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DIGITAL REVIEW

The Apple Vision Pro: Useful Mixed/Augmented Reality (MR/AR) Headset for Archaeology or Not Quite There Yet?

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Overview
Digital eXtended Reality technologies enable users to view and interact with spaces and objects in three dimensions (3D), thus supporting a variety of potential innovative embodied applications in archaeology. Here, we review the Apple Vision Pro as a Mixed/Augmented Reality (MR/AR) headset to determine where it might fit within current archaeological practice. Our interest in this device spans primary field data collection, in situ visual–spatial interpretation, and public education and tourism. Overall, we find that although it makes certain advances on prior eXtended Reality hardware, it does not yet represent a significant enough shift forward to have a major impact on archaeology. However, we do plan to continue our field experiments with this technology to push its limits and to prepare for future improvements to this product and its competitors.

The Apple Vision Pro headset was first released to the public in early 2024 (Chow 2024). This headset joins a long line of eXtended Reality devices developed by companies over the past decade (Kelion 2019; Meta 2022). Digital eXtended Reality technologies allow users to view and interact with spaces and objects in three dimensions (3D), from the completely digital environments of Virtual Reality, to the overlay of graphics onto camera feeds with Augmented Reality, and to the seamless immersive integration of 3D models into the real world with Mixed Reality head-mounted devices (Cobb et al. 2024; Liang 2021:250–251). While the Vision Pro is a Virtual Reality headset, its pass-through cameras can project the real world to the user and enable Augmented Reality and 3D Mixed Reality interactions (Figure 1).

Given the inherently 3D nature of archaeology in the real world, the potential uses for eXtended Reality devices in archaeology are abundant and quite varied. Virtual Reality headsets have seen use in both tourism applications and classroom teaching about archaeology and history (Cobb 2024; Cobb and Nieminen 2023; Kyrlitsias et al. 2021). Augmented Reality apps and Mixed Reality headsets have also been deployed at archaeological sites to guide tourists by providing additional archaeological information and visualizations (Mudička and Kapica 2023).

Moving beyond these informational presentations for archaeology, we have previously demonstrated the potential for utilizing head-mounted Mixed and Augmented Reality devices to enhance data collection and interpretation directly at archaeological sites during active excavations (Cobb and Azizbekyan 2024). We were not only able to do hands-free collection of basic text and image data with the headsets, but we could also place 3D models of previously excavated contexts back into the trench in situ. At our site in Armenia, we captured high-resolution 3D models of all our volumetric excavation contexts using photogrammetry. Furthermore, we developed a novel method to locate virtual 2D planes in the trench for guiding the physical excavation process, and we joined real and virtual pottery sherds. However, we determined that the latest hardware devices had many limitations for regular use in the challenging outdoors conditions of archaeological fieldwork. For example, we found the headsets uncomfortable to wear for an extended time, since they are heavy and hot in the sun, plus their batteries do not last more

Figure 1. Side view of user wearing the Vision Pro (photo by Muhammad Hasan Shahab).

than about two hours, and we suspect the devices may not survive for long in the heat and dust. Thus, we were interested in experimenting with the next latest hardware, the Vision Pro, to determine whether it improved on the earlier Mixed Reality options.

Technical Overview of the Vision Pro

The Vision Pro is a headset meant to be worn on your face to cover your eyes, with straps that attach over and behind the head to hold it in place (Figure 2). Each eye looks into its own screen, where graphics are projected, enabling the 3D effect through parallax (Figures 3 and 4). External cameras can also pass through real-time views of the surrounding environment onto these screens to enable Augmented and Mixed Reality interaction. Each screen reportedly has a very high resolution of 3660 × 3200 pixels per eye, which should enable detailed and realistic graphics (iFixit 2024). Indeed, in our experience, this does produce high-quality, pleasing imagery. The Vision Pro is equipped with significant processor power, including a dedicated graphics processing unit (GPU) to compute camera and sensor inputs and create complex 3D visuals (Apple 2025). Users can purchase one of three internal storage options—256 GB, 512 GB, and 1 TB; all of them work with 16 GB of unified memory, an advanced version of RAM.

Field of View is a key factor in eXtended Reality headsets because it indicates how much of the user's surroundings are visible. Without a headset, the two human eyes together naturally have a horizontal Field of View of about 114°, but each eye also has around another 35° of peripheral vision (Awati 2022). Each eye also has a vertical Field of View of about 150° with facial obstructions. The Vision Pro is reported to have a horizontal Field of View between 100° and 120° and a vertical Field of View of about

Figure 2. The Vision Pro's two lenses and part of the straps and padding (photo by Ruyu Yan).

Figure 3. Photo through one of the lenses, giving a sense of the complicated projection screen for placing graphics in the real world (photo by Ruyu Yan).

90° (Holm 2024). Thus, like all eXtended Reality headsets, the Vision Pro Field of View is smaller than our natural vision, thus cutting off our periphery.

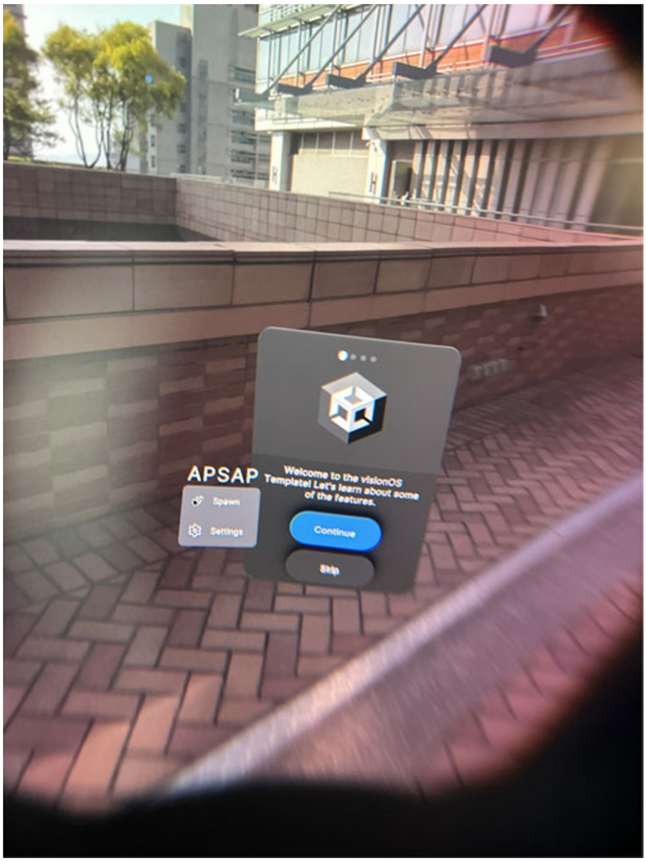

Figure 4. Photo through one of the lenses, showing menus virtually overlaid on the real world (photo by Ruyu Yan).

The Vision Pro has a weight of 600–650 g, depending on the configuration (Apple 2025). An interesting feature of the Vision Pro is that the battery is separate from the headset, thus decreasing weight on the head. However, a disadvantage of not having the 353 g battery as part of the headset is that the headset lacks a counterbalancing weight on the back against the goggles on the front. We noticed that this distribution means more pressure on the nose during extended use, though third-party straps have tried to solve this imbalance (Lang 2024). The headset and battery are connected through a simple cable (visible in Figure 1), so the battery is placed in the user's pocket. In our experience, the battery can provide about two hours of working time, but the fact that the battery is easy to replace is an advantage that can enable continuous use.

The main mode of interaction with apps, menus, and objects visible in the Vision Pro is eye-tracking. A user controls the equivalent of a mouse pointer simply by moving the eyes to look at a potential selection. Then, a user can "click" on something by making a simple hand gesture while looking at the menu item or object. In our experience, this eye-tracking system needs to be calibrated with some regularity, especially for multiple users of the same headset, to maintain accuracy. One of our team members has complicated prescription lenses, but Apple does not yet offer options for full correction, and thus he feels some discomfort when using the Vision Pro for an extended time.

Related to eye-tracking, the Vision Pro can record facial expressions, opening several possibilities for emotional interaction in the technology. For example, for a tourist, the device may be able to recognize when a user becomes bored or excited and respond accordingly during an interactive visitor's program. Furthermore, the Vision Pro can project a user's eyes onto exterior screens, allowing someone

Figure 5. Virtual eyes projected onto the external screens of the Vision Pro (photo by Ruyu Yan).

standing near the user to make eye contact with the user, mediated by cameras and screens, though we felt this sometimes does not look natural (Figure 5). Taking this one step further, a detailed representation of the user's face could be shared remotely with colleagues, thus potentially enhancing unambiguous communication during collaboration.

Comparison with Other Headsets for Archaeological Purposes

We can come to a better understanding of the potential of the Vision Pro for archaeological uses by comparing it with similar head-mounted Mixed Reality devices. We specifically focus on comparing the Vision Pro with the Microsoft HoloLens 2 and with the Meta Quest Pro and Quest 3. The HoloLens 2 has been the most sophisticated Mixed Reality headset on the market for many years, but it has many limitations. While the Quest devices were designed as Virtual Reality headsets, they also support decent Mixed Reality capabilities using camera pass-through. We note that the Vision Pro and HoloLens 2 are relatively expensive compared with the Quest devices (Table 1). We compare all these devices by considering a variety of specifications and archaeological requirements, including the user experience and view, the way the devices interface with the surrounding space, and their technological capabilities.

User Experience and View

In our vision for future archaeological practice, an archaeologist would wear a Mixed Reality headset all day while working in the field, to continuously collect and visualize data. Similarly, tourists would enthusiastically wear a headset for extended site tours, to see information and reconstructions. Thus, a headset should be very comfortable in terms of weight and configuration, and it should be able to withstand the natural conditions of an outdoor dig site. Furthermore, archaeologists should be able to easily record and recall 3D models and data quickly using a simple and intuitive user interface. Interaction with the device should mostly keep the hands of the user free to dig and manipulate the real world. We anticipate that the archaeologist will want to see clear, high-resolution 3D models in the real world, such as by placing scanned features or artifact models back in situ into the trench. Thus, the quality of the imagery should be very high to support precise scientific interpretation.

The headset weights are within 200 g of each other. Since the HoloLens 2 does not have the closed screen of a Virtual Reality headset, it is slightly lighter than the Vision Pro, at 566 g (Table 1). The Quest 3 is the lightest of the group, at 515 g. However, we use the elite strap, which adds a second battery to the back for an extra 313 g. The standard configuration of the Quest Pro is the heaviest of the group,

Table 1. Summary of the Characteristics of the Mixed Reality Headsets.

Headset	Type	Weight	Base Cost	Field of View		Sunlight Visible?	Battery	Status
				Degrees Horizontal	Degrees Vertical			
Apple Vision Pro	closed Virtual Reality with Mixed Reality camera pass-through	600–650 g	$3,500	100–120	90	Y	Replaceable 2-hour	Released Feb 2024
Microsoft HoloLens 2	open Mixed Reality with transparent screens	566 g	$3,500	43	29	N	Internal 2-hour	Released Feb 2019–Oct 2024, now only available used
Meta Quest Pro	closed Virtual Reality with Mixed Reality camera pass-through	722 g	$1,000	106	96	Y	Internal 2-hour	Released Oct 2022–Jan 2025, now only available used
Meta Quest 3	closed Virtual Reality with Mixed Reality camera pass-through	515 g	$500	110	96	Y	Internal 2-hour	Released Oct 2023

at 722 g. None of these devices offers a level of comfort that would allow their continuous use during archaeological fieldwork, but all are suitable for occasional use.

The Vision Pro is the only headset that has in-built eye-tracking navigation. Eye-tracking may be useful for navigating digital user interfaces, but we wonder whether it could have a special purpose in archaeology. The Vision Pro is also the only headset to project the user's eyes onto its exterior screens, though the HoloLens 2 does not need this, since the eyes are not covered. Similar to the other devices, the Vision Pro also has some level of voice recognition that can support user interaction, a useful feature for keeping your hands free while working at an archaeological site.

Although the Vision Pro can recognize some hand gestures, we found its ability to track hand movements more limited than the HoloLens 2 or the Quest devices. This may be because we are unable to access this feature from our custom code, a process that was much easier with the other devices. In the HoloLens 2 and Quests, we could leverage the in-built hand-gesture interaction directly within our custom code to activate menus, and even use our fingers to manipulate virtual objects. We have thus far found it challenging to port these applications to the Vision Pro. Hand-gesture tracking offers a very intuitive way for archaeologists to interact with both the headset menus and with the 3D data, allowing the manipulation of virtual objects in the same manner in which we would hold and move real objects.

We note some major differences among the headsets when it comes to Field of View and sunlight visibility (Table 1). In particular, the HoloLens 2 has a very limited Field of View, at 43° horizontal and 29° vertical. Also, it is difficult to see the screens on the HoloLens 2 in sunlight. On the other hand, the Vision Pro and Quest devices work fine in sunlight, since they pass through camera feeds. Also, the Quest devices have similar Fields of View to the Vision Pro and each other, both with 96° vertical Field of View, the Quest 3 having a slightly wider 110° horizontal Field of View, compared with the 106° of the Quest Pro (Hector 2023). Although not perfect, these Fields of View enable comfortable interaction with archaeological data, unlike the constrained view of the HoloLens 2.

Interface with Surrounding Space

The strength of using Mixed Reality headsets at archaeological sites is the ability to place digital 3D models of features and artifacts into the real environment. For example, we can imagine an archaeologist reviewing a stone wall that has previously been removed from a trench, to compare the stratigraphic situation with walls that are still there. Tourists could look at proposed reconstructions placed over on-site remains. Such virtual models need to have very precise real-world sizes, positions, and orientations for scientific accuracy. To support this functionality, a headset must be able to scan the local space to identify objects and surfaces for integration into the projected graphics.

All the headsets reviewed here can spatially scan the surrounding environment to capture a polygon mesh of walls, furniture, and other real physical objects. The Vision Pro uses this to detect horizontal and vertical planes in the local environment (Figure 6). This functionality is key to being able to place, or anchor, virtual 3D graphics into the real world in a stable manner (Figure 7). We could use this to put 3D scans of previously excavated contexts back in situ into our actual trenches. Unfortunately, none of the devices have long-term anchoring memory, so when a device is switched off and on again, the local environment must be rescanned, with virtual objects again placed into that environment. The devices also do not inherently have a way of knowing the absolute real-world coordinates of their surroundings, which would be useful for working with precisely recorded 3D data at archaeological sites.

A headset must also allow the user to move freely through the archaeological site and see graphics over a wide area. Unfortunately, some devices set a boundary, especially for use in Virtual Reality mode, whereby a user could run into walls or furniture they cannot see. Also, constraining the interaction space improves performance by decreasing demands on memory and processing power. The boundary set by the Quest devices poses a significant problem for their use in the field, as it limits interaction to only about a 6 × 6 m area, whereas trenches at our archaeological site are 10 × 10 m. Neither the HoloLens 2 nor the Vision Pro appears to have this limitation, and we have successfully tested them over an area larger than our trenches.

Technological Capabilities

Underpinning the successful deployment of Mixed Reality headsets at an archaeological site is their technological capabilities. A device should both perform well in the real world and be relatively easy to adapt and program for specific archaeological situations. We are concerned that when the Vision Pro stores the surrounding spatial scans in memory over a large area, this could slow the device down, but we will understand this better with further experimentation. We have also noticed some motion blur and loss of image sharpness when we move our heads. This appears to be particularly problematic in low-light conditions, which could affect use in museum settings. We have not experienced these visual-performance problems with the HoloLens 2 or Quest devices, possibly because they display lower-resolution graphics that are easier to update quickly.

We have programmed new custom applications for the Mixed Reality headsets to fit our specific archaeological needs in the field. Unfortunately, Apple is well-known for its closed-systems approach that forces developers to use their proprietary programming frameworks and workflows. This limitation has made it difficult for us to migrate our applications from the HoloLens 2 or Quest devices into the Vision Pro, since those other devices tend to use more widely and openly available programming frameworks. Thus, we are usually required to re-create our apps from scratch for the Vision Pro, which takes significant time.

Future Vision

Despite the limitations, we have been able to create our first custom application for the Vision Pro to display 3D models of our excavation contexts (Figure 7). Before heading to the field, we tested this app on our university's campus, in a modern building. We were able to anchor 3D models in place within a very large room, which worked fine on one floor, but the models shifted position when we ascended to a higher floor. Although eye-tracking works in our custom app, we can only use hand gestures to click. We have not been able to easily activate functionality that allows us to use our hands to hold and move

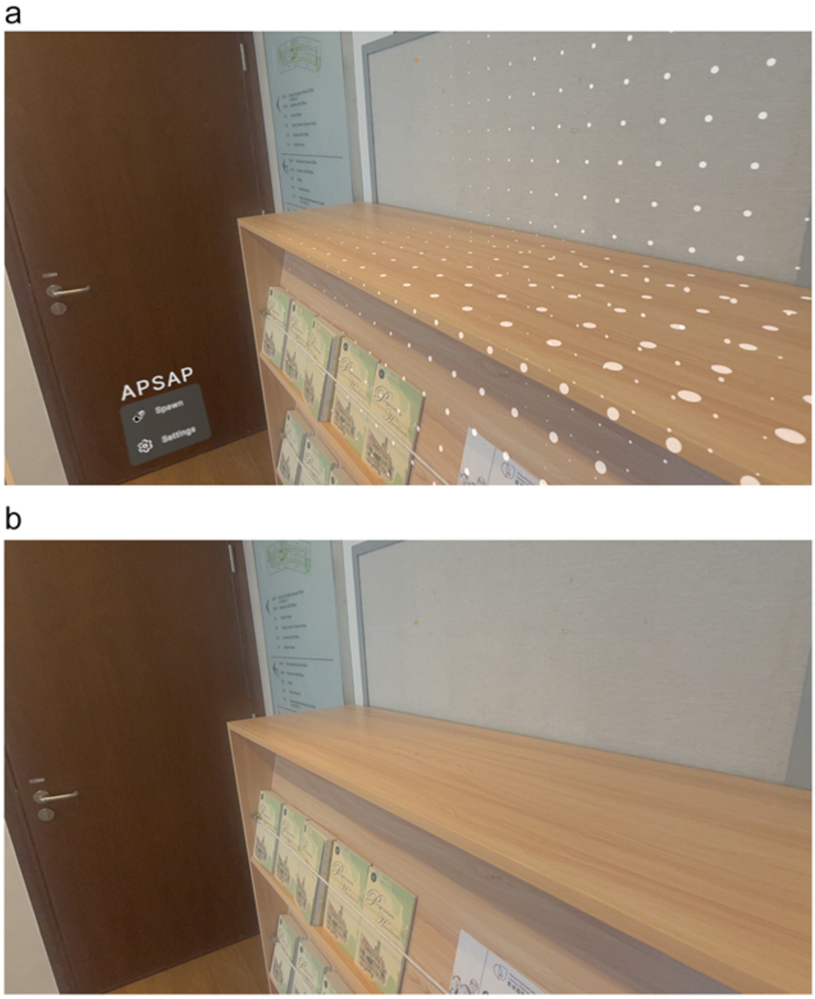

Figure 6. The detection of planes in the local environment by the Vision Pro: Figure 6a shows the virtual dots placed on the nearby planes and Figure 6b shows the actual local scene.

Figure 7. A scan of an excavated stone wall from Armenia, virtually placed into a real outdoor environment in Hong Kong using our custom app.

3D models, as we have done with the other Mixed Reality headsets. Although some of the Vision Pro's limitations may be due to software, recent updates to the Vision Operating System have thus far only addressed minor safety or technical issues. There is definitely scope for Apple to make the device easier to program.

Ultimately, our goal is for archaeologists to be able to use Mixed Reality headsets to see and analyze excavation phases, enhance interpretation with spatial and shape big data, and share information with other specialists and the public. The potential for smooth interactions between the real world and 3D virtual graphics in Mixed Reality provides a unique opportunity for producing high-quality scenes controlled by intuitive navigational tools. As one example, these devices could be used in the context of open-air museums where anyone can view digital overlays of 3D interpretations of remains, perhaps even introduced by digital humanoid guides powered by artificial intelligence (AI).

Yet this is an uncertain time for the development of immersive eXtended Reality headsets. We are still waiting for Microsoft to propose an updated HoloLens device. Apple itself recently abandoned a project to build simpler Augmented Reality smart glasses, so it is unclear where they will take the Vision Pro in the future (Dellinger 2025). At this point, the Meta Quest 3 seems to have the best balance between comfort, affordability, and functionality for archaeologists interested in experimenting with Mixed Reality. But we were pleased with the high resolution of the Vision Pro images, as well as the ease of its eye-tracking interaction function. Our project will continue to experiment with both the Vision Pro and the Quest 3 in our archaeological fieldwork in order to continue to push the boundaries of what is possible and to prepare for our future vision for broad Mixed Reality headset usage in archaeology.

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