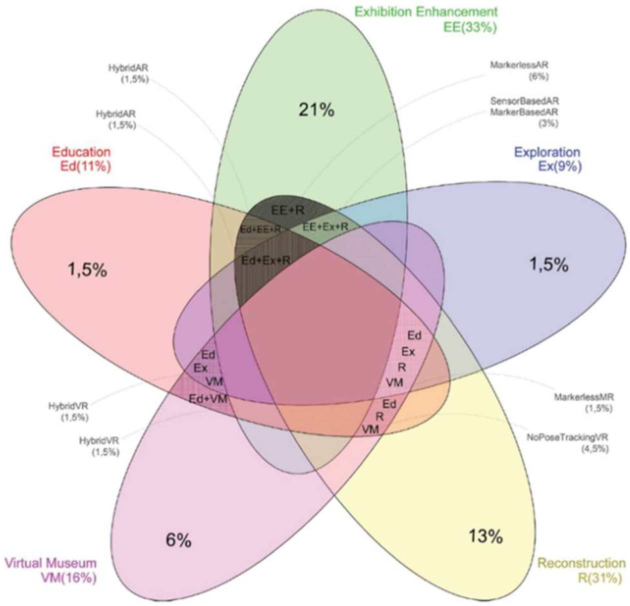


Figure 1. Venn diagram showing the relationships between the different categories of applications of Immersive technologies in Archaeology and Cultural Heritage (Bekele et al., 2018, p. 18, Fig. 2).

The category defined as "Exploration" includes implementations that are mainly created by specialists and aim at visualizing and manipulating the past so as to further current knowledge about it (Bekele et al., 2018, pp. 21-22). Currently, it remains the smallest group of applications, however. When emphasizing in the field of archaeological research, such implementations consist of an even smaller fraction, as Dilena and Soressi (2020, p. 2) stress.

Targets and Research Questions

This small section is the point where this thesis aims at contributing, by exploring the potential and the limitations of using Immersive technologies as part of an archaeologist's toolset for recording and documenting, both at the trowel's edge and in a laboratory setting. This thesis will also emphasize on Mixed Reality (MR) applications and not in the whole Immersive technologies' spectrum, as the hardware used – Microsoft's HoloLens 2 – is best placed in that category, as it will be discussed below.

Two distinct case-studies have been chosen. The first one is linked to field archaeology and the research problem that I aim to address, in this case, is how can

MR be used in the documentation, visualization and contextual analysis of different archaeological features, unearthed during fieldwork or still-standing in a site. This thesis also aims to assess how and to what extent can such tools be implemented in the workflow of an archaeological excavation. Archaeologists today gather a large amount of data and this intensification can be overwhelming when dealing with different types of data too. Thus, MR aims to be a solid basis on which to visualize and explore relations between that data and lead to the creation of possible interpretations and their testing. This could be achieved by creating simple drawings of features in 3D and studying their spatial relationship, both in situ and off-site.

The second case-study presented concerns laboratory work. The target here is to evaluate how can MR assist the documentation of artifacts. This research emphasizes in zooarchaeological problems, and more specifically in the field of digital reference material for animal bones. In this way, I aim to address the advantages of using MR applications both for the study of zooarchaeological assemblages as well as for academic teaching purposes, since these targets are intertwined when using extensive reference collections, either physical or digital ones. Last but not least, these implementations will be compared to other technologies that have been used to address similar research problems. As a result, the efficacy and caveats of the work presented will be highlighted.

Mixed Reality and the Virtuality Continuum

First of all, it is necessary to provide a general background regarding the technology that is used in the case-studies presented below. This will be useful not only to have an overview of the basic terminology used but also to gain insight on the various nuances that differentiate these technologies. It should be already mentioned, however, that even though there is a general consensus how these technologies are defined, there is still ambiguity in the literature regarding their meaning and as a result it is not a rare instance to trace different terms being used to describe the same thing, as is usually the case with Augmented (AR) and Mixed Reality (MR) (Liang, 2021, p. 250). This could easily lead to misinterpretations and confusion. It would be a far-reaching target of this thesis to try to solve these ambiguities, but the terminology used will be set on sound foundations. In the following sections I am using the definitions set by Liang (2021, pp. 250-251) in order to tackle this ambiguity.

The Virtuality Continuum

The work of Milgram and Kishino (1994, pp. 2-4) has been very influential in the effort to define the different Human-Computer Interaction (HCI) environments and their nuances. They use the term “Virtuality Continuum” to describe the whole range of computer display environments spanning from reality on the one end – the world as we perceive it with our own eyes – to virtual reality on the other end, which is a completely digital environment, as it can be observed in the following diagram (Figure 2).

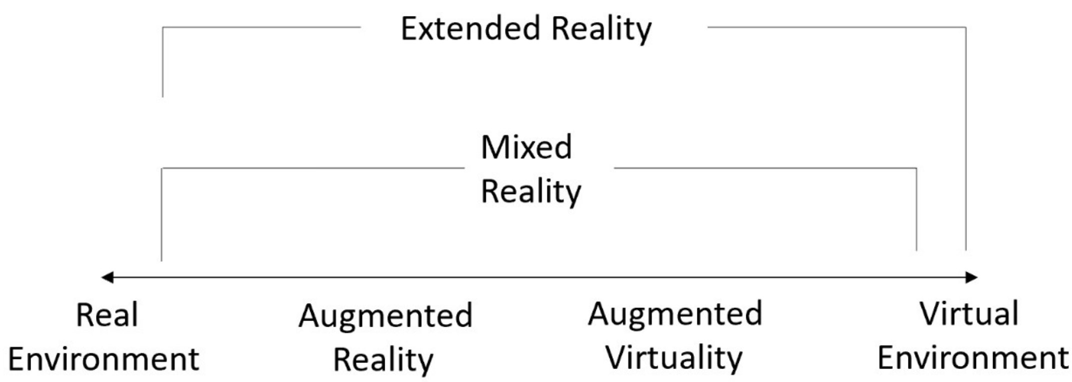


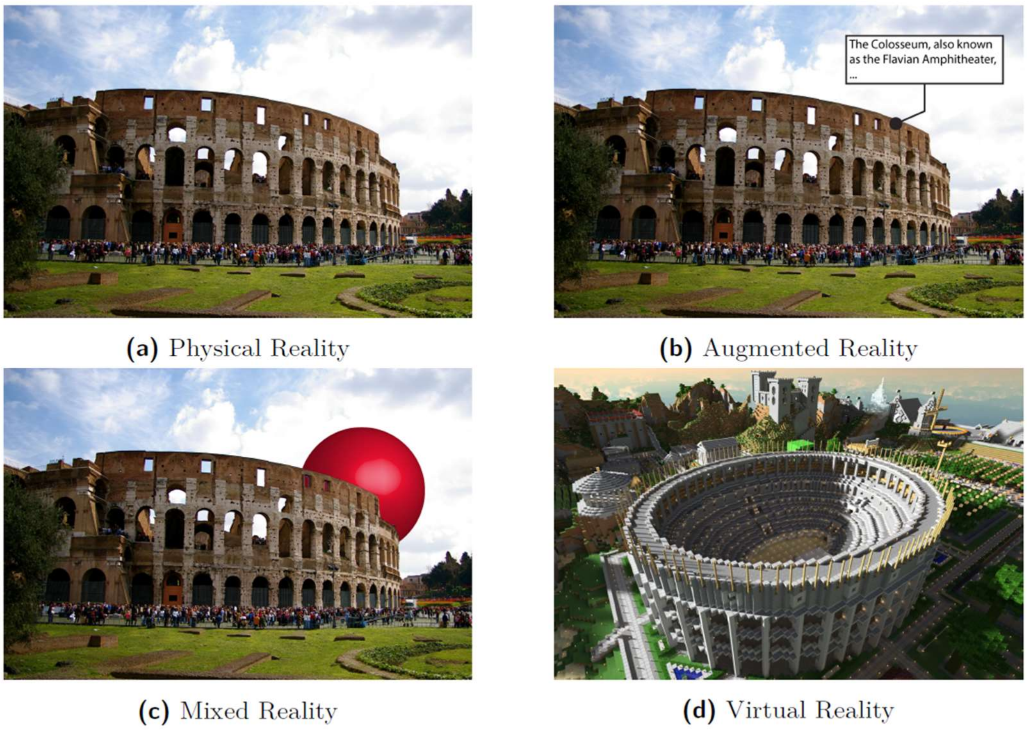
Figure 2. The Virtuality Continuum according to Milgram and Kishino (1994). Extended Realities is used as an umbrella term. (Photograph: Andreas Leitourgakis).

Virtual Reality (VR) is a fully digital world that is intended to cut the user completely off from the real one (Bekele et al., 2018, p. 3). The main aim of this environment is to immerse the user completely in an artificial world. Through the use of Head-Mounted Displays (HMDs) – devices that the user can wear on his/her head that are equipped with lenses functioning as monitors – the user gets a real sense of presence in another reality. That is achieved through the device’s sensors that can track and simulate the user’s perception of this world and his/her movement in it.

So far, we have covered the two ends of the Virtuality Continuum. It is the slight nuances that exist in between that have created this confusion in terminology. Two terms come up at this point, Augmented Reality (AR) and Augmented Virtuality (AV).

As far as AR is concerned, it can be defined as a computer environment where digital content is used to enhance real objects, with both elements coexisting on the display and allowing the user to interact with the digital ones. On the other hand, AV works in similar fashion but in this case the roles of the real and the virtual world are the exact opposite to AR. This means that real objects are used to enhance a virtual environment (Bekele et al., 2018, p. 3; Fogliaroni, 2018, p. 13).

Mixed Reality (MR) is a HCI environment that intertwines the real and the virtual world and essentially combines aspects of both AR and AV. This system also allows for different levels of immersion and realism to be integrated, as the virtual content can play the role of any other real object in the user's view, anchored in a specific location and viewed from different angles or not respecting any rule of physics at all and float in the surrounding space. This results in an immersive experience that is still connected to the real world (Bekele et al., 2018, p. 4; Fogliaroni, 2018, p. 14). Since both AR and MR involve the projection of virtual content on the physical world, they can be confused with each other. Other features that are used to distinguish the two systems is the level of complexity and the hardware used for each system. To be more precise, Liang (2021, p. 250) considers MR to involve more sophisticated and immersive merging of the real and the virtual, whereas AR usually involves simpler



(a) Physical Reality (b) Augmented Reality (c) Mixed Reality (d) Virtual Reality

Figure 3. The different computer environments described above and their nuances. (a) presents the real world, (b) presents Augmented Reality where the real world is enriched by digital media, (c) presents Mixed Reality which provides a seamless integration of virtual objects that the user can interact with. Finally, (d) is a completely artificial world. (Fogliaroni, 2018, p. 14, Figure 2).

superimposition of information or 3D models on top of real objects. In terms of hardware, MR takes advantage of head-mounted devices (HMDs) that provide a more seamless integration of 3D content onto the real world thanks to the sensors and cameras in these devices. On the other hand, AR content is mostly viewed through smartphones and tablets, as these devices are equipped with cameras that can project virtual objects to the surrounding environment (Liang, 2021, pp. 250-251).

Lastly, Extended Reality (XR) is used as an umbrella-term to refer to all VR, AR and MR systems, which can also be referred to as Immersive Realities, as seen in Bekele et al. (2018, p. 4). Figure 3 provides a general overview of the terminology explained above.

These technologies have a wide array of applications in many different fields, from manufacturing and engineering to healthcare and education. In the next chapter I am going to discuss about the implementations of these technologies in Archaeology and Cultural Heritage, in order to serve as a general background for the use of this technology in these fields. Additionally, I will touch upon the targets behind these applications, their benefits and the challenges that arise from their use. The emphasis will be mainly on AR and MR as they use the same technology that will be used for the case-studies described below.

Afterwards, the device used – HoloLens 2 – will be presented from a technical perspective, and its past applications in archaeology and cultural heritage will be discussed, providing insight on some general directions, also followed in the case-studies below. The 4th chapter describes the methodology followed and in the 5th the results of this work are presented. In chapter 6 a short discussion follows, putting these case-studies in the wider context of visualization and interpretation in archaeology with digital tools. Chapter 7 presents some concluding remarks with some general directions for future work.

Chapter 2. Applications of AR and MR technology in Archaeology and Cultural Heritage

The implementation of AR and MR technology in the Cultural Heritage sector has been around for more than two decades by now, serving a multitude of targets. These include providing new ways to motivate people to learn about a specific site or artefact in a more intuitive manner. This pique in interest can be beneficial from a knowledge acquisition perspective. Moreover, providing the ability to interact with heritage digitally can stimulate users positively and help them think about the past in more creative ways (Ramtohul & Khedo, 2024, pp. 10-11). Besides creativity, this technology can enhance feelings of excitement when interacting with cultural heritage. Active participation of the visitor through these applications can be a more enriching alternative to traditional museum and archaeological site visits, as it has been linked with increased awareness from visitors (Innocente et al., 2023, p. 273). Another aim is to create tools that can help users gain more knowledge and insight about the past (Bekele et al., 2018, pp. 16-17). Last but not least, AR and MR are significant factors for the steady rise of the concept of “edutainment” or educational entertainment, especially when combined with tools such as story-telling and augmenting the context of a find in real-time (Innocente et al., 2023, p. 274). In this way, many different aspects of cultural heritage can be highlighted which are otherwise missed when using more traditional methods (Ramtohul & Khedo, 2024, p. 11).

In the following sections a selection of case-studies will be presented, that highlight these targets, and also analyze how these aims are achieved through the design and development of their implementation. These case-studies will be grouped according to their intended target, that is whether they are used to enhance an archaeological site or exhibition, or to enhance research and explore new interpretations about the past.

Enhancing archaeological sites

The development of AR prototypes for enriching visitor engagement in archaeological sites has been a field of significant experimentation with the capabilities of AR technology. Right from the start of the new century, the Archeoguide project provided a prototype for an outdoor AR experience with the aim to make guided tours in the archaeological site of Ancient Olympia more immersive (Vlahakis et al., 2002, p. 52). Through 3D visualizations of important buildings and reconstructions of athletes competing in the Olympic games, the visitor enjoyed a more realistic view of the site, supported by audio narration and additional texts, tailored to his/her age and interests (Figure 4).

Figure 4. View of the stadium in ancient Olympia with 3D models of athletes in action. (Vlahakis et al., 2002, p. 58, Figure 10).

This project could function either through an HMD device, a tablet or a palmtop computer. The latter two options provided videos of the reconstructed structures depending on the position of the user and were easier to carry. Regarding the HMD, the user needed to carry along a backpack with a laptop, responsible for rendering the "augmented" data, and other hardware necessary for positional tracking (Figure 5). On top of the HMD was a camera, feeding the live video that was enhanced with the digital content when reaching certain buildings in a 5 m. distance (Vlahakis et al., 2002, pp. 56-58). This project is one of the few that experimented with different devices at the same time, providing many levels of immersion. Some of the main concerns of users with this application were the limited number of features that could be explored. In terms of accessibility, older users, although motivated, were not comfortable with the hardware, a point attributed to their lack of computer skills (Vlahakis et al., 2001, p.

8). Given the significant time difference of this prototype, it should be noted that although the hardware options have improved drastically, certain challenges persist, such as attracting an older demographic. As far as HMDs are concerned, people these days no longer have to carry heavy equipment, but only a pair of goggles, which can provide high-resolution visualizations. Still the ease of use and movement in space while using AR and MR can be an important issue.

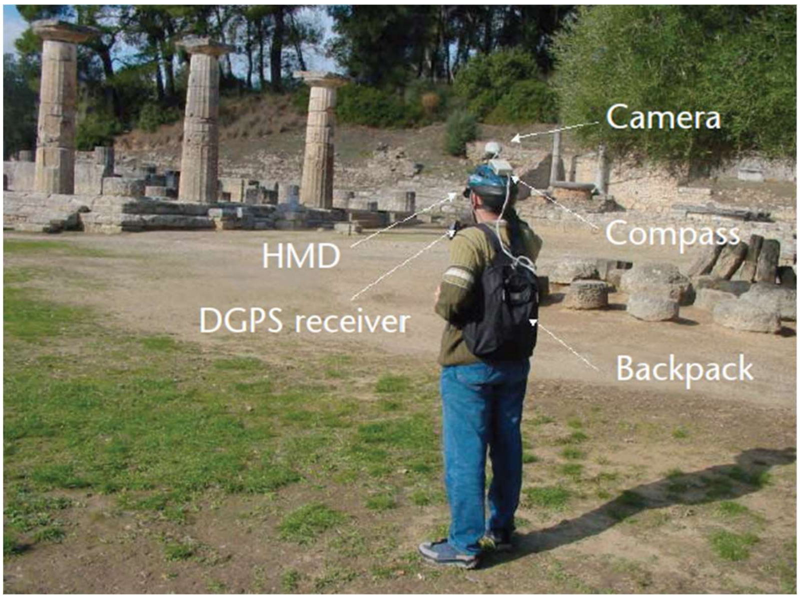


Figure 5. View of the hardware needed in order for the HMD of the Archeoguide project to function. (Vlahakis et al., 2002, p. 57, Figure 7).

During the following years the majority of AR applications implemented in heritage sites were designed for mobile devices, mainly smartphones and tablets. More specifically, the review by Ramtohul and Khedo (2024, p. 12) indicates that almost 50% of case-studies use smartphone-based applications (Figure 6). This choice is based on the fact that during the last decade a significant portion of the population owns a smartphone and that these devices are constantly upgraded in terms of hardware (Kyriakou & Hermon, 2018, p. 1). Tablets also take up a significant percentage of the reviewed studies (33%), with their main advantage, besides portability, being their larger field of view. HMDs supporting AR and MR represent only a quarter of the reviewed studies and will be increasing in number as these devices become more affordable and widespread. Thus, it is apparent that there has been a clear preference for smartphones and tablets so far, that can be attributed to their ease of use and their development in terms of specifications.

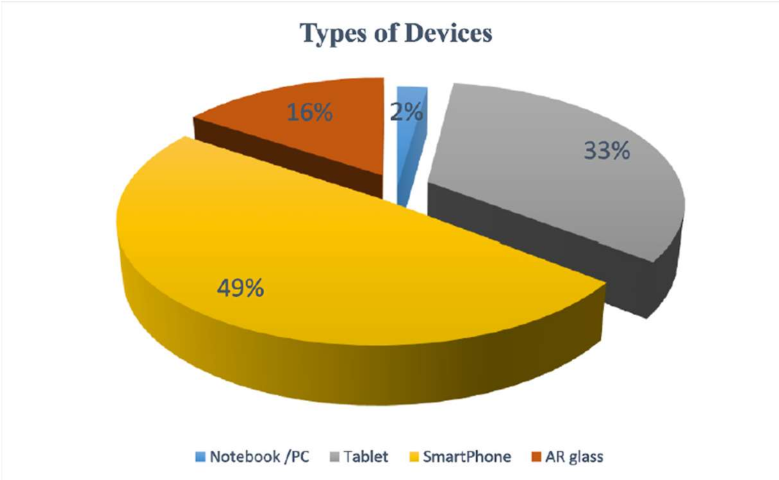


Figure 6. Pie chart of the devices used in AR/MR applications in the Cultural Heritage sector. (Ramtohul & Khedo, 2024, p. 12, Fig. 4).

The rise of Mobile Augmented Reality (MAR) has seen a large variety of applications being implemented in many different contexts and provides a solid alternative for use of AR technology in outdoor spaces. An interesting decision when designing applications for outdoor use is the implementation of a so-called situated simulator (sitsim) which displays the corresponding 3D graphics environment according to the location of the user in the physical space. In this way the portable device is turned into a window to the past with significant potential especially when dealing with structures or even whole environments that are permanently lost or have changed drastically. This type of application falls into the category of Indirect Augmented Reality (Bjørkli et al., 2018, p. 367). Liestøl (2014, pp. 248-250) developed such a platform tailored for a guide in a small part of the Appian Way. As the user would traverse this section of the road, 3D reconstructions of the monuments would appear on the screen (Figure 7).

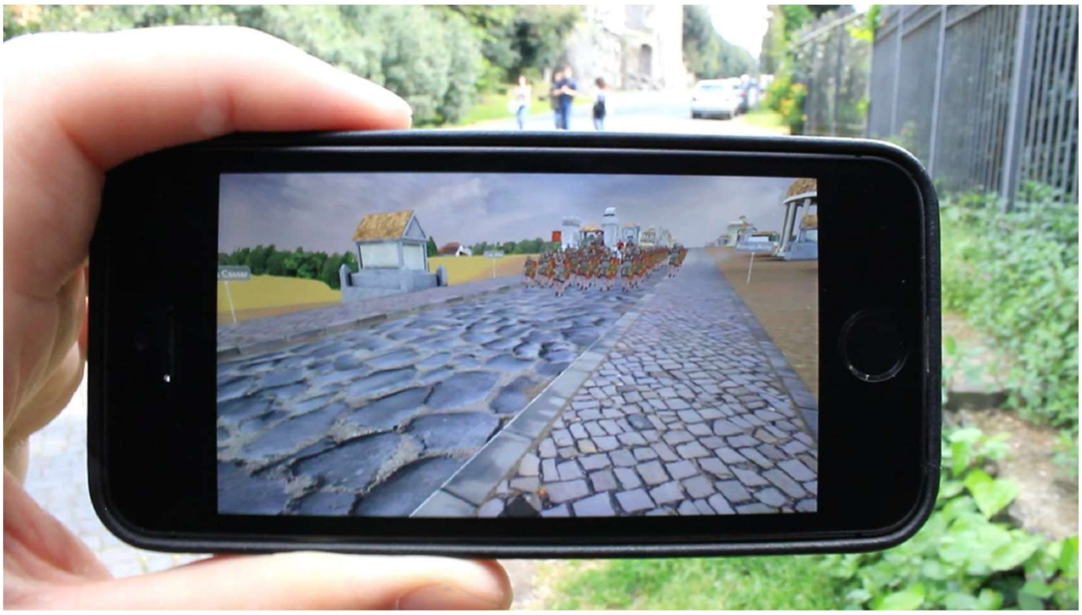


Figure 7. The sitsim in the Appian Way. The mobile device functions as a window and 3D data are presented on the screen according to the location where the user is pointing at. (Liestøl, 2014, p. 250, Fig. 1).

The developers also added another layer of immersion by enabling the user to go through specific events in Rome's history such as 71 BCE and view the aftermath of Spartacus' revolt, combining historical and archaeological knowledge in a more engaging way. The same technology was used for visualizing the differences in sea level near Stone Age sites in southern Norway. The application uses a detailed terrain model and simple textures to allow users to better grasp the differences in sea level while exploring these sites (Bjørkli et al., 2018, pp. 368-371) (Figure 8).

Figure 8. The user using the sitsim can toggle between the different time periods and view the sea level according to his/her location. (Bjørkli et al., 2018, p. 371, Figure 5).

The above-mentioned studies consist just one possible alternative for outdoor MAR usage. Verykokou et al. (2014, pp. 285-287) follow a similar approach in the Ancient Agora of Athens, as the project for the Appian Way. In this case, however, the reconstruction is viewed on top of the actual remains of the foundations as they can be seen while visiting the site. When the user would point the tablet towards the Mesi Stoa, a large portico dated to the Hellenistic period, the 3D model would appear giving the visitor a sense of its actual size and how it dominated the landscape of the Athenian Agora. An important difference is that the visualization is anchored to the real world and not in a fully virtual environment (Figure 9).

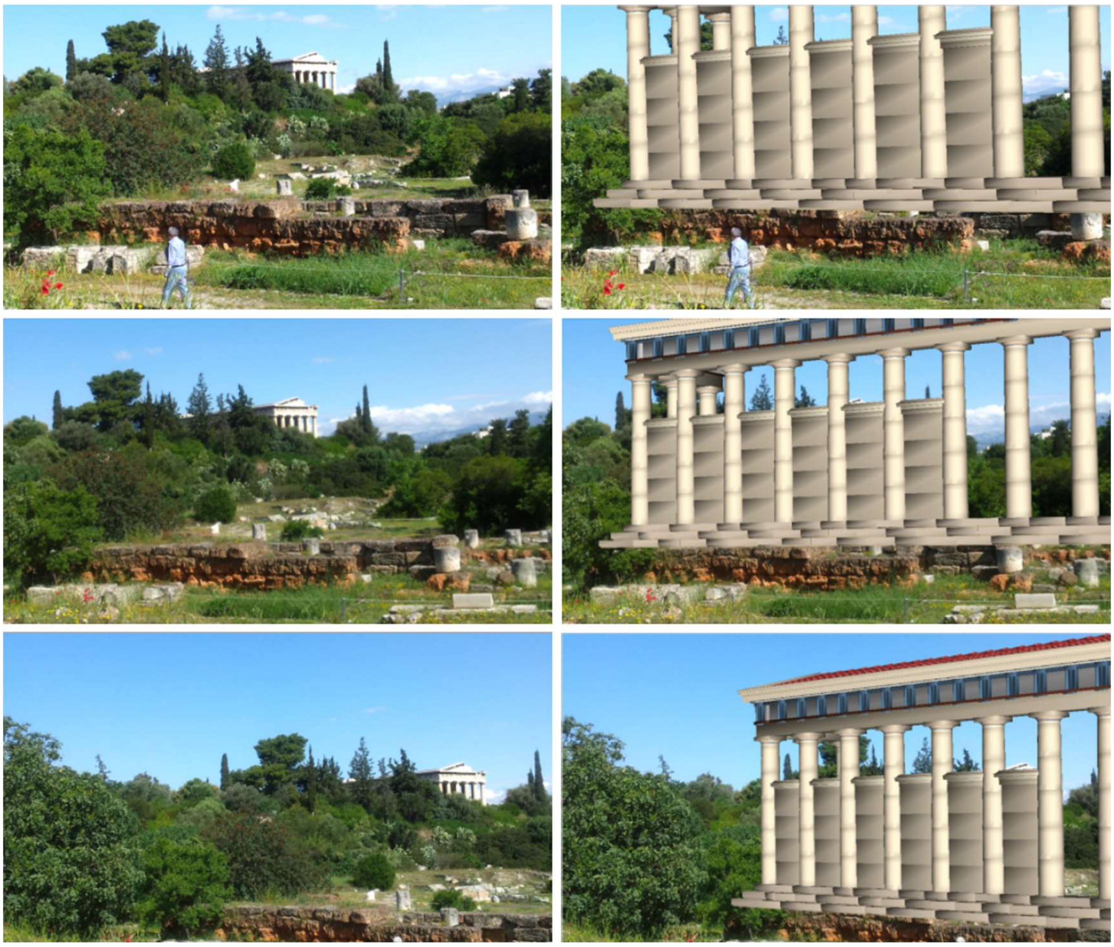


Figure 9. The 3D model of the Mesi Stoa placed on top of its actual remains in situ, with the visualization both activated and de-activated. (Verykokou et al., 2014, p. 287, Fig.4).

The developing team of KnossosAR wanted to create a tool that would serve as a guide for students through the Minoan palace of Knossos and had specific teaching goals about the site and Minoan civilization in general. The app would lead students to specific points of interest in the site and provide information in the form of text or visual reconstructions. The audio narration provided enabled users to place their emphasis on the site itself without having to constantly view at the tablet's screen. A major issue that had to be tackled was the blockage of points of interest by the structures which could be highly misguiding for the visitor. This was addressed by updating the Field of View (FoV) of the visitor in real-time thanks to the tracking sensors of the device (Galatis et al., 2016, pp. 2-3).

A major issue of MAR outdoor applications are the unstable light and weather conditions of the environment that could hamper the experience as the sensors may not be able to register the features they are supposed to augment. Westin et al. (2021, pp. 260-261) tried to tackle these difficulties in a challenging climate, in the site of Tanum in Sweden. The aim of this project was to provide alternative solutions to the wider public for the in-situ visualization and interpretation of the vast corpus of rock carvings following the principal of minimal intervention. The researchers used image-based tracking so as to recognize the rock art and visualize it vibrantly. This technique uses a reference catalogue of 2D pictures of the rock art and was successful in recognizing the specimens even when partly covered by leaves or direct sunlight falling on top (Figure 10). This study places emphasis on the capability of AR technology to enrich heritage sites and boost engagement with the public while actively preserving the site. At the same time, it also stresses the need for additional visualization methods to be implemented in tandem, since image-based tracking is not consistent under all circumstances, which could hinder the user experience (Westin et al., 2021, pp. 267-268).

Figure 10. The user points the smartphone towards the rock art and the latter is highlighted on the screen, thanks to the 2D image-based tracking. (Westin et al., 2021, p. 267, Figure 7).

Enhancing museum exhibitions

In contrast to outdoor environments, indoor spaces provide a more easily controlled setting for the implementation of AR and MR technology. Museums, in most cases, have the necessary infrastructure in order to establish suitable lighting conditions and a stable internet connection, which are prerequisites for most such applications. So, it is not a surprise that the majority of such case-studies were applied in a museum space, according to Ramtohul and Khedo (2024, p. 9).

These characteristics are evident in the creation of the TombSeer project for the enhancement with AR content of a replica of an Egyptian Tomb, located in the Royal Museum of Ontario. The main target of this endeavor was to move beyond a traditional exhibition and make the visitor an active participant who is earnestly engaged in learning about past societies through interactions with gestures and gaze-based input (Figure 11). This prototype used a Meta AR HMD with built-in sensors that allowed movement as well as hand and eye tracking (Pedersen et al., 2017, pp. 7-9). Natural Interaction (NI) is an element that many developers of AR and MR experiences are aiming for, so that interaction with 3D content is more seamless and does not require the user to have any background in the use of such technology to appreciate the application. A similar approach was adopted by Kyriakou and Hermon (2018, pp. 4-5), who experimented with a headset powered by a smartphone with a depth sensor attached to it that enabled NI hand gestures. The participants in the testing phases were asked to interact with a series of 3D models of artifacts that were coupled with questions intended to further engage with the visitor. The results of this study showed that the majority of users felt comfortable with this technology. It must be noted, however, that a portion of the participants still needed a little time and a short demonstration to adjust to the interaction system (Kyriakou & Hermon, 2018, pp. 7-8).

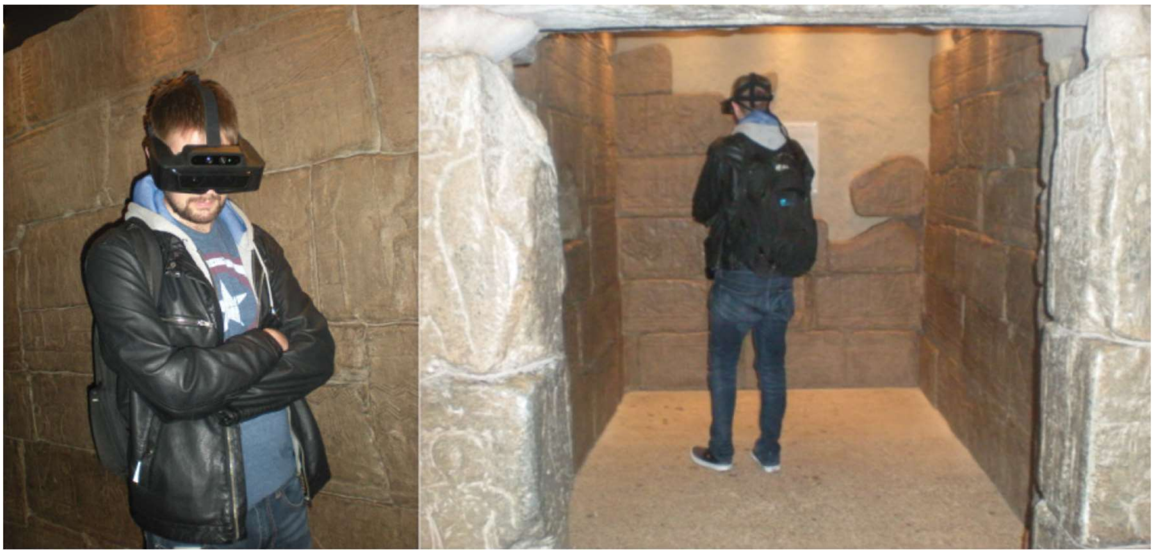


Figure 11. The testing phase of the TombSeer project in the replica of the Egyptian Tomb. (Pedersen et al., 2017, p. 11, Fig. 9).

Furthermore, the study of Nofal et al. (2018, pp. 44-46) provides insight into the ways that AR technology can boost the learning outcome of a museum visit by placing an isolated artifact in a digital reconstruction of its architectural context. This is even more important when the context of such an artifact is permanently lost after being deliberately destroyed, as in the case of the head of an Assyrian Winged Genius, originally located in the palace of Nimrud and now exhibited in the collections of the Royal Museum of Art and History in Brussels. A model of the room where it was located was produced which the visitor could explore through a tablet (Figure 12). In this way the user could examine the whole relief in association with the head in the museum's collection but also its relation with the rest of the room, its ceiling and its architectural features. Participants in the evaluation of this method were urged to move around the space of the exhibition. This study demonstrated how AR tools can stimulate the curiosity of the visitors while also helping them better understand and recall the information that is presented to them (Nofal et al., 2018, pp. 58-61).

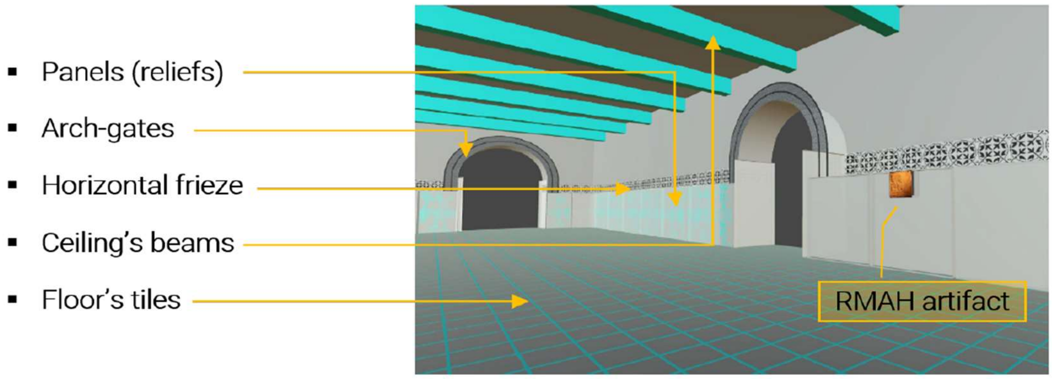


Figure 12. View of the digital reconstruction of the room where the relief is located. Not only its position but also its architectural context can be explored through the portable device. (Nofal et al., 2018, p. 48, Figure 4).

Enhancing archaeological fieldwork and research

AR and MR technology has provided new ways to visualize and interact with archaeological data not only for the wider public but also for active researchers with expertise in archaeology and cultural heritage. These tools have started developing since the start of the 2000s and have advanced significantly since, providing more immersive tools for data visualization and enabling new perspectives for archaeological interpretation. Of particular interest are the AR and MR tools implemented for the documentation and visualization of excavation data, either on- or off-site. Thus, it is worth examining the targets behind these projects, their relevance as well as their limitations, both in terms of hardware but also of applicability.

Firstly, Benko et al. (2004, pp. 1-2) placed their emphasis on creating an MR environment to visualize and examine excavation data – from stratigraphical data to whole categories of archaeological material, such as pottery – after the end of a fieldwork season. This system was designed to aid in the interpretation process of all this data but also to help in the planning of the work of the following years. As the excavation process involves a large team of people, this system was intended to support the collaborative view of 3D data in a MR environment by multiple people at once, through the use of HMDs. The “Visual Interaction Tool for Archaeology” (VITA) – the name of this prototype – supported the 3D visualization of excavated structures either in “life-size-world”, covering an area of 10*10 m. (Figure 13), or in a minimized version, essentially functioning as a ground plan. This view was enriched by Harris Matrix data, linking stratigraphic units with their corresponding material, making their spatial association clearer (Benko et al., 2004, p. 3).

Figure 13. The user in the “life-sized mode” of the VITA project. (a) shows a feature in the excavation and (b) shows how the user can toggle and view it through the HMD device, together with artifacts located there. (Benko et al., 2004, p. 3, Figure 1).

Except for the HMD, the user would need special gloves that enabled hand tracking in order to interact with models of artifacts or make selections, or alternatively use voice input. Since all these devices had to be connected to a computer to function, moving around was not so straightforward for the user (Figure 14). What is more, through a tabletop monitor, the user could toggle between 2D and 3D data and interact with them while wearing the hand tracking gloves (Benko et al., 2004, p. 5). In the evaluation process of this prototype, it became apparent that this tool could be an important supplement to the analysis of excavation data, together with traditional methods, as it visualized many types of data while associating them spatially. It could also assist academic teaching, as students could learn about the site and the excavation process through a lab setting, before the actual field season (Benko et al., 2004, pp. 7-8)

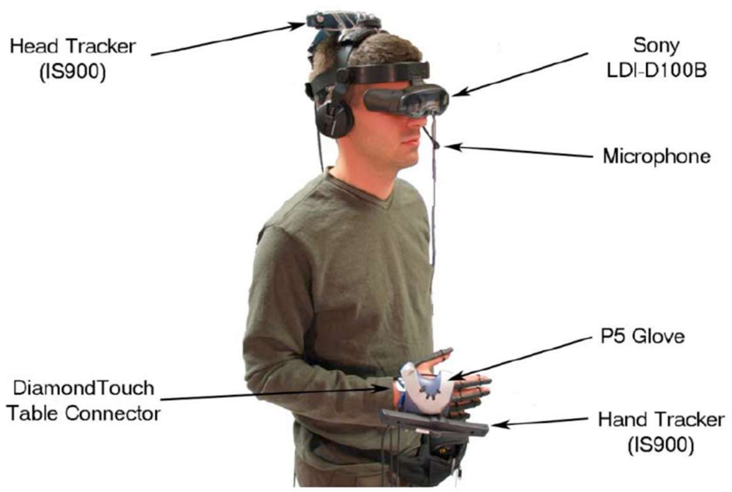


Figure 14. All the hardware used for the VITA project. These devices needed to be plugged in to a computer, hindering movement during use. (Benko et al., 2004, p. 4, Figure 5).

The potential of AR and MR tools for visualization of archaeological data in a post-excavation setting is significant. Kayalar et al. (2008, pp. 1-2) experimented with a platform that could be used during the excavation and could assist its documentation and visualization while fieldwork progresses. It was implemented in the Yenikapi Marmaray excavation and it functioned through an ultra-mobile PC unit equipped with sensors responsible for positional tracking. The Interface of the platform allowed the user to view the map of the site and examine the stratigraphic details of the different areas where fieldwork was conducted. Additionally, the user can create a 3D model of a structure or feature and add points of interest in the augmented view (Kayalar et al., 2008, p. 5) (Figure 15). This prototype is one of the first endeavors to create an AR-based platform with which a field archaeologist can, at the same time, add and edit information about the features excavated and visualize them, using the same device.

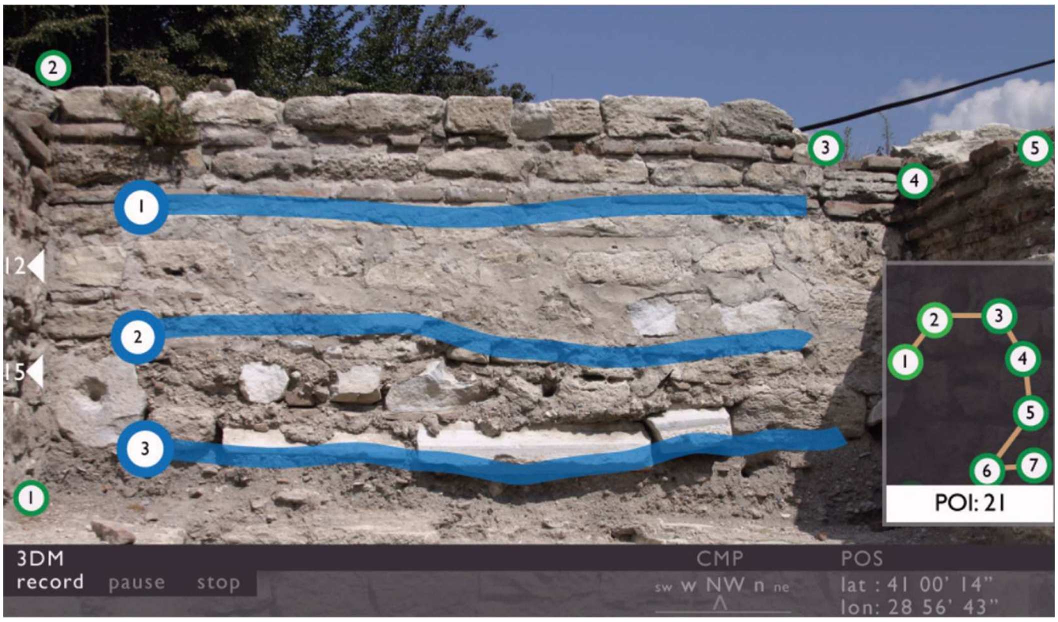


Figure 15. The interface responsible for the creation of 3D models during field work, with points of interest added. (Kayalar et al., 2008, p. 4, Fig. 4).

Dilena and Soressi (2020, pp. 3-4) recently developed an application that combines many aspects of the previously mentioned implementations in order to visualize the excavated finds in the location that they were unearthed on top of a 3D mesh of the site. More specifically, this app was designed for use in a computer but also a tablet (iPad) that enabled the MR visualization of the excavation and the corresponding finds. The user could toggle and interact with a 3D model of the excavation site at its real, enlarged or minimized scale, both on- and off-site, providing significant flexibility in the environments it can be implemented (Figure 16). In addition to that, the user can also use filters and display only specific materials or stratigraphic units, thus visualizing the spatial association of the unearthed finds (Dilena & Soressi, 2020, pp. 8-9).

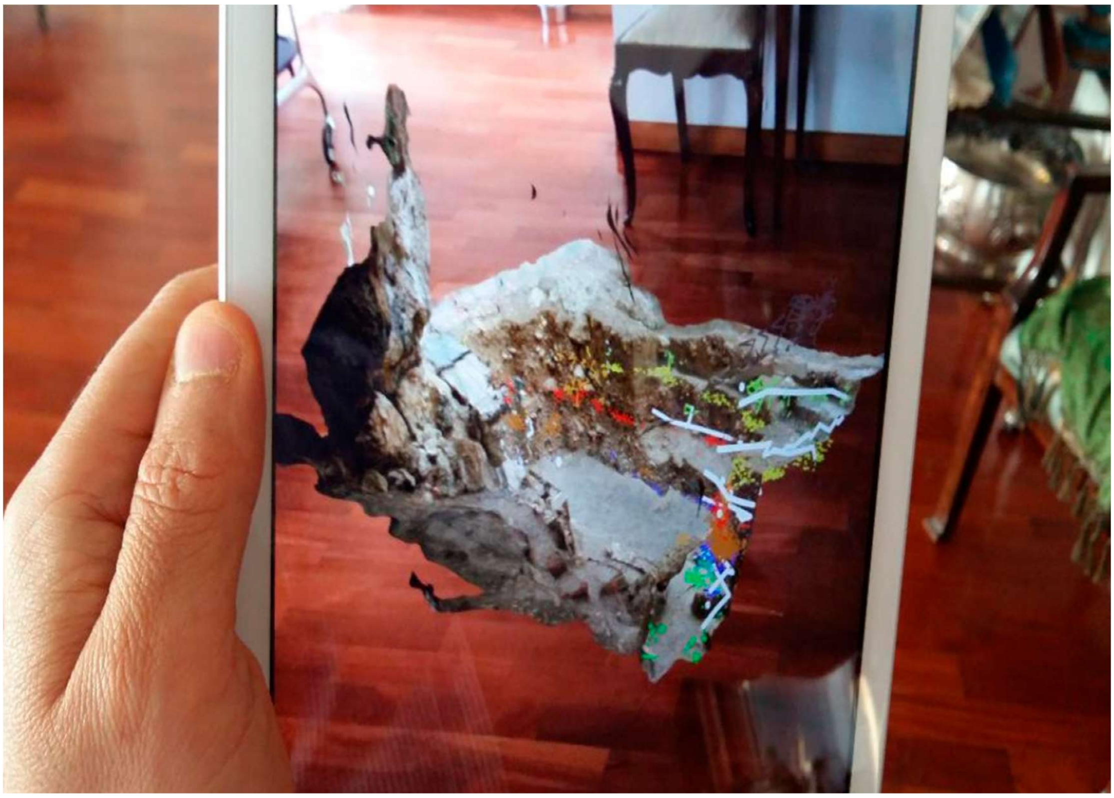


Figure 16. Minimized view of the 3D model of the excavated site, which can be toggled both in situ but also off-site. The colored models represent different categories of materials unearthed. (Dilena & Soressi, 2020, p. 8, Figure 6).

It should be noted, however, that the researchers faced some significant limitations, mainly linked to the 3D visualization of the excavated site. Using a large database in junction with a 3D mesh can easily run the memory capacity of the mobile device used to its limits. Moreover, due to inaccuracies of the sensors of the tablet, anchoring the 3D model was problematic, which is an important obstacle when trying to interact with the displayed data. The case-study chosen for this prototype had the advantage that it was not so extensive in terms of size. When dealing with vast excavated areas, carefully dividing the space is necessary so as to be able to achieve a visualization similar to that in the article (Dilena & Soressi, 2020, pp. 11-12).

Quite recently, Cobb and Azizbekyan (2024, p. 374) published a series of experiments where the HoloLens 2 – among other MR devices, such as the Meta Quest Pro – was used to assist a wide range of tasks during archaeological fieldwork. These include documenting stratigraphical data, visualizing previously excavated structures in situ and guiding the excavation of currently explored trenches. This experimentation with many hardware options highlights the need for combining comfortable and light HMDs with high processing power (Cobb & Azizbekyan, 2024, p. 383). The results are promising in terms of data collection and anchoring 3D models of excavated features on top of still-standing ones, opening new ways for analyzing stratigraphical data (Figure 17).

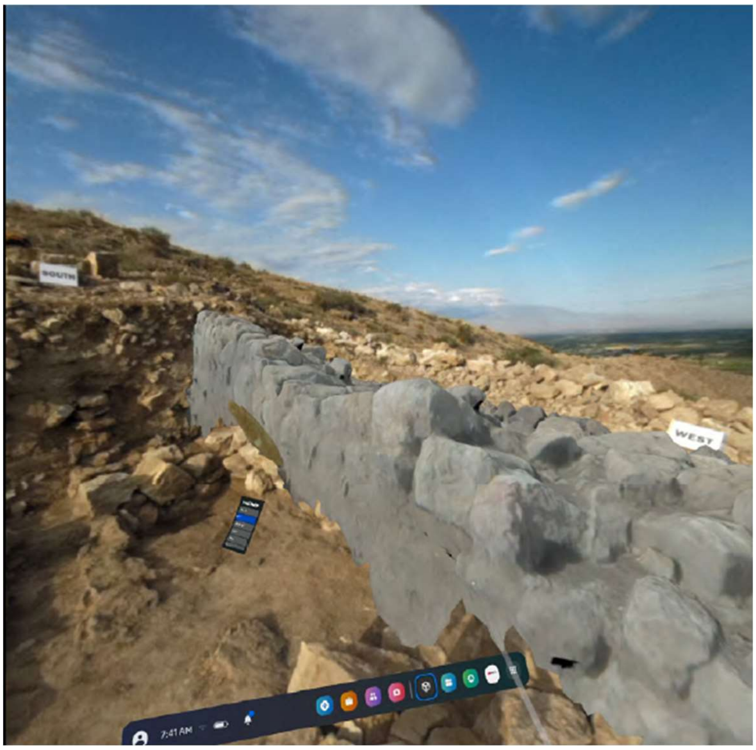


Figure 17. Placing previously removed features back into their original location, using Meta Quest Pro. The wall was removed in order for excavation to continue and its 3D model is placed back in its original location in MR. (Cobb & Azizbekyan, 2024, p. 378, Figure 14).

Regarding the digging guide, it consists of a flat plane whose depth can be adjusted and thus highlight how much one should dig in order to create a flat surface (Cobb & Azizbekyan, 2024, p. 381), which can provide a practical solution in keeping excavation trenches tidy or exploring test trenches. Some important limitations that were stressed, however, concern work under direct sunlight, as the digital data are not easily visible under such conditions (Cobb & Azizbekyan, 2024, p. 383).

Archaeological fieldwork is not limited only to excavation of course. Other sub-disciplines, such as landscape archaeology can benefit significantly from the implementation of AR and MR technology not only in a lab setting but also in situ, as it has been demonstrated by Eve (2017). More specifically, the author is an ardent supporter of the combination of Geographic Information Systems (GIS) technology with MR, which will allow the researcher to examine all different kinds of spatial data in the physical space. He describes this as an “Embodied GIS”. In this case, the user is not simply viewing the data but can also interact with the databases in real-time, offering an additional way of treating and interpreting spatial data in combination with more traditional methods. The “Embodied GIS” aims at giving new perspectives regarding interpretation as the data are examined “in situ” taking into account other senses, except for vision, such as smell and sound. When tested in the Bronze Age site of Leskernick hill, in Cornwall, the sight of the reconstructed huts (Figure 18) provided a view of the landscape that otherwise could not be grasped in a computer-based GIS. As a result, MR could serve as an effective tool for enriching phenomenological approaches and bring this discipline closer to more traditional aspects of field work.

Figure 18. View of the “Embodied GIS” with visualization of prehistoric huts in situ. (Eve, 2017, Figure 3)

Challenges and limitations in the implementation of AR and MR in Archaeology and Cultural Heritage

The following section serves as a short discussion over some general prerequisites and concerns when trying to use this technology in Archaeology and Cultural Heritage. As more and more advanced hardware options become widely available, the number of relevant applications that are developed is on the rise. Ramtohul and Khedo (2024, pp. 16-17) have named a number of issues that could hinder such implementations, that interested parties should take into consideration when delving into AR and MR.

First of all, a significant investment of funds is needed not only for acquiring the necessary equipment and infrastructure, such as a stable internet connection and suitable lighting conditions, but also for acquiring the skills needed to work with and maintain these applications. An adequate skillset will help make the most of this technology and its potential, while at the same time minimizing its possible constraints. Another important constraint is related to the hardware used for AR and MR environments. Especially in the case of MAR, the users are spending a lot of time looking at their screens and, in the end, could be placing their emphasis on their mobile devices instead of the artifacts and monuments in front of them. These devices should not be distracting the user but, on the other hand, should motivate him/her to observe the real objects and the surrounding environment (Ramtohul & Khedo, 2024, p. 16).

In regards to the content viewed during the AR/MR experience, there should be significant interaction included, in order to engage the users and not simply restrict them to passively browse through information. A fine line should be kept, however, so as not to overwhelm the users with large amounts of information, which could end up discouraging them from further using such an application.

All in all, it is apparent that AR and MR technology has been applied in Archaeology and Cultural Heritage for many different purposes during the last two decades and with significant results. A wide array of fields has been discussed, highlighting the targets of this technology and its relevance for Archaeology today. From providing tours in archaeological sites and enriching museum exhibitions to enabling the documentation of archaeological data during fieldwork and opening up new perspectives for interpretations, Immersive Realities have proven that they consist valuable tools for educating the public about the past. Furthermore, academic research can also benefit greatly from them, as they provide the chance to answer archaeological questions, both in- and outdoors, by using 3D visualizations merged seamlessly with the surrounding environment.

Chapter 3. Microsoft HoloLens 2

This brief introduction to Microsoft's HoloLens 2 – the device used for the different case-studies that will be described below – aims at providing insight on its technical characteristics in regards to hardware and human computer interactions that shape this MR experience. HoloLens 2, released in 2019, is the second generation of Microsoft's Mixed Reality HMDs (Figure 19). This version has many of the specifications of the original model (HoloLens 1) with some important improvements and upgrades, which will be presented below (Guo & Prabhakaran, 2022, pp. 1-2).

Figure 19. The Microsoft HoloLens 2 HMD device. (Microsoft, Retrieved August 17, 2024, from https://learn.microsoft.com/en-us/hololens/hololens2-hardware).

Display

All the necessary components for the display of the system are located on the visor of the HMD, in the front of the headset, which can also be flipped so that the user can rapidly change between experiencing an MR environment and a real world one.

The HoloLens is characterized as a passthrough device. In contrast to Virtual Reality HMDs, where monitors are placed right in front of the user's eyes, the HoloLens has clear lenses, through which the surrounding environment can be viewed. From this point, holograms are projected to the space in front of the user. In regards to holograms, it should be noted that they are objects made of light and sound that can have many different characteristics – from realistic to cartoonish ones – and behave like any other real object. Since the device adds light to the user's surroundings, surfaces that are black in color are rendered transparent. Some holograms can emit sounds which are blending in with other sounds of the nearby environment, instead of cutting off the user from reality (Microsoft, 2022f).

The device comes with a larger Field of View (FoV) in relation to the previous generation. More specifically, the FoV is 43 ° horizontal, 29 ° vertical and 52 ° diagonal and thus the projected holograms will not disappear from the user's periphery of vision, even when he/she moves his/her head slightly (Laukkonen, 2020).

Regarding the optics of the machine, the light engines in the visor are the first important element and offer 2k resolution, providing a clear and sharp image on the screen (Microsoft, 2023a). The component that actually presents the digital elements in front of the user's eyes is the so-called combiner. The light engines project light which is then reflected on this special surface, thus making them visible, working in similar fashion as regular projectors. Simultaneously, the surrounding environment is also visible through the combiner, as light from other sources can still pass through this surface, effectively blending the virtual objects with the real world. The light then reaches the user's eyes under specific angles, so as to maintain a consistent and realistic feel to the digital elements (Colaner, 2016). This effect is called Total Internal Reflection. The image seen by the left and the right eye is slightly different in order to create an illusion that the object is really there.

Sensors

The sensors of the HoloLens are responsible for the interactions between the user and his/her environment. They include head tracking, eye tracking and depth sensing. It is important to ensure a high level of speed and responsiveness in order to achieve an immersive experience in a MR environment.

First of all, as far as the head tracking is concerned, it is achieved through four cameras, two on each side of the visor. Together with the Inertial Measurement Unit (IMU) holograms stay in the corresponding place in the user's vision when they move their head or body. The IMU is consisted of an accelerometer, a gyroscope and a magnetometer, which respectively calculate and report on linear acceleration, orientation and gravitational forces (Occhipinti, 2017, pp. 14-15). These features enable the so-called Six Degrees of Freedom Movement (6DoF), allowing all possible movement tracking, both translational (forward/backward, left/right, up/down) and rotational (essentially permitting the user to tilt his/her head) (Figure 20). What is more, through the use of two Infrared cameras, eye movement is tracked and measured. These sensors are also responsible for eye calibration too, which must be configured before use in order to make sure that viewing holograms is accurate and glitch-free (Microsoft, 2022d).

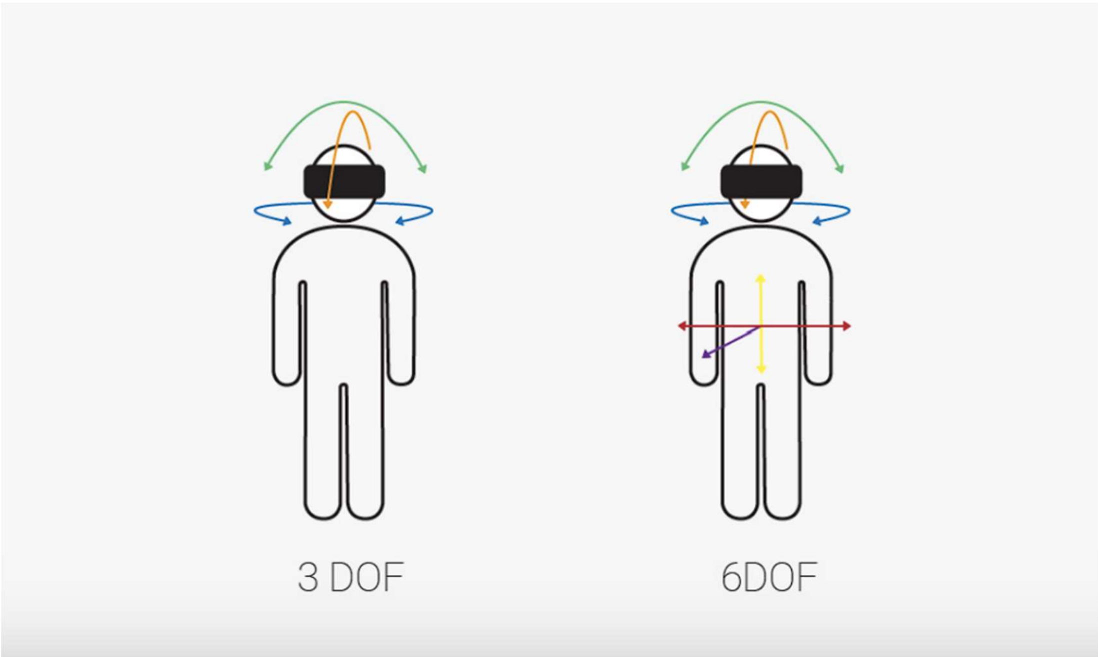


Figure 20. Visual representation of the tracking capabilities of a 6-Degrees of Freedom device in comparison to a 3-Degrees of Freedom one. (Delight XR, Retrieved August 17, 2024, from https://delight-vr.com/xr-glossary/).

The tracking of hand movements is achieved through the 1-MP Time-of-Flight depth camera. In addition to that, this camera also reconstructs nearby surfaces, thus allowing the placement of the produced holograms (Figure 21). It should be noted that the tracking of head and eye movements is done in milliseconds and enable a smooth interaction with the displayed information.

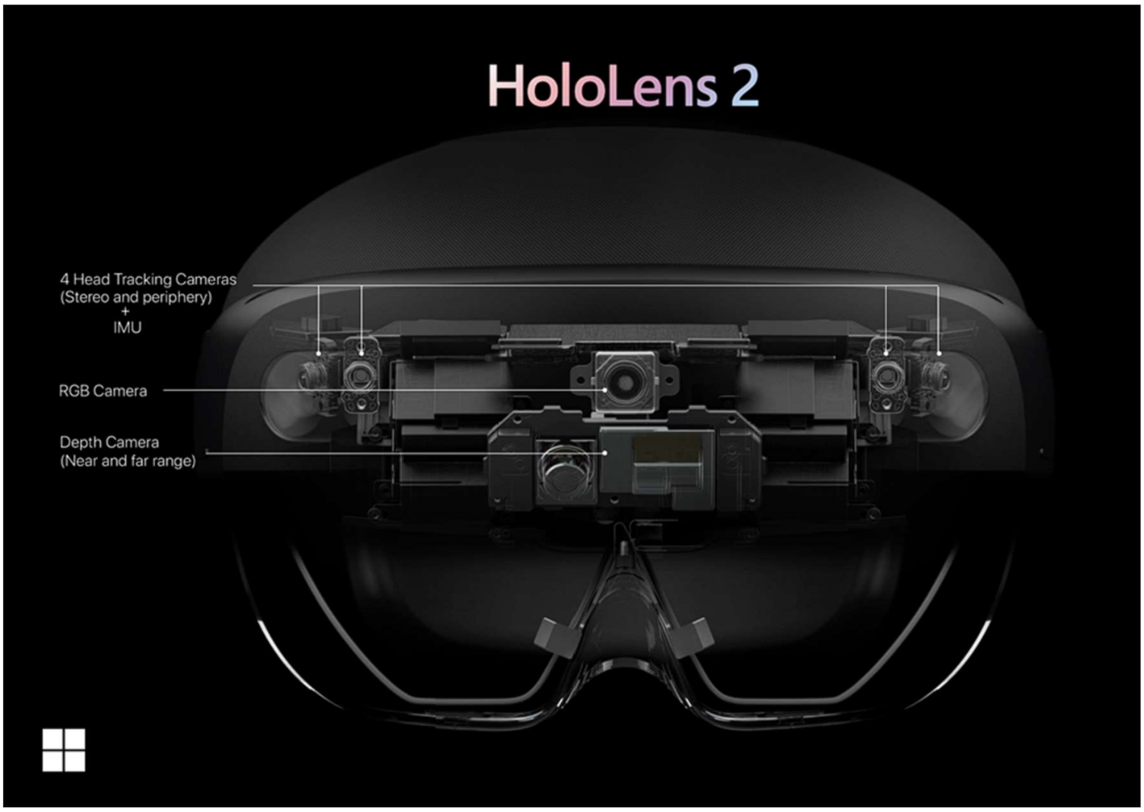


Figure 21. The sensors – responsible for head and hand tracking – of the HoloLens 2 on the visor of the device. (Retrieved August 17, 2024, from Microsoft, https://learn.microsoft.com/en-us/hololens/hololens2-hardware).

Human and Environmental Understanding

All of the above consist of the tools necessary in order to gather and display data in the HoloLens 2. However, it is through a series of hand gestures and eye-based commands as well as voice input that the user can interact with the virtual elements intertwined with the real environment.

Taking advantage of the hand tracking sensors of the HoloLens 2, the device can recognize the user's gestures while interacting with the holograms and the menus of the graphic interface. The developers have coined the term "instinctual interaction" as they intend that the user interacts with the displayed media in a fashion similar to real objects or to smartphones, as far as menus and 2D media are concerned. When a user's hand gets close to a hologram, a bounding box appears that is highlighted according to the side and corner where the hand is located. Then, the user can grab it to move it around, or grab one of its edges to rotate it. Another way the user can manipulate the holograms is by pinching one of the corners of the bounding box to change its scale, both to enlarge or minimize it (Figure 22). The same rules apply when a user interacts with a 2D menu, when visiting a website for example. By touching the slate, the user can press a link or a button, scroll and zoom but also interact with the slate itself, moving it to a different location or scaling it as the user sees fit (Microsoft, 2022c).

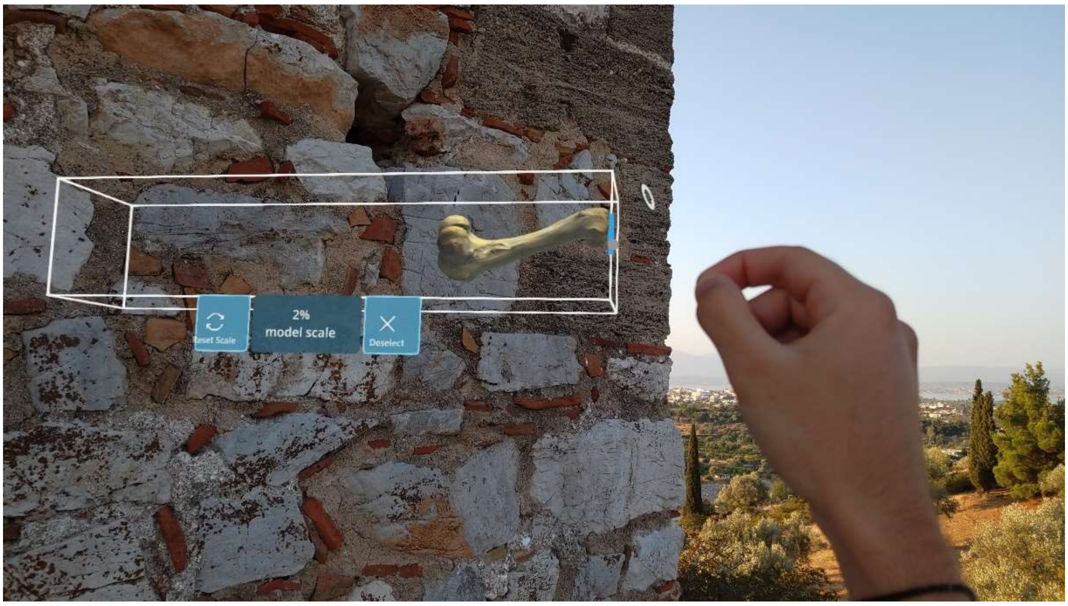


Figure 22. Interaction with holograms through "direct manipulation". The affordances of the interface are displayed when the user approaches his/her hand and selects a hologram. Then, the user can move it, rotate and scale it at will. (Photograph: Andreas Leitourgakis).

If the holograms and/or menus are not located within arm's length – approximately farther than 50 cm according to the developers – then the user can interact with them by using the so-called hand ray. In that case, a line with dashes stems out of the user's hand with which he/she can point at the holograms. Once this line gets near a hologram it becomes solid and a dot appears at the end of it, indicating the point of interaction. The user can manipulate these objects by pinching the thumb and index finger and releasing them (Microsoft, 2022e) (Figure 23). It should be noted that the user can switch between the two different modes of hand gestures automatically.

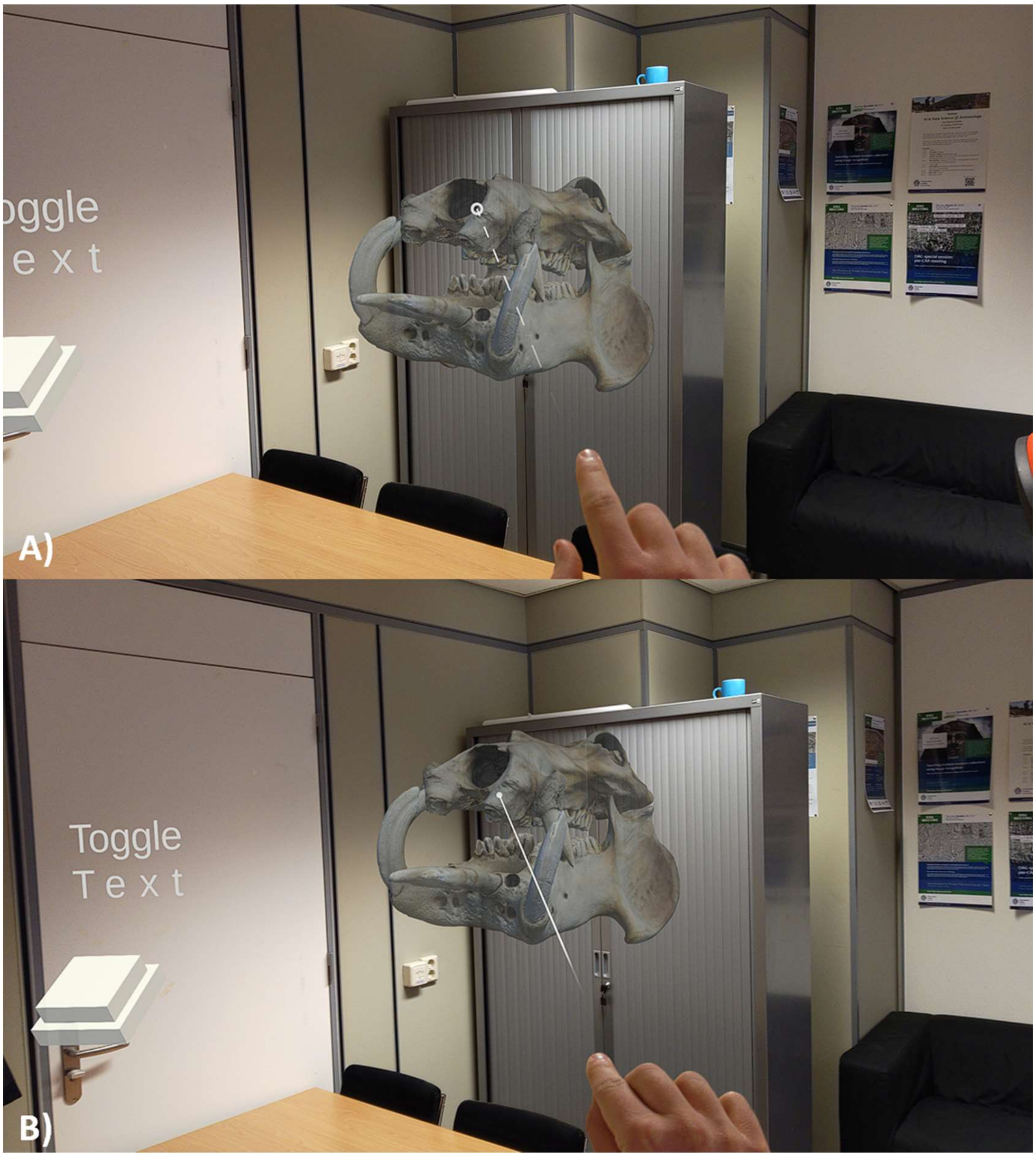


Figure 23. Interacting with a hologram from a distance. A) Thanks to the "hand-ray" the user can select a hologram. B) After using the "pinch" the user can move the hologram and interact with it. In this case the line becomes solid. (Photograph: Andreas Leitourgakis).

Another possible mode of interaction with holograms is through eye tracking. The corresponding sensors track the user's gaze allowing him/her to browse through and select certain features just by looking at them and staying focused on them for a small amount of time. The system provides the user with visual feedback so there is certainty which feature is going to be toggled. This feature is referred to as "gaze and dwell" by the developers (Microsoft, 2023b). Last but not least, eye tracking can be combined with voice commands, providing another hands-free alternative mode of interaction. In this case, instead of just looking at a feature, the user can use the "select" command when looking at a hologram, or say the command written below a button, such as "close" for example.

These commands work in combination with other functions that allow the HoloLens to understand the space it is in and the surfaces that surround the user. This feature is called spatial mapping and it takes advantage of the depth sensor mentioned above. After a 3D mesh model of the nearby space is created, the user is able to place holograms on top of real-world surfaces, adding to the illusion that the hologram behaves as any other real object in that given space (Teruggi & Fassi, 2022, p. 489). Furthermore, the user can occlude holograms in a specific area, make them interact with other objects with real world physics, such as a ball bouncing off the floor, or even navigate them in the surrounding space as a person would do. These features grant that the MR experience is immersive and perceived as close to the real one as possible (Microsoft, 2023c).

The Holographic Processing Unit

In order to handle all the data coming from the multiple sensors of the device, Microsoft developed the Holographic Processing Unit (HPU). HoloLens 2 comes with the second generation of this processor, which is responsible for the creation of the holograms and the smooth interaction with them in the various ways described above (Pollefeys, 2017). This version of the HPU comes with an AI coprocessor, allowing the system to analyze data without accessing the cloud and, as a result, achieving better performance rates.

The device also runs on a custom Windows 10 Operating System, also known as Windows Holographic OS. It generally has a small storage space at 64 GB and 4 GB RAM, marking a slight improvement in comparison with the first generation. At this point it should be mentioned that although Microsoft announced in December 2023 the discontinuation of its Windows Mixed Reality platform (Jones, 2024), it assured that it would continue to support HoloLens 2 devices. Another announcement recently, indicated the halt of production of the HoloLens 2 as well. Microsoft's involvement with MR is currently shrinking as significant layoffs in this department have been announced. At the same time competition from other big tech companies, such as Meta and Apple, is on the rise (Endicott, 2024).

Applications of the HoloLens in Archaeology and Cultural Heritage

Both generations of the HoloLens have been previously applied in Archaeology and Cultural Heritage for a number of purposes, which will be described below. However, the publication of such case-studies has been rare so far although their number is steadily increasing in the last few years (Rahaman et al., 2019, p. 6). The aim of this section is to highlight the multiple ways this tool has been used to enhance cultural heritage and archaeology and at the same time address the lacunae of this technology through specific case-studies. It should be clarified that in this section both versions of the HoloLens are taken into account.

HoloTour

First of all, a team from Microsoft developed an application for the HoloLens that could guide people in popular archaeological sites, such as the Colosseum or Machu Picchu, called HoloTour. This is not an on-site application but a virtual tour to the site that the user can experience remotely and targets at providing a sense of active presence in a series of famous sites (Microsoft, 2022b). More specifically, in the case of the Colosseum, the application provides a tour of the site at its current state of preservation which can be enhanced by changing views that display reconstructions of the monument as it would have been during its heyday (Figure 24). Through cooperation with graphic designers this popular site was recreated and the user would be able to get a sense of how it would feel to stand either in the emperor’s box or in the arena floor while the crowd is cheering during a gladiator fight. These details aim at stimulating the user’s senses and not just viewing a lifeless virtual space (Microsoft, 2022a).

Figure 24. The reconstruction of the Colosseum as seen through the HoloTour app. (Retrieved August 17, 2024, from Microsoft, https://learn.microsoft.com/en-us/windows/mixed-reality/out-of-scope/case-study-creating-impossible-perspectives-for-holotour).

The HoloLens in Museum exhibitions

The museum studies sector has benefitted significantly from the use of MR technology and has been a field of significant experimentation with the HoloLens as it will be demonstrated by this selection of case-studies. The primary target of two innovative applications, tailored for usage as supplementary material for museum exhibitions, was to enhance learning during visits through active engagement with artifacts. Not only that but also the developers wanted the visitors to emphasize on the artifacts themselves without any distractions coming from looking at other screens while exploring the exhibitions, which is mainly the case when using smartphone or tablet-based AR applications, as it has already been stressed (Pollalis et al., 2017, p. 566; Pollalis et al., 2018, pp. 196-197). The team behind the creation of HoloMuse used 3D scans of ancient Greek artifacts which the user could select through hand gestures, examine them closely by rotating them or changing their scale while also viewing additional information about them (Pollalis et al., 2017, pp. 567-568) (Figure 25). Furthermore, ARtLens was developed for the enhancement of pieces of nineteenth and twentieth century art from West Africa, currently in the collection of the Davis

Museum. The application provides additional visual and textual material, highlighting the context of the chosen artifacts and their meaning in the communities that created them. On the other hand, however, interaction with the holograms was not straightforward for all visitors, due to the more complex required gestures of the HoloLens 1 (Pollalis et al., 2017, p. 569; Pollalis et al., 2018, p. 198).

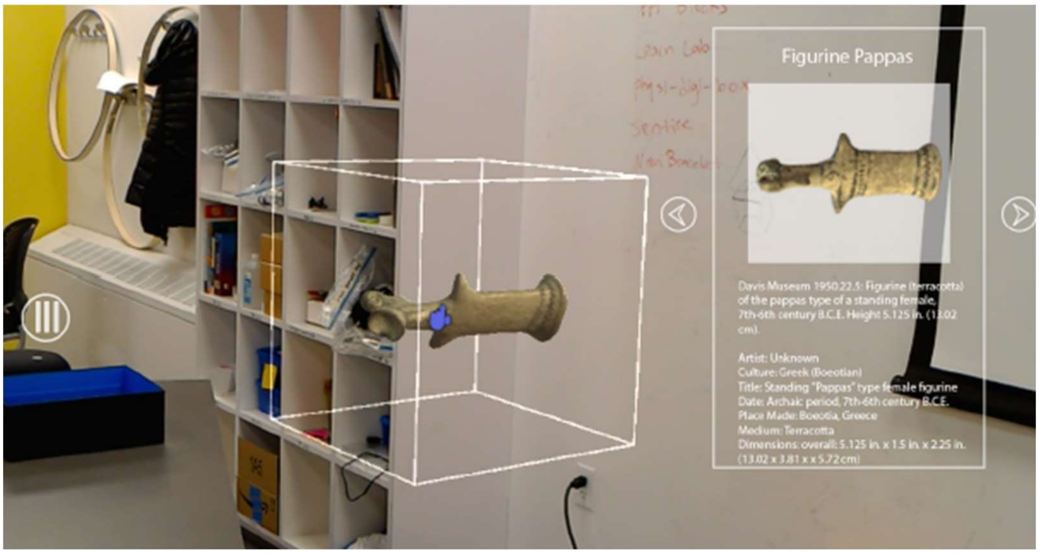


Figure 25. Interaction with holograms and interface of the HoloMuse app. (Pollalis et al., 2017, p. 568, Figure 7).

Scott et al. (2018, pp. 1-3) developed a prototype for the Porthcurno Telegraph Museum that creates an MR environment for interaction with a World War 2 telegrapher, also using HoloLens 1. The participants in the testing phase were given the task to write a message using Morse code. This study uses two different types of user input to create a more interactive and performative experience for the visitor. The first one works through interaction with a hologram – an augmented diagram with characters in Morse code – by using hand gestures and the second through a tangible interface (Figure 26). Regarding the latter, a tangible interface combines manipulation of a physical object that produces and can interact with an MR interface (Bekele et al., 2018, p. 10). In this case this connection is achieved through network. The point of this project was not to favor one method over the other but to highlight their advantages in each case. Despite the limitations with the system's hand gestures, such projects provide an immersive experience and add a gamification aspect that requires even more active participation by the user (Scott et al., 2018, p. 4).

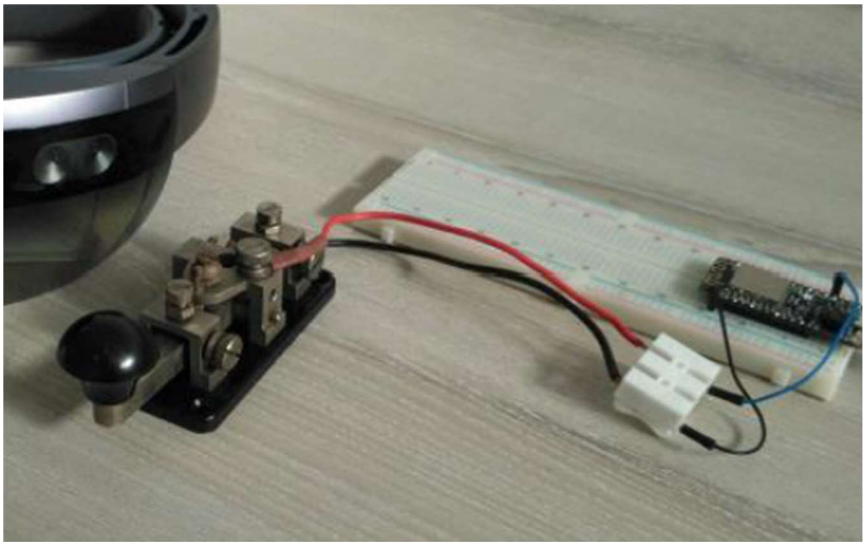


Figure 26. The tangible interface of the Mixed Reality Telegrapher. (Scott et al., 2018, p. 2, Figure 1).

Mapping Cultural Heritage sites

As far as Cultural Heritage Management is concerned, the HoloLens 2 has been applied in order to facilitate the mapping of important heritage sites and aid the decision-making process regarding their maintenance. To be more precise, Teruggi and Fassi (2022, pp. 489-490) created an MR application that uses the HoloLens' spatial mapping function, taking advantage of the device's depth sensor as it has been described above. The aim of this project was to test its capabilities and limitations in a large heritage monument. The researchers decided to map three different parts of the Milan Cathedral which correspond to three totally different case-studies in terms of scale, architectural complexity and lighting conditions, namely the south nave of the temple, the so-called Sordine below the roof and the narrow "Minguzzi" spiral staircase. The 3D mesh models produced with the HoloLens were then compared with ground truth data gathered during the survey campaign of the site.

The mapping was achieved by moving around while wearing the HoloLens 2 and looking at all directions, so as to cover as much of the space as possible. The results indicate that the spatial mapping capability of the device can be highly accurate, with the best results documented in more confined spaces, closer to "human scale", as in the case of the so-called Sordine. Moreover, its limitations became apparent, regarding the range within which the depth sensor can map the surrounding space. In the south nave the device could map only 4 m. of the total 24 m. high structure (Figure 27).

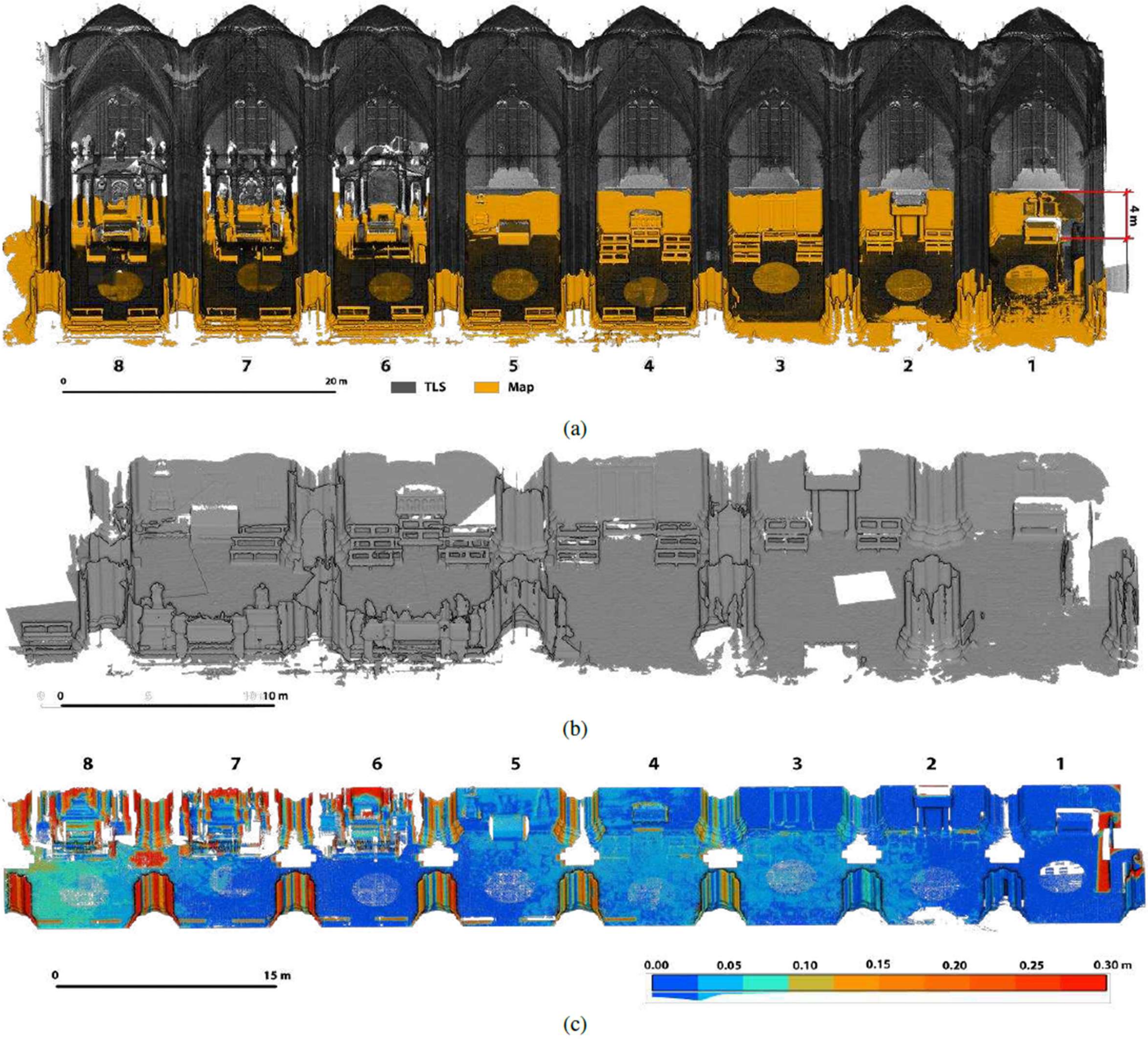


Figure 27. Comparison of the data gathered through the spatial mapping feature of the HoloLens 2 and the ground truth data of the south nave of the Cathedral. (a) shows the capacity of the device to map the nave, as it only recorded 4 m. of the whole space (in orange). (b) demonstrates the errors in the 3D mesh produced by the HoloLens. (c) indicates the ground

truth data with large deviations from the HoloLens data, colored in red. (Teruggi & Fassi, 2022, p. 492, Figure 4).

Some errors and biases were also attested, which were significant in some rare instances, shifting the location of features more than 0.5 m (Teruggi & Fassi, 2022, pp. 491-492). Thus, in large scale buildings it cannot map the whole surface and the range where data can be viewed consists a small fraction of the whole structure. Bad lighting can also be a hindrance when mapping, a fact highlighted during the survey in the narrow staircase (Teruggi & Fassi, 2022, pp. 495-496) (Figure 28).

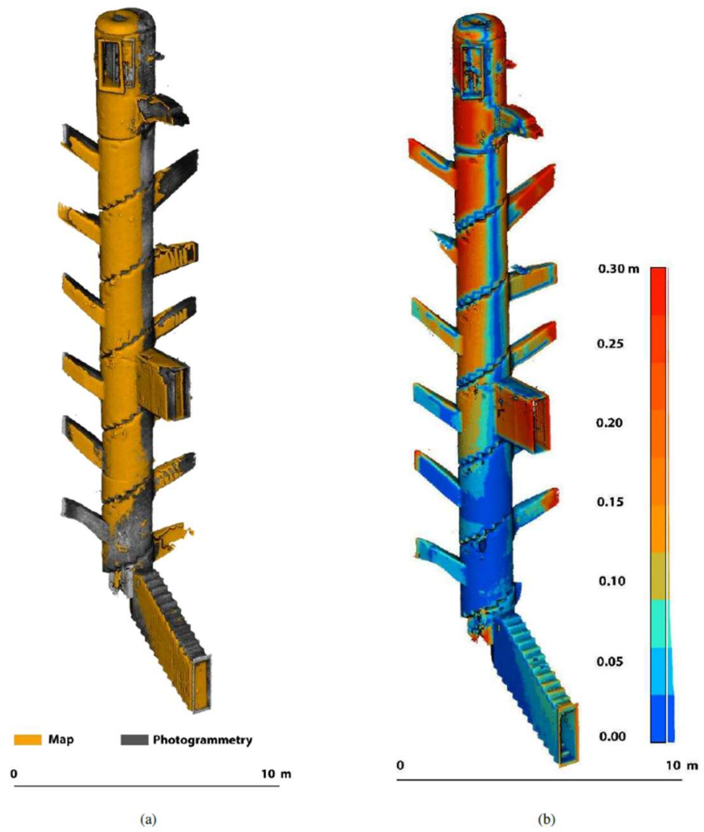


Figure 28. Comparison of the data gathered through the spatial mapping feature of the HoloLens 2 and the ground truth data of the narrow staircase. In this case study it is clearly demonstrated that the bad lighting conditions negatively affect the accuracy of the spatial mapping feature of the HoloLens 2. (Teruggi & Fassi, 2022, p. 494, Figure 6).

Research and Education

An important case-study in the field of archaeological research was conducted by Gaugne et al. (2019, pp. 82-84) that utilized the HoloLens 2 in order to aid the process of the micro-excavation of an Iron Age cremation urn. After the cremation urn was CT-scanned, a 3D model was produced, indicating the materials inside it, which was then superimposed on a 3D-printed copy of this urn (Figure 29). Through the HoloLens, the participants in the survey would observe the location and the orientation of the artifacts inside. As a result, this experiment could be useful for archaeologists in their preparation for the actual micro-excavation and contribute to minimizing errors and damage to the artifacts (Gaugne et al., 2019, pp. 87-88).

Figure 29. On the left one can see the excavation of a cremation urn. On the right the 3D printed model of a cremation urn is enhanced with CT-scan data in a MR environment. (Gaugne et al. 2019, p. 81, Figure 1).

A rare case study from the field of academic teaching highlights the potential of using 3D models in MR environments as a supplement for university lectures. More specifically, a team of byzantine archaeologists in cooperation with computer scientists developed the "Mixed and Augmented Reality in Blended Learning Environments" (MARBLE) project to evaluate the influence of MR visualizations in academic teaching. During the testing phase, the participants could not only interact freely with the 3D models presented but they could also cooperate and work as a team in the MR learning space. One of the positive aspects noted is the ability to interact with complex architectural structures through added tools such as the "clipping tool", with which one can create cross sections, thus allowing students to learn about architecture more intuitively in comparison to more traditional, 2D methods, such as ground plans (Figure 30). The downside, however, is the HoloLens' limited processing power, which imposes several restrictions on the models that could be used in such a learning environment. More precisely, the 3D models that can be imported and displayed must generally have a low number of polygons, thus setting a barrier to the data that can be displayed in this way (Miznazi & Stroth, 2022, pp. 2-3).

Figure 30. Interaction with a 3D architectural model of a church. A cross-section is produced through the "clipping tool". (Miznazi & Stroth, 2022, p. 3, Figure 2).

The above-mentioned applications indicate the large potential of the HoloLens as an important tool serving academic research and teaching purposes while at the same time highlighting the limitations of the technology at hand. Such studies take advantage of the gamification and awe-effect that new users usually experience during their first interactions with the device, but at the same time add significant depth and complexity in order to support the acquisition of new skills and provide solutions furthering archaeological research. These are some of the main traits of the device that this thesis aims at expanding.

Other Hardware solutions for MR applications in Archaeology

At this point it should be mentioned that Microsoft is not the only (big tech) company that has delved into the field of MR technology and in particular HMD devices supporting MR environments. At the time of writing, other companies, such as Apple and Meta have released HMD devices that target a wider audience, and not business purposes specifically, as is the case with the HoloLens. These devices share many common characteristics with the latter while adding significant improvements in terms of hardware. This short presentation of other available MR devices aims at providing a wider picture of the state of the art in this technology today, while also place the HoloLens 2 in its context within this category. Moreover, it will be evaluated whether certain hardware upgrades featured in these devices could provide the solutions necessary in archaeological MR applications, as they were highlighted through the above-mentioned case-studies.

Magic Leap 1 & 2

The two generations of HMD devices manufactured by Magic Leap were released approximately in the same period as the two HoloLens models – the former released in 2018 and the latter in 2022 – and they were tailored for similar target groups, as both companies aimed at providing solutions for business, manufacturing, healthcare and education.

Magic Leap 1 had a smaller FoV compared to the HoloLens 2, but in terms of storage space and memory capacity it offered double the capabilities of the latter (128 GB and 8 GB respectively). The relatively recently released second generation of Magic Leap HMDs marks a significant improvement in FoV size, more specifically 44 ° horizontal, 53 ° vertical and 70 ° diagonal and is equipped with even larger storage and memory space (256 GB and 16 GB respectively). Both devices are connected via cable to a "Compute Pack", a small unit linked to the headset that provide an additional processor designed for more demanding tasks, while another processor is located on the headset itself, destined for less intensive tasks. The user has to fit this unit into a pocket in order to keep it close. This system supports eye tracking as well, but it comes with a wireless controller instead of relying on hand gestures only (Magic Leap, n.d.).

Meta Quest Pro

Around the same time as the Magic Leap 2, Meta released its own HMD device that combines VR and MR features. Meta Quest Pro is a full-color passthrough headset that provides high resolution display and has similar specifications to Magic Leap 2, with 256 GB storage space and 12 GB RAM. Regarding the FoV, it consists a major upgrade compared to all previously mentioned devices, as it offers 106 ° horizontal view. Interacting with the device can only be achieved through two wireless controllers, which add an extra layer between the user and the media he/she interacts with. Its 10 MR sensors enable 6DoF movement, as does the HoloLens.

This device also offers the ability to adjust the level of immersion, that is to toggle between a VR – complete immersion – or an MR experience – without blocking the real world (Meta, 2024). This feature could provide valuable solutions for archaeological exhibitions, as the user would toggle between a view of a reconstruction of an artifact or structure and the real-world view, while displaying additional information and media in both environments.

Apple Vision Pro

Apple released the Apple Vision Pro HMD in early 2024 which combines aspects of MR and VR devices and is tailored as a consumer device, despite of its large price tag (3500$).

It is also a passthrough device with all the hardware present in the HoloLens, but the number of cameras is significantly upgraded, having 12 in total, offering high display resolution – 6.5 megapixel. The device's depth sensor is enhanced with an additional LiDAR sensor that can create 3D meshes of the surrounding environment. This system also supports hand tracking similarly designed as that of the HoloLens, with no additional controllers needed. Another strong point is the chip set that allows for high performances, with the 256 GB R1 chip that is responsible for handling all the input from the sensors and cameras. On the upper side of the headset there is also a button that allows the user to control the level of immersion in the display, leaving the user to decide which environment to use in each case, following the steps of the Meta Quest Pro (Heaney, 2024).

As far as hardware is concerned, the Apple Vision Pro demonstrates the development of this sector during these last few years, with significant improvements in performance rates noted. However, the battery always connected to the device via cable could limit movement. The same could be the case as a result of the device's weight – 650 grams – causing fatigue after prolonged sessions. The need for hygiene protocols after the device changes hand, during exhibitions for example, adds another challenge to its wider application in the Cultural Heritage sector (Wintor, 2024).

Taking all these aspects into account, it should be noted that the advanced processing power of these devices in comparison to the HoloLens could play an important role when designing an MR application for archaeological purposes, allowing for the processing of even more complex learning scenarios, using 3D models of higher detail. What is more, when designing an MR experience for a museum exhibition or for the purposes of a course, the developer should keep in mind that the user would have to get acquainted with the interaction system first. Especially for people not familiar with this technology, getting used to the interaction system is essential so as to ensure they get as much from the experience as possible. As it has been discussed, the controls have been a negative point for many users when interacting with the digital content for the first time. The developers also have to make sure that the tethered units are always connected with the HMD, which could severely limit movement. Thus, another parameter is added when designing such applications.

Last but not least, many newly released HMD devices opt to provide both MR and VR experiences, enabling a large FoV with high resolution. This advanced level of flexibility could benefit archaeology significantly in the coming years, as the same device could immerse the user in various degrees, each one addressing a different research question and educational goal.

Chapter 4. Methodology

A thorough overview of the HoloLens 2 capabilities and its previous applications has already highlighted certain areas in archaeological research where MR technology could provide new perspectives for documentation and interpretation. In the following section the case-studies chosen will be presented, firstly by indicating the aims behind each one and their implementation process.

Case-study #1: Documentation during fieldwork with HoloLens 2

The first case-study aimed at testing the ability of the HoloLens 2 to document and record archaeological features in situ, both architectural and movable, during fieldwork. Moreover, another target was to assess how and to what extent can this tool become a part of a field archaeologist's toolset. These aims were addressed by using the Documenting And Triaging Cultural Heritage (DATCH) (https://github.com/datch-ucf/datch2-docs/tree/main) prototype open-source software, developed by the University of Central Florida (PI: Dr. Scott Branting). The site chosen for testing DATCH was Chalcis, Greece in cooperation with the "Beyond Chalkida: Lansdcape and Socio-Economic Transformations of its Hinterland from Byzantine to Ottoman Times" (HMC) project, led by professor Joanita Vroom. There will be a short introduction to the project itself, the sites where the DATCH software was tested and their significance. Afterwards, a presentation of the software under examination will follow.

The HMC project and the Medieval towers in the hinterland of Chalcis

The HMC project takes place between 2020-2025 and is a collaboration of Leiden University with other international and Greek research institutions. The city of Chalcis was an important trade hub in the Aegean region and maintained that role from Byzantine times (named Eurippos) and onwards, even when it came under Venetian (named Negroponte) and Ottoman rule (named Eğriboz). One of the main aims of this project is to provide insight on the relations between the city and its hinterland, by combining published excavation data with newly acquired data from the multiple surveys conducted in the region. The study of all the kinds of materials collected (e.g. pottery) will shed light on the economy of the region and build a solid framework for understanding its role and function as an administrative and commercial center. Since the area of the survey has not been systematically researched before, this project will also fill a significant gap in the study of the region (Vroom, 2022, p. 463).

The main points of interest in the 2024 campaign, as well as in previous seasons, were the towers located in the hinterland of Chalcis, whose density is also great in this region. As far as their dating is concerned, most of them have been generally dated to the period of Latin rule of the island (1205-1470), as the Venetians implemented the feudal system in Euboea and thus the construction of such towers booms (Loizou, 2017, p. 626). Their style of construction, however, stone masonry bonded with mortar and use of spolia, cannot be dated with precision as the same manner of construction is also characteristic of the Byzantine period as well (Blackler, 2022, p. 405).

These structures are not part of a larger fortification but are free-standing in the landscape. Their rectangular shape and large dimensions – up to 18 m. high – make them an imposing feature. In most cases they are divided in floors that would serve as reception rooms and private rooms for the owner of the tower. Their ground floor would also be used for storing the produce from the nearby area that the tower watched over. At the top floor, the tower was crenellated and a small wall-walk provided a complete overview of the region (Loizou, 2017, pp. 629-630). Taking all these characteristics into account, it has been suggested that these structures were serving multiple roles, from the accommodation of the local lord and his family, functioning as an administrative center where produce would be stored, to being a symbol of might, both social and economic. Their defensive attributes would be useful in case of an attack, but Loizou (2017, p. 633) highlights their residential character and the level of comfort they would provide. On the other hand, Blackler (2022, pp. 408-409) adds another parameter that could enhance their defensive character, without ignoring their other functions mentioned above. Through the use of GIS data, it appears that the towers in this region of interest, but also in the whole island, had lines of sight to at least another such structure or fortification. As a result, they could be part of a wider signaling system on the island, that would be used as an alarm in the event of an attack.

All of the above mark the significance of these towers in the study of the landscape south-east of Chalcis. The current HMC project can add valuable insight to their uses and maybe provide more data for their dating. More specifically, the towers under examination are the following: the two towers of Mytikas (Figure 31), the tower at Bailelekas, Karaouli and Kastri. The HoloLens 2 was used only in the first two sites in the testing of the DATCH software for documenting the towers and this work was conducted in situ from the 26th to the 28th August 2024.

Figure 31. View of the two towers of Mytikas from the south. (Loizou, 2017, p. 638, Figure 5).

Overview of the software

DATCH is an application installed in the HoloLens 2 and can be toggled as any other app, from the main menu. After starting up, the user can bring up the main menu of the application by bringing their palm up, facing the goggles. Interaction with this menu is based on the set of hand interaction and/or voice commands presented above. As a first step, one can pin the menu in a certain spot or toggle it again when needed. Then a series of buttons are available which the following actions (Figure 32).

Figure 32. View of the main menu of the DATCH software while in the field. The menu is toggled when facing the palm of your hand, as shown. The options available, from left to right are "Draw", "Create", (Photograph: Andreas Leitourgakis).

The first important feature of this software is the "Draw" one. Through this button the user can select between drawing straight lines, curves or more complicated shapes just by pinching the thumb and the index finger. This function works like holding a digital pen. These lines can be connected automatically and create polygonal or random shapes, by toggling the "Close Shape" feature. The color of the line and its width can be adjusted at will, giving the opportunity to make distinctions between the features drawn. Furthermore, the "Create" button allows the user to add measurements and characterize certain features with multiple ways. More specifically, tags can be added and anchored wherever there is a feature of interest, a necessary tool for identifying and documenting them.

Then, through the "Measuring Tools" one can measure both 2D – mainly height and width – and 3D features. The former is achieved with the "Measuring Tape" and the latter with the "Measuring Cube". What is more, space can also be divided in MR through the "Peg Grid" feature, which creates a grid whose dimensions and distances between the pegs can be altered. In this way, the creation of grids, for creating excavation trenches for example, can be simplified and accelerated as well. After creating the grid each individual peg can be interacted with and change color, creating further divisions in a specific area, serving the purposes of a micro-excavation for example. The size of the grid can be altered by increasing or decreasing the distance between the pegs. The number of pegs can also be adjusted, both for the length and the width of the grid, which can end up covering an extensive area. For smaller surfaces the "Drawing Plane" can also function as a grid, but this time in 2D. It can be set either parallel or perpendicular to the ground and moved around. Additional lines can be drawn on this grid and be anchored to its intersection points, thus creating sounder measurements, a prerequisite when dealing with the excavation of a specific feature such as a hearth or the foundation trench of a wall.

The last available menu is the "Tools and Settings" which holds all the necessary buttons to create a new, save and open an older file. An interesting feature in this menu is the "Toggle Mesh" button, which uses the HoloLens' depth camera to create a 3D simplified mesh of the area the user is currently in and indicates all features in a small radius. As it has already been indicated through the case-studies of Teruggi and Fassi (2022, p. 489-490) described above, the HoloLens' spatial mapping capability can deliver adequate results in providing an overview of the area under consideration. This could be useful, both when mapping sites that are currently being excavated or others that require conservation. Additionally, images can be imported to the field of view through the "Import Image" button. Adding 2D media in the project can aid the documentation project by comparing previous drawings of a structure or toggling information necessary for making an assessment about the site. DATCH also enables the use of GPS for georeferencing features during fieldwork. In this case, however, it is necessary to have a DGPS connected to the HoloLens.

Case-study #2: An animal bone reference collection in MR

Background and significance

The second case-study aimed at the creation of a virtual reference collection for animal bones in a MR environment. As far as physical reference collections are concerned, they are used for multiple reasons, serving teaching but also research purposes. The use of extensive reference collections in zooarchaeology is a prerequisite in order to identify the material that has been collected during fieldwork, including the identification of the specimen itself, but also the taxon, age and sex of the animal. Furthermore, they also play a fundamental role in studying human and animal interactions, delving into issues such as animal domestication (Spyrou et al., 2022, p. 3). Besides these purposes, however, it is also a valuable teaching tool as students can get acquainted with animal anatomy and the morphology of each bone through a reference collection (Nobles et al., 2019, p. 5706).

The creation of reference collections in digital environments has been one of the main points where computational methods have been applied to zooarchaeology (Spyrou et al., 2022, pp. 2-3). The use of high-resolution 3D models of bones provides the opportunity to interact with them and grasp their geometry as well as the intricacies of each specimen by zooming in on their details (Zechini, 2014, p. 215). One of their main advantages is that they can enhance more traditional tools of zooarchaeological research, namely illustrated guides of animal bones found in books. As it has been stressed by Betts et al. (2011, p. 757), 3D models can be a valuable teaching tool for animal anatomy that is easily accessed via the Internet. When the need arises, the collection can be revised and/or enhanced as well with similar ease. What is more, when used in tandem with more traditional 2D tools, such 3D data can highlight additional points of interest on the bone, making them more easily traceable (Betts et al., 2011, p. 757).

A useful case-study that covers many of the above-mentioned points is the Laetoli Productions' Vertebrates collection (https://www.vertebres3d.fr/) that although having a limited number of available specimens, it provides a useful set of tools that can could be used for the identification and documentation of such material. More specifically, it allows the user to have an overview of the skeleton – either complete or not – and zoom in on specific bones. This selection can be made in groups of anatomic units – the spine of the animal for example, or by separating a specific bone of the skeleton. What is more, the user can toggle the different bones consisting of an animal skull and get acquainted with the terminology as well as their position on it. Other useful features provided include the measurement of length and angle of certain features. This type of feature could be useful when comparing the digitized specimen with a fragment from a zooarchaeological assemblage, gathered during excavation.

Similar implementations in an AR or MR environment have been rare so far. The Bonify project provided valuable insight on the usability and accessibility of virtual reference collections by experimenting with multiple environments, both with a web platform and with an AR headset (Figure 33) (Nobles et al., 2019, p. 5708).

Figure 33. The equipment used for the AR application of the Bonify project. The Smartphone-based AR device uses the cards presented as markers to toggle the 3D models. (Nobles et al. 2019, p. 5709, Figure 2).

The results from the questionnaire involved a small number of people, nevertheless indicate that such technologies can be beneficial for both students and researchers and that the majority would be inclined to make use of them again in the future. As the participants stressed, the main reason for that is that they solve the accessibility problems mainly associated with restrictions imposed for physical reference collections and their portability, especially in the case of AR (Nobles et al., 2019, pp. 5710-5712). Transporting zooarchaeological assemblages to labs equipped with extensive reference collections is not always an option, as political and/or logistical reasons can be very restrictive (Nobles et al., 2019, p. 5706; Spyrou et al., 2022, p. 3). The hardware option used however - a smartphone-based AR headset –

proved to be a hindrance for some users and was a significant drawback in their experience.

Thus, we are led again to the main targets of this current endeavor. These include, first of all, how this important tool, both for research and education, can be transformed to a MR experience. Additionally, what are the advantages and caveats of using such a reference collection. Since this is an immersive experience, it is interesting the explore the new possible insights such a tool could provide and, in this way, enhance traditional reference collections. Besides that, it will be evaluated how accessible and user friendly such a platform is, following the methodological framework set by Nobles et al. (2019) for the Bonify project. The methodology for the creation of a MR environment that will suit the purposes of an animal reference collection will follow below.

The goal of the Virtual Animal Reference Collection through HoloLens 2

Before getting into the details regarding the creation of the MR platform hosting this virtual reference collection, some considerations had to be taken in mind so as to render this tool as useful as possible. One of these concerned the specimen that would be used to test this platform.

Initially, the focus was on species that are common finds during archaeological excavations, such as pigs and cattle for example. However, after discussing with the director of the Laboratory for Archaeozoological studies of Leiden University, Dr. Laura Llorente-Rodriguez, it became evident that the focus should be more on rare and wild species, that are not represented adequately in the conventional reference collection of the laboratory. Since the species that are more commonly found in archaeological contexts are well represented in the reference collection with many different age groups also present, such an endeavor would be turned obsolete. Not only that but the effect of working with both archaeological and reference material hands-on is a crucial element in zooarchaeological work, as addressed by Dr. Llorente-Rodriguez. Archaeological assemblages get fragmented in many different ways and thus, getting acquainted with their weight and surface is a necessary step when trying to identify and document them. This is not possible through a hologram and as a result the emphasis was changed, towards specimens that are not available in the reference collection, as it was deemed this would hold more potential for their usefulness.

The Bonify project, presented above, aimed specifically at addressing the issue of the distinction between sheep and goat, as these two species share many similar morphological characteristics, although their cultural significance is much different (Nobles et al., 2019, p. 5706). Having a specific aim for this project that targets a point where the conventional reference collection lacks can lead to the creation of a valuable supplement for it. This is the reason why a specific research aim has been set for this MR reference collection as well.

The creation of the MR environment

This platform was developed using the Mixed Reality Toolkit (MRTK) provided by Unity (Microsoft, n.d.-a). Unity is a game development engine that although not open-source provides free access to users through a personal license. In order to access the Unity ecosystem, one needs access to the Unity Editor, available through the Unity Hub application. Rahaman et al. (2019, pp. 7-10) also provide an overview for the creation of a MR environment using Unity for cultural heritage. The following flowchart (Figure 34) presents the methodology described below and the elements needed in order to create this project.

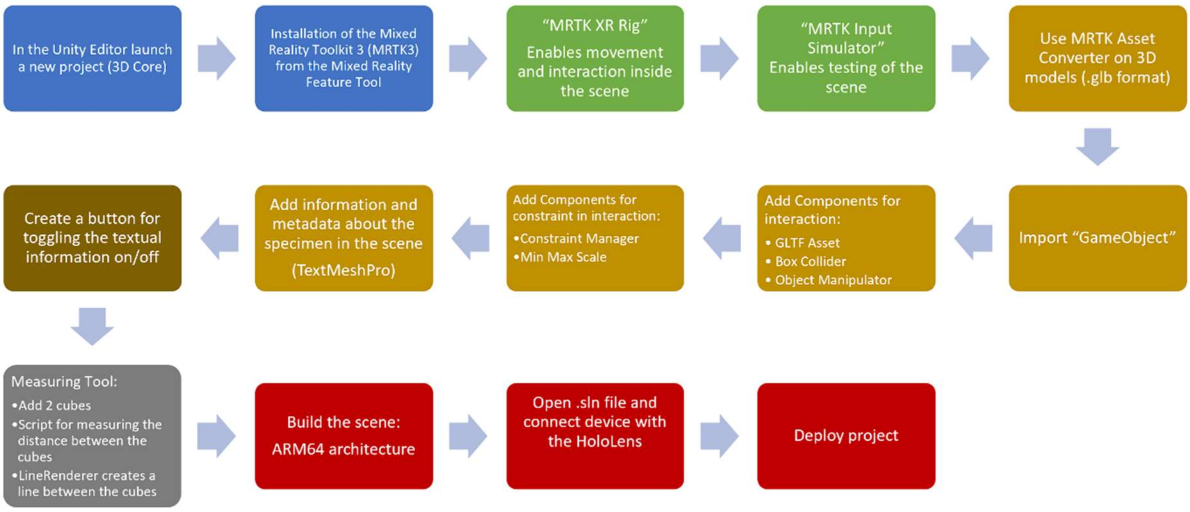


Figure 34. The steps needed in order to create the MR environment in Unity for the Virtual Animal Reference Collection. (Photograph: Andreas Leitourgakis).

The first step in creating any kind of MR experience suitable for the HoloLens 2 is configuring the Unity engine for Windows Mixed Reality. After creating a "New Project" and choosing the "3D Core" template, a scene is created. It is a Unity building block which corresponds to a certain level or environment of an application or game. It is crucial then to set the platform to which the project will be exported in the end, and that is the "Universal Windows Platform" – the default platform for every app created for a Windows device.

Since the basic configurations regarding the identity of the project have been made, the next step is to import the MRTK, an open-source software that supports functionality for the HoloLens 2, among other AR and MR devices. As it comes with pre-built components controlling all the interaction input, namely the hand gestures, eye-gaze interactions and voice commands, as well as the User Interface tools, such as menu bars and buttons, it allows the user to quickly set up the MR environment and emphasize on the content that will be presented through this project (Microsoft, n.d.-a). In order to get access to this kit, I imported this package in my Unity project from the "Mixed Reality Feature Tool". The latter provides several features packages, and the ones installed include the "Mixed Reality OpenXR Plugin" and all the features of the latest version of the MRTK.

After importing the toolkit some additional configurations have to be made to the project settings so that it enables the use of the MR features and interaction methods. More specifically, the OpenXR plugin directly enables all the features used in the HoloLens 2, by selecting the "Microsoft HoloLens feature group". The Interaction Profiles, the way the user interacts with an MR app can then be added from the same plugin. In this case, I added the "Eye Gaze Interaction Profile" and the "Microsoft Hand Interaction Profile". A new scene is then added and the features from these packages are available in the Editor.

The first main component added to the scene is the "MRTK XR Rig", which serves as a pre-built foundation for the project that handles the camera tracking, used for movement, and interaction with the holograms that will be added to the scene. Another valuable tool is the "MRTK Input Simulator", through which I could run tests of the actual interaction methods and movement inside the scene, using a mouse and keyboard instead, without using the HoloLens at this development stage (Microsoft, n.d.-a).

At this point, the necessary components for a MR experience are present in the project and the content that will be used for the virtual reference collection can then be added to the scene. Before delving into the details about how to add content however a discussion about the type of content used will follow. An important step was deciding what 3D model would be imported for this prototype that would serve the purposes stated through the research question. It should also be noted that this model should also be suitable for the specifications of the HoloLens as well. As far as the former is concerned, a vast array of 3D models of animal skeletons can be accessed online with no extra cost through various websites. For this project, Sketchfab (https://sketchfab.com/) was deemed the platform most suitable as it contains a large record of 3D models of high-quality which are created in many instances by research centers and museums for educational and public science purposes. The models can be downloaded in different file forms from the website. In order to use them in the device the imported assets must be in the .glb file format.

The model that was chosen was downloaded from Sketchfab for free. It is the skull of a juvenile hippopotamus (Hippopotamus amphibius) from the collection of the Lapworth Museum in Birmingham (specimen TN015A) (Figure 35).

Figure 35. The 3D model used for the MR reference collection. View of the model on the Sketchfab platform (Retrieved December 5, 2024, from Sketchfab, https://sketchfab.com/3d-models/hippopotamus-skull-2e90e06b3d5547e0aec53bf600012a26).

As far as its characteristics are concerned, the 3D model has a triangle count of 1.1 million with more than 500k vertices. Such a highly detailed model would be difficult to be imported in the HoloLens 2 due to the high processing power needed and as a result it could severely hinder the performance of the application. In order to optimize the model and ensure that it would be functional the Windows MR Asset Converter tool (WindowsMRAssetConverter) (Microsoft, n.d.-b) was used. This tool renders the asset compatible with MR environments for Windows and optimizes the triangle count so that it can function properly, without overloading the processing unit. It is a simple but necessary step for applying digital media in a MR environment.

After the conversion is finished, then the 3D model can be imported to the Unity project as a new Asset (Figure 36). In Unity, all the objects that the player can see and interact with are called “GameObjects”. Thus, a new empty GameObject is created in the existing scene and the 3D model is added to it in the Hierarchy. The first way to manipulate the object in the scene is by manipulating its position in it. This can be adjusted through the Position parameters in the Transform section of the GameObject. Its position is set right in front of the user when starting the project so that it can be located automatically and interacted with straight away. Before delving into how to configure the interaction with the object, the “GLTF Asset” Component must be added to the object. As this is not a built-in 3D model of the Unity engine, this component must be added so as to properly display it in the .glb format. It also plays a role in adding realistic lighting to the asset, while ensuring at the same time that loading the object becomes more efficient. Now a 3D object is in the scene but the user cannot interact with it. The solution for this is provided by adding the Components mentioned below.

Figure 36. The Unity project interface with all the necessary tools for MR functionality, controlling movement and manipulation of objects as well as the 3D model that will be viewed through the HoloLens. (Photograph: Andreas Leitourgakis).

The first one is the “Box Collider” which creates a rectangular area, enclosing the 3D asset. It works as a boundary for the imported asset and can detect when a hand gesture or hand ray is approaching it. In order to actually interact with the object, however, the “Object Manipulator” component is needed, as it enables moving, scaling and rotating of the object through hand gestures. The “Constraint Manager” component, when applied together with the “Object Manipulator” can further control how the user can interact with the 3D model in the scene. More specifically, it sets a series of rules that restrict certain types of manipulations on the object, limiting its rotation only on the Y-axis, thus rotating it only horizontally, or how big or small the object can get when scaled up or down respectively. Another important restriction that I thought it would be important to add is concerning the scaling of the object. An important feature of this reference collection is the ability to “zoom in” specific parts of the bone and observe them closely. Thus, being able to double its size could serve this purpose. On the other hand, minimizing the model has been disabled, so as to avoid confusion in regards to the real dimensions of the specimen. As a result, the smallest dimensions that the model can get are the real-world ones (Figure 37).

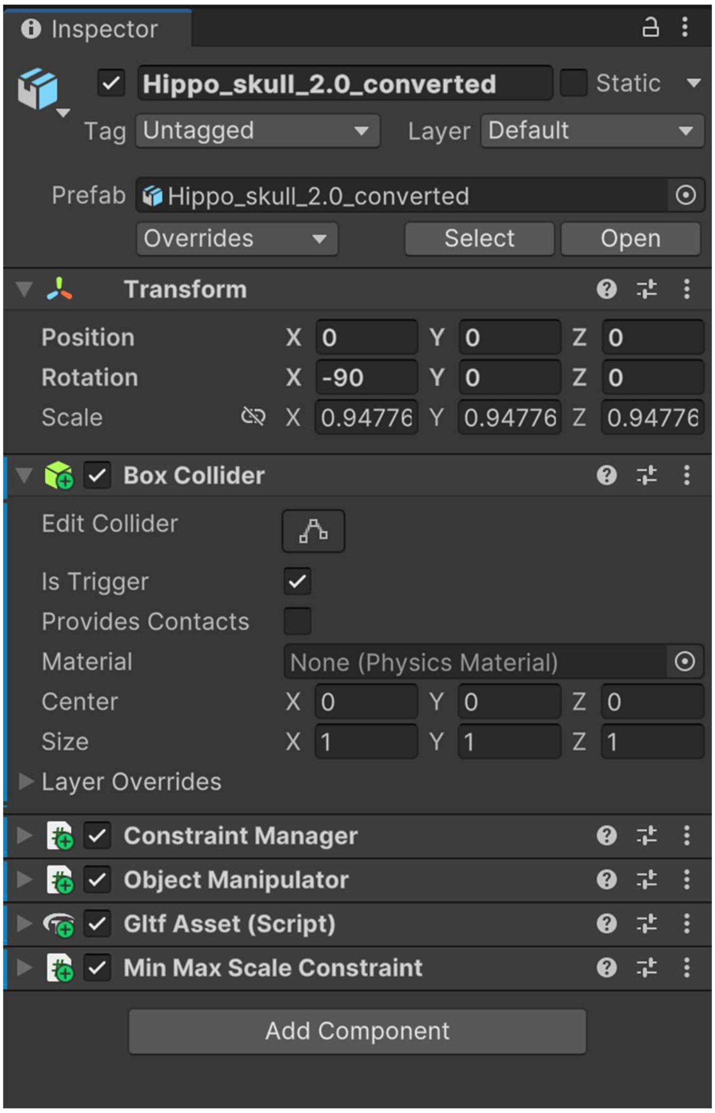


Figure 37. All the components needed for the basic manipulation of custom 3D objects in Unity. The presented components enable not only manipulating and interacting with the GameObject but also set a series of constraints in terms of movement and scaling, so that interaction with a 3D model is behaving in similar fashion as with real objects. (Photograph: Andreas Leitourgakis).

Besides adding the 3D model of the skull and interacting with it, the user should be provided with certain information regarding the identification of the specimen in question. That information includes the species of the specimen (*Hippopotamus amphibius* in this case), as well as its age and sex – a juvenile male – and the anatomical unit – the skull of the animal. Additional metadata concerning the creator of the model and its origin from Sketchfab are also present (Figure 38). This text is added to the scene with the TextMeshPro (TMP) component which can be easily added and adjusted to the correct location, in the corner of the user's line of sight. This component is added as an object in the project Hierarchy, but under the 3D model of the skull, so that it follows the movement of the model and it does not stay static in the scene. As a result, both objects behave as one.

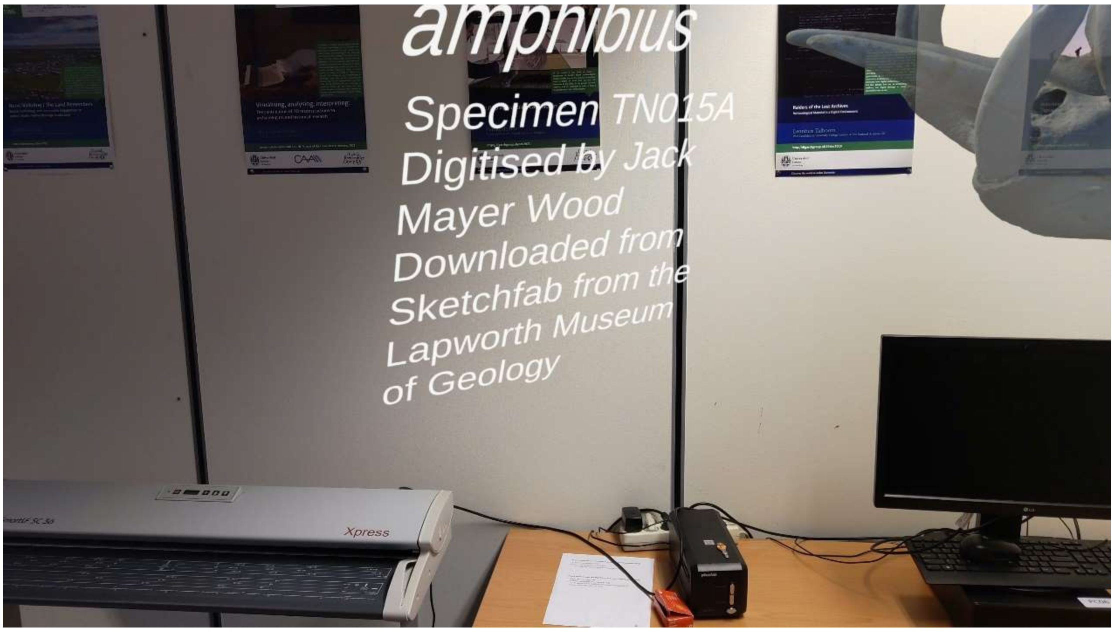


Figure 38. The metadata about the specimen used in the Virtual Animal Reference Collection. (Photograph: Andreas Leitourgakis).

I considered that it would also be useful to be able to isolate the 3D model itself on the scene, without the additional information. The reason for this is that when the user will want to emphasize only on the virtual specimen and the actual artifacts from an archaeological assemblage, the text would easily be getting in the way, causing nuisance. This is why an additional component was added to the TMP that toggled the text's visibility on and off. This was achieved by adding a "New Script" component and adding the relevant lines of code in the Microsoft Visual Studio platform in the C++ programming language. This option is toggled on or off both with hand gestures – through the use of a button. As far as the former is concerned, a pre-built pressable button from the standard assets of the MRTK software was added to the scene with the name "Toggle Text". Then the button must be configured properly, by adding the Text Visibility script to the "OnClicked" function of the button.

In addition to the above, a Measuring Tool was created for this project, so that any object, real or virtual, can also be measured. Two small cubes – standard Unity assets – were added to the existing scene so as to function as handles and are always present. A script was added as a component so that the distance between the cubes is measured and displayed, while a green line indicates that same distance (Figure 39). A text component was added to display the measurement and face the user.

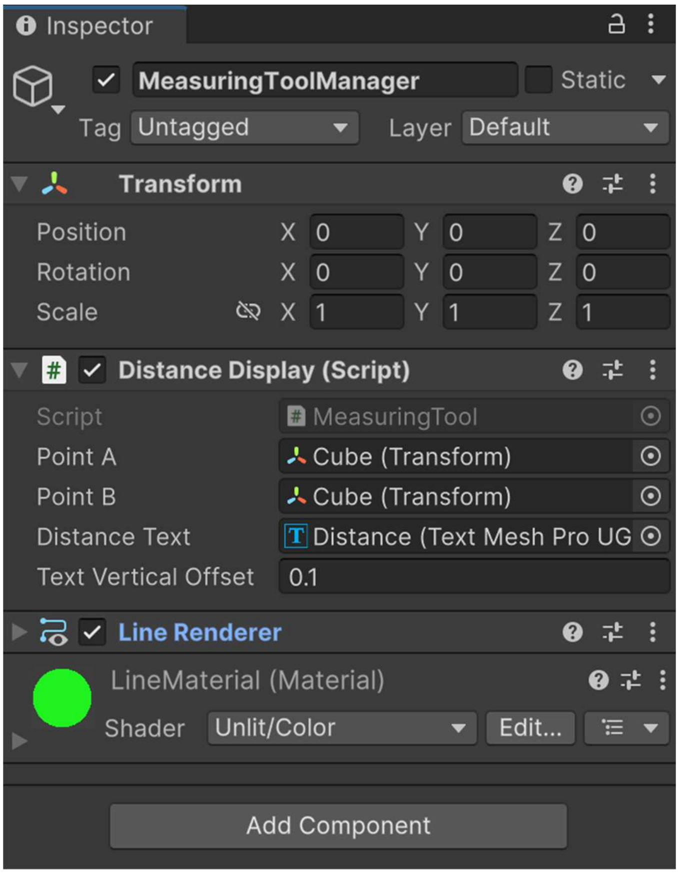


Figure 39. The Measuring Tool Manager created and its components in Unity. The custom script calculates the distance between the 2 cubes, while the Line Renderer creates a line between them. (Photograph: Andreas Leitourgakis).

After all of the above have been completed the final step is to build the scene in Unity. This results in an .sln format file that can be opened through the Microsoft Visual Studio platform. The file is opened and then it is set to be deployed to the HoloLens 2 after setting both devices (the one used to create the scene and the HoloLens 2) to developer mode. After the deployment procedure is done, the application can be found in the HoloLens 2’s Home Menu. The evaluation of the MR environment will follow in the next section.

Chapter 5. Results

Case-study #1

The use of the software is generally easy to get acquainted with and changing between the different features provided can also be seamless. The only drawback is the responsiveness of each interaction which was not always stable, as pressing a button could require multiple tries before seeing the result. In addition to that, the menu and the hand gestures were also twitching at times and delayed interactions with the software.

First of all, we are going to start reviewing the results from the “Draw” feature. During all the tests of the DATCH software I tried to create as detailed drawings of the masonry of the walls of the towers as possible. In this phase, the drawings of the stones were made by following their contours. This was achieved by getting close to the wall and using the pinch interaction right onto their surface, and keeping my fingers in that position so that the digital pen would remain toggled (Figure 40A).

Figure 40. Drawing of a portion of the masonry of the Bailelekas tower. A) On-site demonstration of the drawings. The contours of the stones have been followed and different colors have been used, a function that could be used to highlight differences in material used. B) The same section of the tower as seen in an indoor setting. (Photograph: Andreas Leitourgakis).

The significant drawback in this case is the automatic closing of the shape, which created small protruding surfaces, that are not part of the masonry. In the current version of the prototype this feature could not be toggled off, thus when reaching the starting node of the line additional care was needed in order to minimize the discrepancy. Small discrepancies are also evident in some cases when parts of the line drawn disappear from the view, creating small gaps on the contour.

In Figure 40B one can see the elements drawn in an indoor setting. Opening the DATCH file after fieldwork has the main issue that the user cannot control the location where the features will be displayed, which could pose some limitations when interacting with that data.

An interesting case was the stones right on the edge of the tower, which required moving around the edge and following the curve of the masonry while keeping the same interaction active (Figure 41). The same discrepancies discussed above were evident but the overall geometry of the stone was digitized successfully. Drawing stones that were situated close to one another could also cause some problems, as the algorithm falsely tried to connect these shapes when the digital pen was set close to a node of another shape/stone. This was tackled by moving the pen slowly in these points of close proximity between nodes.

Figure 41. Drawing features right on the corners of the tower. View from northwest of the large block on the corner of the Baleleikas tower. (Photograph: Andreas Leitourgakis)

After creating some drawings, the next feature that was added to them was the “Measuring Tape” in order to get an overview of the dimensions of the specimens digitized. In most cases two measurements were taken, the length and maximum width of a stone, so as to demonstrate its accuracy and functionality when combined with other 3D elements, the drawings in particular (Figure 42).

Figure 42. Adding measurements to drawn features using the DATCH software. View of the western side of the northern Mytikas tower, indicating drawings of stones and their measurements. A) Drawings and measurements on the actual wall. B) The same section viewed in an indoor setting. (Photograph: Andreas Leitourgakis).

The dimensions are portrayed in a clear manner even when measuring the same specimen, however adding too many tapes may become impractical, as there is the danger of moving the wrong one by accident. Measuring large dimensions, such as the whole western side of the northern tower of Mytikas was also feasible and did not require much effort for the correct placement of the tape.

Digitizing a feature and measuring it was completed by adding a tag to it, so that it can be identified easily and highlighted in case it was of special interest, as was the case with a 19th c. inscription, found on the southern side of the northern Mytikas tower (Figure 43). I also tried to copy the letters of the inscription using the "Draw Lines" feature so as to document its contents too, but that endeavor was unsuccessful, since the letters were too close to each other and the algorithm always intermingled them falsely, creating an undecipherable text. The challenging aspect of adding a tag was anchoring it to the desired feature. In many instances even small hand gestures could move the small cube – used to pinpoint exactly to which feature the tag is related to – and change its position.

Figure 43. Observing and interpreting features using tags in DATCH. View of the tag highlighting a modern addition to the southern side of the northern Mytikas tower. (Photograph: Andreas Leitourgakis).

Other architectural features highlighted were the multiple postholes on the western side of the same tower. As it is a narrow opening, drawing it with the digital pen proved difficult but an alternative was used in this case in order to document this feature. Calling in the “Toggle Mesh” feature was able to cover a larger part of the posthole, with some gaps still remaining however. This feature was also used in order to check the maximal surface of the tower that could be recorded. The mesh was not uniform and covered only a small part of the whole tower. Even with this limitation in mind, it could still be an important tool when used for the documentation of excavated features by creating this 3D mesh in quick fashion, as it can provide an overview of the geometry of the feature, without surface details.

Another function that I experimented with was the “Peg Grid” as I tried to create a grid that could match with the trial trench excavated near the western side of the northern tower of Mytikas and potentially act as a guide, in case it needed to be extended (Figure 44). This endeavor was not as successful however, as the trench was very small in size – just 1 x 3 m. – while the size of the grid could not be altered freely, as it has been noted above. Setting a 5 x 5 m. grid could also be useful in the intensive survey phase of the project and aid the grid creation process. This could be achieved by anchoring one grid of the same size right next to the other.

Figure 44. The “Peg-Grid” function in DATCH. Setting a 5 x 5 grid near the northern tower of Mytikas. (Photograph: Andreas Leitourgakis)

Calling all of the above-mentioned functions was done under different lighting conditions, in order to evaluate practical aspects, such as the brightness of the device and the efficacy of the hand gestures. All the functions and features were successfully used even under direct sunlight, with the brightness level on the maximum. Careful selection of the colors for the features drawn is necessary, as they can be hard to trace under direct sunlight when the contrast is low. Making mistakes under these conditions was more common because of this reason. Initially, there was concern whether it would be practical to move around while wearing the HoloLens in the hilly terrain near the towers. As the device does not obstruct the view of one's surroundings and it is not that heavy either, normal caution was needed when moving around.

Case-study #2

As it has already been mentioned, the Virtual Animal Reference Collection project can be easily accessed from the Home Menu of the HoloLens 2, as any other application. After opening it up the user can clearly see the hippopotamus skull straight away, as well as all the relevant information added on the left side of their line of sight.

Testing of this prototype took place in Leiden University's Laboratory of Archaeozoological Studies, both by Dr. Laura Llorente-Rodriguez and me, with the aim to evaluate its user-friendliness and accessibility. During testing, the 3D model was viewed alongside real specimens from the Laboratory's collection, so as to evaluate its efficacy and spot potential challenges in its implementation. This session was a valuable opportunity to discuss further potential developments of this prototype and points where it could be optimized, in terms of content and functionality (Figure 45).

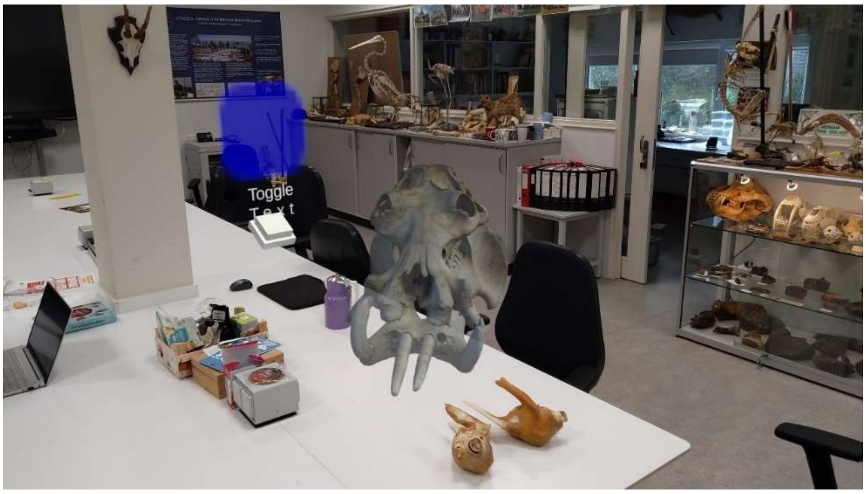


Figure 45. General overview of the content presented through the virtual animal reference collection. The 3D model of the skull with the button

next to it toggling the text with the information about the specimen on and off. (Photograph: Andreas Leitourgakis).

Interacting with the skull is easy and can be achieved both from afar – thanks to the hand ray – and from close range. Even when manipulating the model in a fast pace, the performance is not facing any issues and the responsiveness is high. In a few instances, however, the model would remain toggled and as a result change position, ending up somewhere else in the room without the user noticing. This confusion could be easily fixed by restarting the app. This is a point where users not familiar with the HoloLens's hand interactions could face difficulties. Thus, a quick tutorial on its systems of interactions could prove useful before starting up the application. The user can place the specimen wherever they deem suitable and get close to it, in order to observe its details. Enlarging the bone is also very helpful in this case as the user can place their emphasis on one point and get a much more detailed look.

As far as the text is concerned, it follows the movement of the model, without getting mixed up (Figure 46). In the testing phase there were instances where parts of the text were not completely visible, as there were drawers getting in the way and obstructing the view.

Figure 46. The virtual animal reference collection in action. The text accompanying the 3D model of the Hippopotamus skull. (Photograph: Andreas Leitourgakis).

Using the button is also straightforward although it sometimes needs a few clicks before actually showing the intended result – toggling the information on and off when clicked. Responsiveness of the user interface is again a small issue, as with the previous case-study. The current version of this prototype does not support toggling the button with voice commands, thus the user must toggle it manually. It does not follow the user but stays fixed where the user initiated the application.

The next thing that was evaluated was comparing the 3D specimen with bones of the same species at the same time. The Laboratory only has bones from an adult male *Hippopotamus amphibius,* thus using the skull of a juvenile was useful for tracing anatomical differences between the two (Figure 47).

Figure 47. View of the Virtual Animal Reference Collection through HoloLens 2, while testing in Leiden University's Laboratory of Archaeozoological Studies. The user can interact with the 3D model and compare it to actual specimens. In this case a juvenile (3D model) and an adult Hippopotamus amphibius are being compared. (Photograph: Andreas Leitourgakis).

As the 3D model of the skull was articulated, it was more difficult to compare their teeth but they were still examined in close proximity to each other. More specifically, it was possible to compare the canine of the adult *Hippopotamus* with the one from the 3D model and place them side by side (Figure 48). When handling the premaxillae of the adult one and got them close to the 3D model, while it was still easy to trace the differences, the 3D model sometimes was moved by accident, as the program registered the hand holding the bone as triggering a hand gesture when very close to it. Subtle movements and a steady hand minimized the risk of accidentally moving the 3D specimen, however.

Figure 48. Application of the virtual reference collection in the lab.Comparison of a canine of an adult male Hippopotamus amphibius with the 3D model of a juvenile one above. (Photograph: Andreas Leitourgakis).

Holding the 3D model of the articulated skull of the juvenile *Hippopotamus* highlighted the difference between the two and consists an important contribution to the existing physical reference collection in the Laboratory.

The final step was to test the custom Measuring tool. Handling the two cubes is straightforward although getting them close to the model again requires careful movement, as the specimen can easily be toggled by accident. The measurement is visible and seen on the left of the user (Figure 49).

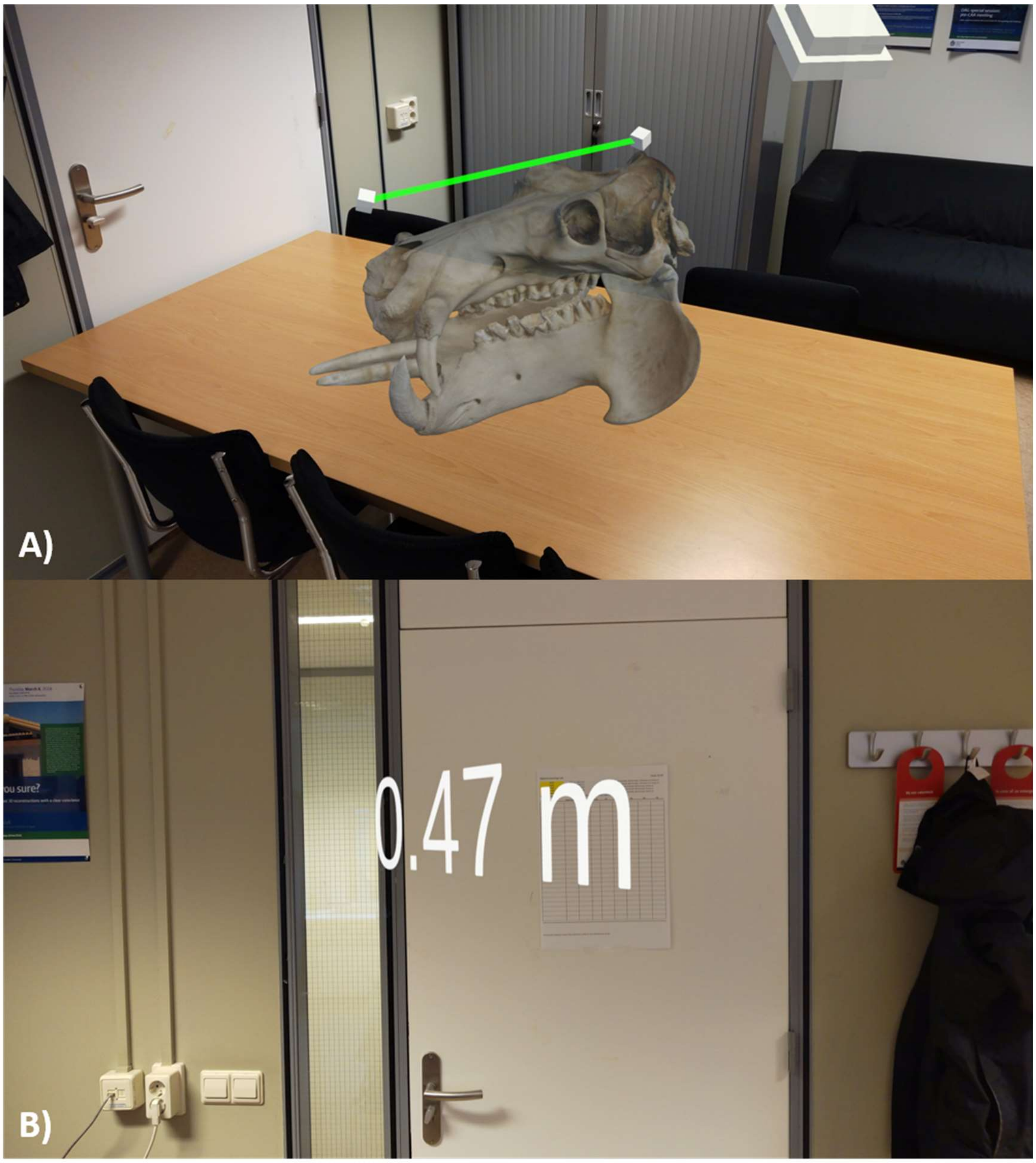


Figure 49. The custom Measuring Tool in action. A) The virtual ruler is placed on the model so as to measure its length. B) The actual value is displayed separately on the left side of the user's sight. (Photograph: Andreas Leitourgakis).

This simple environment presented ensures that the user is not overwhelmed with data. Quite the contrary, only the most necessary aspects are present since the bone can be isolated from the additional information about it, as when getting a certain specimen out of a drawer of a standard reference collection.

Chapter 6. Discussion

DATCH as a tool for archaeological visualization and interpretation

Creating tools for visualizing archaeological excavations has been a field of significant experimentation with many different computational tools since the late 1990s (Di Franco et al., 2012). The targets of these applications have been multiple, from assisting academic teaching – as Di Franco et al. highlight with their 3D Virtual Dig application (2012) – to finding new ways to address research questions. Presenting archaeological fieldwork to the wider public but also other specialists has been another central point in this endeavor (Morgan, 2009, pp. 471-472).

What is more, in certain excavation projects nowadays, the creation of 3D visualizations of stratigraphic units and features consists a basic component in the workflow of the excavation. The case of the Kaymakçı Archaeological Project (KAP), presented by Nobles and Roosevelt (2021, pp. 591-593) is indicative of how fundamental is the accumulation of 3D stratigraphic data for documenting excavated features. They also stress how the extended use of 3D data requires the development of spatial thinking, as it heavily influences the way archaeologists structure their data and, consequently, how they relate and interpret them spatially (Nobles & Roosevelt, 2021, pp. 609-610).

Archaeological visualization of excavations: some basic guidelines

The current section aims at placing the DATCH software in the general context of visualization tools for excavations. In order to achieve that, previous case studies with similar goals in disseminating excavation data to other experts as well as the public will be discussed. This will in turn indicate certain aspects of these projects which will be considered in order to evaluate the DATCH software. As it will be highlighted, DATCH does not serve only as a tool for visualizing features but also provides novel ways to explore that data.

In many cases, projects that undertake the visualization of excavation data aim at reconstructing not only the sequence of stratigraphic layers and features but the buildings and structures found in a site. This results in complex digital systems that enable recording of data, their reconstruction and visualization, while also being connected to large databases handling all kinds of material or features excavated. The 3D MURALE project is one such case, which had tools for all of the above functions early on, but emphasis will be put on the aspect of visualization (Cosmas et al., 2001, p. 297). More specifically, this system enabled viewing the 3D layers and the artifacts within them in a simplified manner, while also creating a kind of timelapse that presents the stratigraphy in chronological order (Cosmas et al., 2001, p. 304). It is apparent that, even early on, such tools were focusing on visualizing the stratigraphic relation of artifacts and provide an intuitive way to reconstruct their sequence. In the site of Itanos, in Crete, a 3D reconstruction of the necropolis was created with similar aims, and first of all to visualize a complex stratigraphic sequence – created by the many phases of its use (Ercek et al., 2010, pp. 82-83) (Figure 50). In a second phase, these reconstructions would be used to enable online virtual visits to the site. These characteristics indicate that a useful archaeological visualization can be a solid basis both for forming and testing hypotheses about an excavation, while also rendering the site more approachable to the public (Ercek et al., 2010, p. 84).

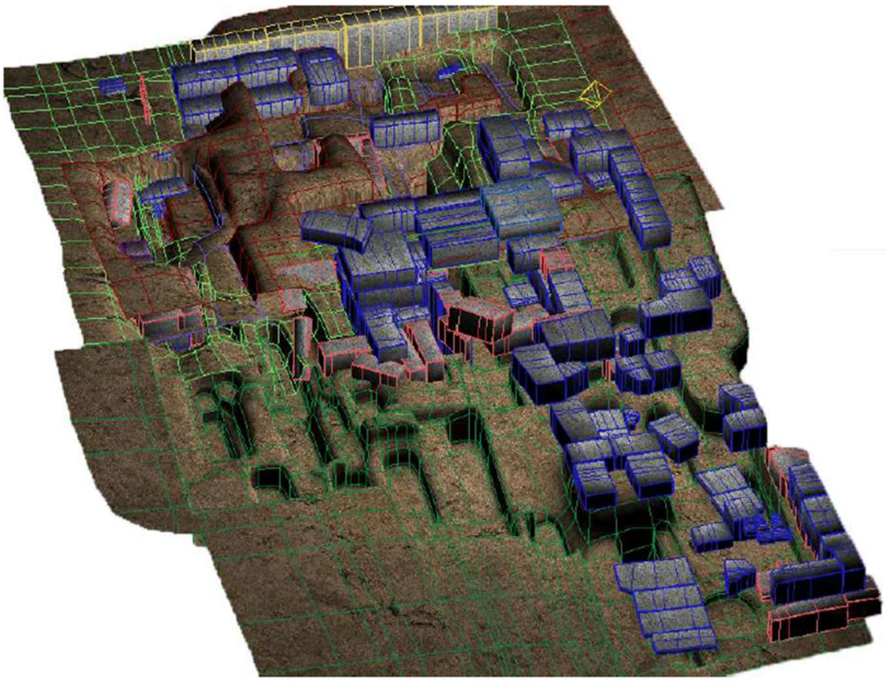


Figure 50. The 3D model of the ancient necropolis of Itanos. The different colors are used to indicate different phases of use. (Ercek et al., 2010, p. 83, Figure 5).

Such visualization projects were successful in creating a realistic presentation of a site and its details but they lack in one specific aspect. That is embodiment. Even if the reconstruction is as accurate as possible, the space viewed is devoid of any life and, in most instances, seen from above and afar, an experience that no past inhabitant of the site would have, rendering the experience not so informative about past experiences, as Morgan stresses (2009, p. 472). More recently, this call for embodiment has been addressed by some interesting applications. Opitz and Johnson (2016, pp. 5-6) support that a sense of embodiment when visualizing excavation data can be a useful tool towards more critical interpretations of a site. In order to test this, they created a visualization of a Republican period house in Gabii, where the user could move in its space and observe the remains, while also examine its stratigraphy and what type of artifacts were collected (Opitz & Johnson, 2016, pp. 10-12) (Figure 51). Seeing the whole site from above was also added as a feature and this combination proved to be more useful when used in tandem with a more sensory stimulating interface.

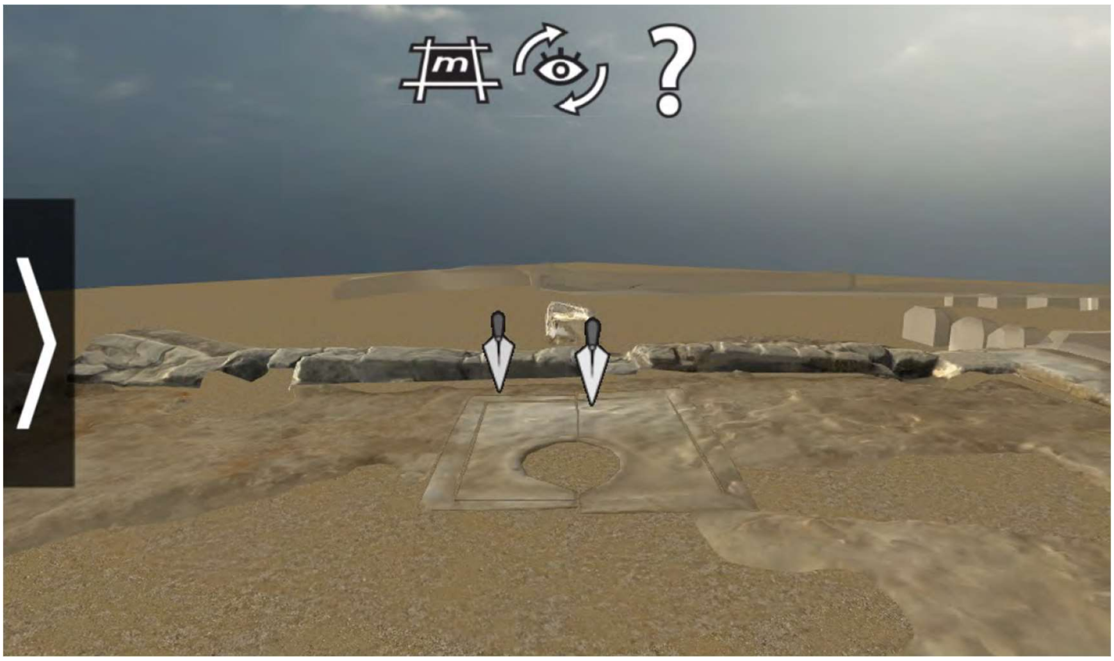


Figure 51. View of the interface of the VR application of the Gabii project. The user can move around in the actual remains and toggle specific features, as shown. (Opitz & Johnson, 2016, p. 9, Figure 3a).

The use of VR tools is also a step in the same direction, adding an immersive element to the embodied experience, as it is demonstrated by Lercari et al. (2018) in Çatalhöyük. This team created the Dig@IT VR application to create an immersive environment where the player can explore the remains of a Neolithic Building (B.89). Some important features of the app are the ability to spatially examine specific stratigraphic units and review available data and metadata about them (Figure 52).

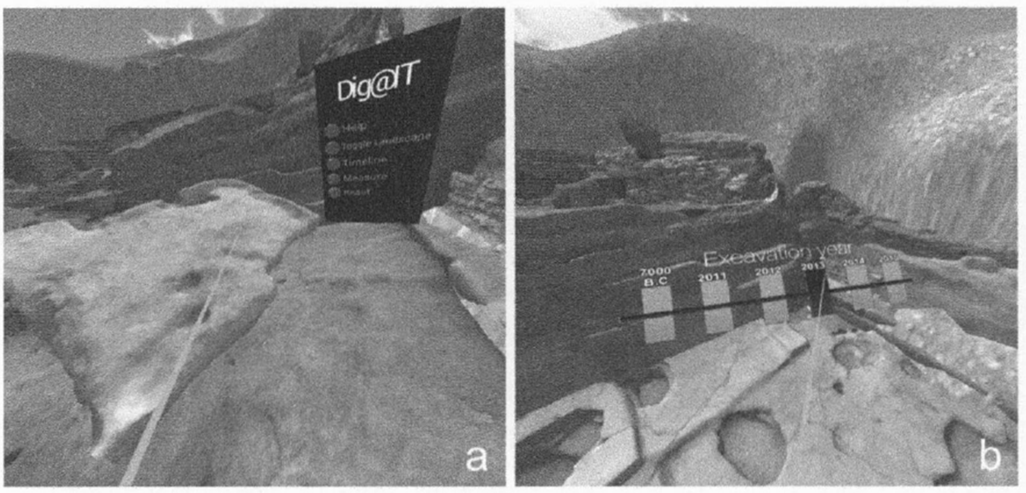


Figure 52. The Dig@IT VR application in Çatalhöyük. a) shows the menu of the VR environment while inside structure B.89. b) indicates the function that toggles the data between the different excavation seasons, functioning as a timeline showing changes in the site as the excavation advances. (Lercari et al., 2018, p. 382, Fig. 9).

This can be enhanced by toggling 3D models of artifacts found there and make measurements for all these features as well (Lercari et al., 2018, pp. 381-382). The result is an embodied experience that surpasses the limits of 2D media and encourages a spatial three-dimensional interpretation of this structure, as it enables to examine data that have been destroyed in the process and making connections between data that would not be as visible otherwise (Lercari et al., 2018, p. 378).

DATCH can also be seen as a step further towards the same direction as it enables an embodied experience, whether on- or off-site. The kind of interpretative thinking that Lercari et al. (2018, p. 378) advocate for can also be supported for MR environments. In this case, however, the physical constraints of an excavation site remain, while these can be surpassed easily in a controlled VR setting. Nonetheless, the chance to examine archaeological features using DATCH's simplified drawings in the actual site and while still connected to the surrounding environment is significant. This is because, MR enables a totally embodied exploration which is based on making spatial observations.

Another tool implemented in Çatalhöyük that can be directly compared with DATCH is the interface for digital drawing. The main difference in this case is the hardware used – a tablet PC (Forte, 2014, pp. 14-16). The aim was the creation of a record where features and potential interpretations would be noted daily, serving as a type of digital excavation diary, as indicated in Figure 53.

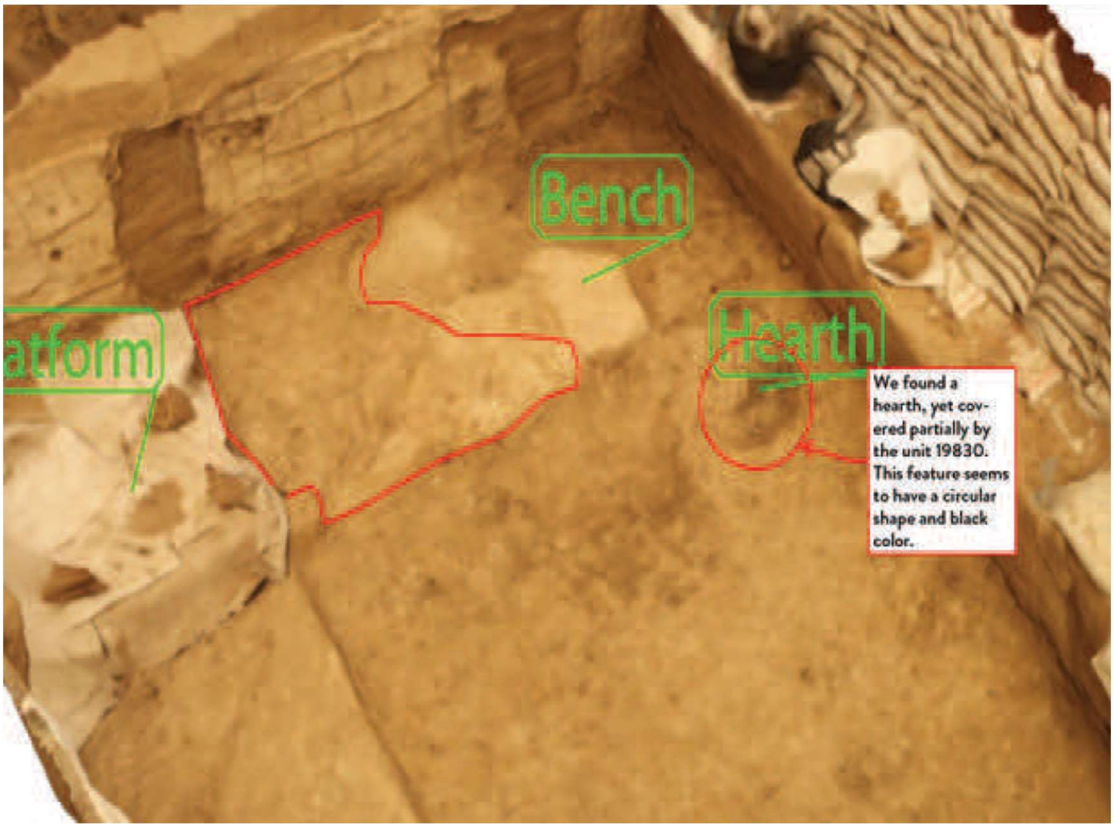


Figure 53. Digital drawing interface used in Çatalhöyük. The digital drawing from structure B.89 with interpretations and tags on features. (Forte, 2014, p. 16, Fig. 18).

Since this platform was accessible to all researchers in the program, it formed a collaborative tool where ideas and theories could be explored. These characteristics also form the backbone of using DATCH for fieldwork recording as well.

Visualizing archaeological fieldwork in Mixed Reality

As we have seen so far, using the DATCH software in outdoor conditions was effective not only in documenting features and measuring them but also provided the opportunity to visualize them in a more immersive way, while remaining connected with the real surrounding landscape. In the context of MR and AR applications implemented in the same field, DATCH combines many of the positive characteristics of the prototypes described above. As far as VITA, created by Benko et al. (2004), is concerned, DATCH consists a simplified and easier to use alternative where features can be visualized both in situ and in a different setting. The level of detail presented by the former remains much greater, as it was connected to the excavation project's database (Benko et al., 2004, p. 4). Currently, DATCH does not support connection to a database, from where 3D assets would be imported. On the other hand, if more devices were available, it would enable users to have the same file open and review the documented features in the same location but also remotely as well. As a result, the prospect of collaborative work with DATCH could easily be realized.

The case-study by Kayalar et al. (2008) presents many similarities with DATCH, in that it enables recording features and visualizing them in situ. In this aspect, the latter can be viewed as a more immersive version of the former. DATCH too allows the user to have an overview of previously completed work and add on to it by drawing more features that are being unearthed (cf. Kayalar et al., 2008, pp. 2-3). In addition to that, their spatial correlation can be visualized in a more immersive manner, highlighted by adding tags and, last but not least, explored in multiple ways. For example, hypothetical lines can be drawn – connected to the existing features – and test the feasibility of a theory about the nature of a structure. Measurements can also be added to support or cast doubt on a potential interpretation. In this was way, DATCH could also play the role of an explorative tool for generating interpretations and testing them visually.

Many of the above-mentioned characteristics are also in line with the MR environment Dilena and Soressi (2020) presented. Despite its limitations in positioning the 3D model and instances of blurry visualizations (Dilena & Soressi, 2020, pp. 11-12), this case-study highlights the potential of visualizing an extensive database, where information about stratigraphic layers and different kinds of materials is recorded, and viewed in MR. Cobb and Azizbekyan's (2024) multifaceted experimentation with MR tools sets these endeavors in a sounder basis too. An application combining the capabilities of DATCH regarding in situ documentation and the vast catalogue of 3D and spatial data that Dilena and Soressi's (2020) application holds, could result in a more holistic understanding of an excavation site. The ability to visualize features that have been removed in situ, in detailed fashion, as presented by Cobb and Azizbekyan (2024, pp. 378-379), is a direction that can benefit the documentation of an archaeological site using MR. Moreover, the spatial thinking aspect would be further supported, since all artefacts could be easily brought up to the user's viewpoint and connected with the rest of the archaeological record.

Thus, the DATCH software can be a valuable asset in a field archaeologist's toolset. Not only does it enable collaborative work – provided there are more HMDs available – in both field and lab settings, it also paves the way toward some of digital archaeology's challenging issues. These include a need for more experiential approaches in archaeology, a key advantage of MR technology, and integrating a spatial component to the core of how archaeologists do fieldwork. Although DATCH does not enable such detailed visualizations as other case-studies mentioned above, it aims at providing an immersive testing ground for hypotheses and an embodied tool for documenting and visualizing features.

Virtual Animal Reference Collection: enhancing zooarchaeology with holograms

The current version of the reference collection for wild and rare animals is still a prototype, providing some basic guidelines on how such an interface should be structured and what information it should hold in order to be useful for zooarchaeologists. Additionally, this application has been reviewed in a lab setting only by one expert – Dr. Laura Llorente-Rodriguez – and me. This remains a very small sample, which does not allow for overgeneralizing, some key advantages and challenges can be indicated however.

Getting past the “wow” factor and towards a meaningful contribution

When compared to other relevant endeavors, such as the Bonify project (Nobles et al., 2019) described above, the MR environment presented here is adequately addressing some of the issues that had rendered elements of the Smartphone based-AR application used unsatisfying or difficult to use. It should be noted that, unfortunately, cases of motion sickness are not a rare occurrence and this can be a hindrance for some users, as it was noted by Nobles et al. (2019, pp. 5710-5711). This is the case for all types of extended realities. The interface of the reference collection created however is much easier to use, as it does not need any additional medium to display the 3D model of the bone, as is the case with the Bonify AR, which used cards as markers to show the models.

As it has been stressed before, this project does not aim to replace the conventional reference collection. On the contrary, it aims to be a valuable supplement for it, and especially for the animal species that are not adequately represented there. Thus, the fact that user satisfaction was higher with the physical one, does not deem the virtual edition a lost cause (Nobles et al., 2019, p. 5713). Such options can be a valuable solution when access to a reference collection is not possible. This is the case especially when working in remote locations, as participants in the questionnaire of Nobles et al. also indicate (2019, p. 5711).

Another advantage of this interface is that, besides serving as a tool for identifying archaeological specimens, it can also be useful for teaching purposes, so that students get acquainted with the anatomy of an animal. Di Franco et al.’s (2015, pp. 260-261) multiple experiments using different visualizations of artifacts indicated that people were highly motivated to interact with 3D models in an immersive environment. These virtual elements maximized their enthusiasm and also boosted the learning outcome. Even though the objects in the virtual reference collection cannot imitate the physical characteristics of the real objects, they can be more useful in attracting the attention of the students and increase the acquisition of knowledge. The element of embodiment should also be highlighted here as it can significantly improve learning outcomes, as Bozia stresses (2023, p. 140) based on research from many different academic fields. Bozia uses the HoloLens to visualize a database of inscriptions for epigraphy specialists but also students. This application provides the user with the same interaction affordances – that is manipulation and interaction with the object – as the interface for the animal bones, described above (Bozia, 2023, pp. 141-142). In this way, this current project also aims at creating a virtual space where, even though tactile affordances are missing, the user can interact and visualize the specimens in a totally new way, not following the rules or the real world, but staying connected to it at all times (Bozia, 2023, p. 142).

The further development of such an interface would allow for the creation of a portable virtual reference collection, that specialists would be able to carry wherever their assemblages are located and thus surpass the practical limitations that are associated with the transportation of archaeological material and access to laboratories. Only a MR HMD would be needed, and connection to the cloud in order to load the models, a much more practical solution for fieldwork in remote areas.

In this section the potential of the prototype of the virtual animal reference collection has been highlighted. Not only can it serve as a tool for identifying archaeological specimens but it can also function as an educational source for zooarchaeology students. This MR environment could become an important part in a specialists' toolset, both during fieldwork and in the laboratory.

Limitations

In regards to the in-situ implementation of the DATCH software, it should be stressed that due to the limited time of the fieldwork program only a small section of the walls of the towers was actually digitized. It was deemed more useful to experiment with its features in as many different settings as possible, different lighting settings for example, instead of emphasizing in one place and drawing all of it. As the towers are still preserved in considerable height, it was only possible to register only a small section of them, a limitation that has already been addressed by Teruggi and Fassi (2022, p. 491), and actually draw an even smaller one. DATCH would be really useful in case a structure was unearthed in the nearby test trenches, as it would be reachable in all its dimensions in this case.

Access to the site was also an important factor that had to be taken into consideration, so as to use the HoloLens in the safest possible location, thus Bailelekas and the two towers of Mytikas were chosen. As the tower in Karaouli was covered in high vegetation, it would not be practical to work there for longer time spans. An additional caveat was that there was no Total Station available for the days I was working in Chalcis, thus georeferencing the drawings was not possible, an important feature of DATCH. To be more precise, when GPS functionality is activated, the software can create a map of the features present in the user's active project (DATCH-UCF, n.d.).

As far as the 2^{nd} case-study is concerned, the current version of the animal bone reference collection prototype only presents one 3D model; however, it would be interesting to be able to view more than one models at the same time, as one would do with multiple specimens from a physical reference collection. This would enable not only comparing the models with the archaeological specimens but also making comparisons between the 3D assets themselves, a necessary tool when identifying animals with morphological similarities as in the goat/sheep problem mentioned in Nobles et al. (2019, p. 5707).

Chapter 7. Conclusion

Taking all of the above into consideration, both case-studies highlight the potential of implementing MR technology in archaeological research, serving a multitude of different research problems.

Not only is it used to visualize digitized structures, it can also provide novel ways to interact and interpret them. The short testing phase of the DATCH software in the HMC project provided a glimpse of the potential benefits of using MR technology during fieldwork. The software provides tools for drawing and measuring features in situ using the natural interaction system of the HoloLens 2. In this way, this device provides an easy-to-learn tool for documentation of archaeological sites. Additionally, using the software for recording features in excavation trenches can enhance traditional tools used, such as 2D drawings, as it combines the advantages of 3D media with a strong sense of embodiment. This type of visualization opens a new perspective in how archaeologists document their work and test their hypotheses, as it can visualize features in the exact location they were located, without losing the sense of being in the site. This is thanks to MR's main characteristic, the use of the real world as the basis for any immersive experience.

Consequently, such an environment can not only enhance an archaeologist's spatial thinking ability, but it can also be the background for experimenting with possible connections between features and visualize multiple assumptions, that can be tested as the excavation proceeds. Ideas can be passed on to others as the device changes hands. If more HMDs were available, the documenting and experimenting process would become truly collaborative. This aspect could really change the way excavation projects shape and build on their research questions. The same is true not only during fieldwork but also post-excavation. As archaeological visualization consists a necessary component for disseminating our work to other specialists and the public, this tool is a step towards a more immersive and embodied examination of the archaeological record.

Some limitations have to be taken into account as well. Safety is a significant concern when implementing such technologies in the field. While the HoloLens 2 –

and such MR HMDs in general – do not obstruct the view of the user, the 3D media could distract the user from real obstacles in the field, which in turn could cause serious accidents. Motion sickness is also another constraint that could render the experience unpleasant for a group of users. Regarding the interface of the software, trying to draw very small details or features that are located close to one another currently poses some problems as the algorithm mistakenly connects them. This results in unrealistic data that could confuse other users if they are not familiar with the site. This is why it is important to implement such tools in tandem with traditional methods, so as to take advantage of all benefits of this multifaceted toolset.

When the focus is shifted towards zooarchaeological research problems, the presented prototype for a virtual animal reference collection in MR functions as a supplementary tool for conventional reference collections. This immersive environment can provide a feasible alternative for the enrichment of reference collections with material that otherwise is very time-consuming and logistically challenging to acquire. This case-study presented emphasized especially on rare and wild animals, which fall into this above-mentioned category, and can be a valuable contribution for Leiden University's zooarchaeological reference collection. Moreover, it can assist the identification of animal remains, as it allows the user to manipulate both the 3D asset and the actual artefacts at the same time and change between the two seamlessly. It can also function as source material for academic teaching of anatomy for zooarchaeology students too.

Some significant caveats arose when addressing the usability of this prototype. The same concerns about safety still stand for this case-study although it is more suited towards use in indoor settings, which are more easily controllable in general. Testing this prototype with a larger group of specialists and students would be ideal for making more robust claims about its user-friendliness and accessibility, given that it is destined for use by anyone, regardless of their technological skillset. The fact that it also contains one 3D model in the current version also does not portray the full potential of such software.

All in all, MR has proven to be a useful tool for addressing research problems that are not new for archaeological research. Instead, this immersive environment has the potential to play a central role in many archaeological sub-disciplines, whether it is implemented at the trowel's edge or for zooarchaeology. A major challenge when dealing with immersive technologies is getting past the initial "wow-factor" and providing a useful and accessible experience. As more and more hardware solutions are becoming available, MR could become an integral part of archaeological research, allowing the integration of digital toolsets in multiple archaeological settings.

Future research

The work presented above shows that much could still be done in order to further optimize such MR implementations in the field of archaeological research. In regards to archaeological visualization, the DATCH software could be used in similar fashion, as in the current case, during excavation but this time connection with a database should be configured. This database would hold 3D models of features – structures and/or artifacts – ideally georeferenced. The result would be a more versatile toolset where the drawings and interpretations of the excavators could be enhanced by 3D models of features that are no longer in situ. Consequently, this phase would consist another step towards more complex visualizations in this embodied MR experience.

Concerning the virtual animal reference collection, adding whole skeletons of wild animals would be a significant contribution for the collection of the zooarchaeological laboratory. Other categories that are often not adequately represented are very small mammals and birds, categories which are also common finds thanks to flotation and sieving. Additionally, the HoloLens or any other HMD could serve at the same time as a portable reference collection that the specialist carries where the assemblage under study is located. Adding the skeletons of large and medium sized mammals, such as cattle and goat/sheep, could be beneficial when no reference material is present, although this would need a large number of specimens in order to be useful. This endeavor could be combined with a questionnaire aimed at specialists and students in order to assess how this tool could be added to the zooarchaeological toolset. Furthermore, it would be interesting to test how a MR interface is evaluated when compared to web-based platforms hosting reference collections in terms of accessibility and user-friendliness.

Similar reference collections could be designed for other disciplines as well, for osteoarcheology for example, for the study of human pathology in the past, or for pottery, by making catalogues of 3D models of known pottery types. On the one hand they could serve as an identification tool for such cases and at the same time create source material for educational purposes. It would be interesting in this way to highlight the potential and limitations of visualizing different types of artefacts in MR.

Abstract

The aim of this presentation is to provide an overview of the capabilities and challenges of the implementation of Mixed Reality (MR) technology in archaeological research. The hardware option that is used for this project is Microsoft's HoloLens 2, released in 2019. In order to evaluate it, two distinct case-studies have been chosen, the one related to archaeological fieldwork and the other linked to laboratory work, and more specifically for zooarchaeological purposes.

In regards to the first case-study, the aim is to test the ability of the HoloLens 2 to document and record archaeological features in situ. Another target was to assess how and to what extent this tool can be implemented in the workflow of an archaeological survey and/or excavation. As far as the second case-study is concerned, the target was to create a prototype of a virtual reference collection for animal bones in a MR environment which is focused more on rare and wild animal species, as these are, in most cases, not adequately represented in conventional reference collections.

The Documenting And Triaging Cultural Heritage (DATCH) open-source software was used for the first case study, in Chalcis, Greece. It was used at the medieval towers found in the hinterland of Chalcis with the aim to make drawings of the masonry, but also make measurements and add interpretations that could be useful for the study of these structures. As far as the MR animal reference collection is concerned, this platform was developed using the Mixed Reality Toolkit (MRTK) open-source software in the Unity game development engine. Imported 3D models of wild animals from Sketchfab (https://sketchfab.com/), available for free from the Lapworth Museum's collection, are used as the basis for this digital reference collection with the aim to create a prototype of a supplementary edition for the physical reference collection.

DATCH offers a quick and efficient way to create simple drawings of structures, following the contour of the masonry blocks. Making measurements and creating tags for highlighting and/ or identifying certain features, such as postholes or inscriptions found on the tower's masonry, can enhance these drawings and be a valuable tool for visualizing features in a more intuitive manner, even after fieldwork is over. Regarding

the MR reference collection, the 3D content was viewed in tandem with real specimens of the same species – a male *Hippopotamus amphibius* in this case. Working with both types of objects at the same time was seamless, manipulating the 3D model in such a way that was similar to the specimens of the conventional collection.

Both case-studies highlight the potential of implementing MR technology in archaeological research, serving a multitude of different research problems. Not only is it used to visualize digitized structures, it can also provide novel ways to interact and interpret them. When dealing with animal bones it can assist the identification of animal remains and/or academic teaching of anatomy too. As more hardware solutions are becoming available, MR could become an integral part in testing hypotheses and creating new knowledge when studying the past, movable or not.

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