CASE STUDY

Immersive Virtual Reality in Archaeology: Enhancing Research and Public Engagement

A Case Study of the Temple of Juno Excavations in Agrigento, Italy

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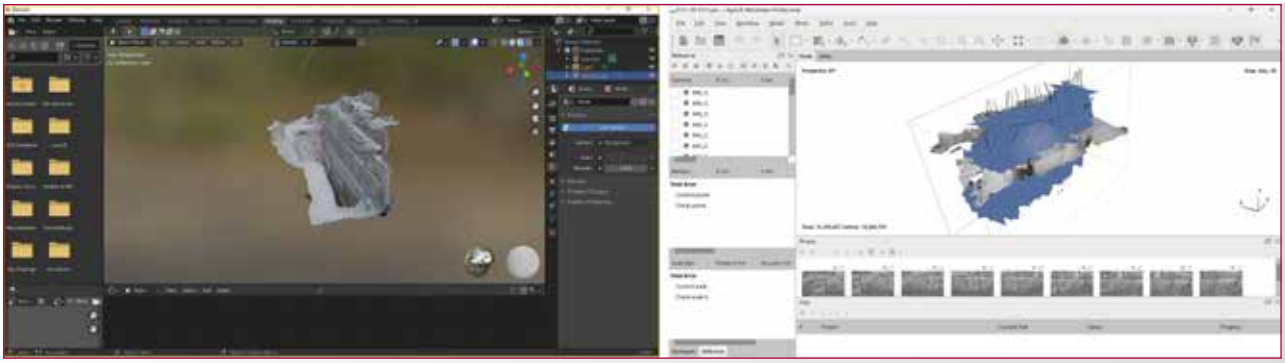

Fig. 1 - - Metashape (left) and Blender (right) showcasing the 3D model of the site.

Immersive Virtual Reality (VR) is having a revolutionary impact on the field of archaeology. It is not only facilitating greater public engagement, but also providing tools that can be used to optimise workflows and enhance data analysis, as well as fostering interdisciplinary collaboration. This project illustrates the potential of VR to effect transformative change regarding both research and cultural heritage dissemination.

This paper introduces "Valle dei Templi VR" (VTVR) a prototype virtual reality application developed at the Institute of Mechanical Intelligence at Sant'Anna School of Advanced Studies in Pisa, in partnership with the Scuola Normale di Pisa under the auspices of the Archaeological Park of the Valley of the Temples at Agrigento. The project, demonstrated on the archaeological digs in the Valley of the Temples in Agrigento, aims to revolutionize how archaeological sites are documented by offering archaeologists immersive, real-time access to excavation data. Unlike VR tools designed solely for public exhibitions, this application caters specifically to archaeologists, providing them with a comprehensive collection of resources, such as excavation reports, images, videos, and detailed 3D scans of excavation layers. One of the most time-consuming aspects of archaeology is the post-excavation phase, where data analysis and integration are critical. This system helps streamline those processes by facilitating faster organization and retrieval of excavation data, significantly boosting the efficiency of research and site or artifact analysis. The VR application also offers a virtual exploration of archaeological sites, delivering a deeper and more authentic experience than traditional methods of presenting archaeological findings.

With its ability to let users interact with 3D models of the excavation, the tool represents a major leap forward in archaeology. By providing professionals with an immersive platform for accessing, analysing, and sharing excavation data, the application supports enhanced collaboration, innovation, and insight within the field. The objective is to demonstrate how VR can provide researchers with an immersive experience akin to that experienced by the original excavators when collecting their data. At the same time, VTVR has been designed to address the needs of various stakeholders, from professional users to non-specialist audiences.

DESIGN

Archaeological research depends heavily on stratigraphy, a concept derived from geological principles of sedimentation. In this context, stratification refers to the formation of distinct stratigraphic units (SUs), which are discrete layers or deposits in the soil resulting from either human activities or natural events. Each SU represents a continuous and homogenous formation in both time and space. The accurate identification and contextualization of each SU are critical for archaeologists to draw informed conclusions regarding the function of a site, its chronological development, and the phases of human occupation.

During excavation campaigns, such as those led by the Scuola Normale Superiore under the direction of Gianfranco Adornato since 2020 at Temple D in the UNESCO-listed Valle dei Templi, the volume of documentation generated can be extensive. This documentation includes written records, such as excavation diaries, lists of significant finds, and inventories of SUs, as well as graphical records like trench maps, section plans, and photos of the SUs. For each SU, there are also detailed lists of discovered materials, catalog entries for individual artifacts, drawings of pottery fragments, and photographs of the findings. For archaeologists, this detailed documentation is essential for reconstructing the context of artifacts. However, the challenge lies in managing fragmented records that link excavation findings with material analysis. To resolve this, data is systematically stored in both physical and digital formats, shared via hard drives and cloud storage for ongoing team access. In order to enhance this procedure, it would be advisable to implement a unified methodology for the documentation process, integrating excavation data with artifact analysis for accurate interpretations and future publications.

Objectives

The project aims to create a living 3D model of the archaeological site that captures its transformation over time. This model provides detailed access to each Stratigraphic Unit (SU), offering a visual timeline of how

Fig. 2 - Starting screen of the VR application

the excavation site has evolved. Users can analyse excavation data in real-time, seeing the status of active digs, how SUs have changed throughout the process, and finalized models of completed areas The prototype has been designed as an ever-evolving resource, with the capacity to continually integrate new data and discoveries. It is anticipated that this will make it a valuable tool for both researchers and the general public. The model's modular design permits seamless updates, thereby ensuring that the model develops in tandem with ongoing excavations, rather than merely reflecting a fixed point in time.

While this meets the specific needs of archaeologists, a significant focus of the project also involves bridging the gap between the specialized world of archaeology and the public. Part of this effort includes developing tools aimed at non-specialists, allowing them to explore the discoveries and research processes in an engaging and informative way. Such a project not only broadens public understanding of the archaeological field but also fosters greater appreciation for the cultural heritage uncovered through research.

The system is designed to extend beyond the technical aspects of archaeology, incorporating historical and cultural insights related to the site. This will facilitate engagement with a broader audience, transforming the tool into an educational platform where users can explore the site's history in a visually intuitive and immersive manner.

Moreover, another requirement of the project is to facilitate the effective communication of archaeological findings to a non-specialist audience, ensuring that users have access to tools which simplify complex data. These tools must provide clear, intuitive visualizations and explanations of discoveries, fostering greater public interest and appreciation for cultural heritage and archaeological work.

Information acquisition and processing

A critical phase of the project involved the development of a comprehensive methodological and operational framework, essential for successful implementation. This phase underscored the significance of integrating theoretical insights with practical applications, thereby ensuring that the project was firmly anchored in both conceptual understanding and real-world implementation.

We spent a period working at the Valley of the Temples archaeological site, where our main objective was to produce accurate 3D models using photogrammetry techniques. This approach was essential for acquiring detailed and accurate data on the current condition of the

Fig. 3 - Selection and navigation starting menu (left) and Technical Data Sheet for a Stratigraphic Unit (right).

site. It also allowed us to document the excavation locations, creating a highly detailed and realistic virtual representation of the excavation site. This period was crucial not only for the collection of data, but also for gaining first-hand insight into the day-to-day operations of the archaeologists on site. Observing the excavation work provided a better understanding of the complexity of their tasks and the difficulties inherent in accurately documenting each artefact discovered. Currently, as previously stated, the documentation process is largely unstructured and relies on fragmented textual descriptions, scattered digital images and freehand sketches.
The absence of a unified system or central repository greatly hampers the ability to quickly retrieve and interpret this heterogeneous information, resulting in delays in research, limiting collaborative potential and complicating decision-making.

IMPLEMENTATION

Building the prototype for the VR information system involved a complex, multi-layered approach to ensure that archaeological data could be accessed and understood intuitively. In the following parts, we detail the methods used: first, we outline the steps taken in the development process, covering both the suite of software tools employed and the hardware needed for visualization; additionally, we examine the factors that significantly influence the user experience, including the design of the user interface, the strategic use of transparent overlays to display terrain, and the manner in which users navigate and interact within the virtual environment.

Tools

Archaeologists traditionally rely on tables within text documents to log excavation data, as discussed earlier. To improve the organization and management of stratigraphic data, we introduced the use of CSV (Comma-Separated Values) files, which are compatible with spreadsheet programs such as Google Sheets and Microsoft Excel. This format offers better data structuring and can be seamlessly imported into our system for processing.
For generating 3D models of stratigraphic units (SUs), we utilized *Agisoft Metashape* a photogrammetry software specialized in producing highly accurate and detailed visual representations, and Blender, an open-source 3D modelling suite. The terrain modelling involved importing GIS data, including geographic and spatial elements like topography and reliefs, into *Blender*. This data enabled the creation of an accurate and detailed model of the site's geographic context (Fig. 1).
The resulting models have been exported into the fbx format and the subsequently imported into Unity 3D, a game engine for

Fig. 4 - Three-dimensional reconstruction of the original temple.

VR development used to design the user interface, build the VR environment, and implement the application's interaction and visualization frameworks.

To capture a comprehensive 360-degree panoramic view of the archaeological site, a specialized application was employed: the *Street View Download 360* application was used to capture a comprehensive 360-degree panoramic image of the archaeological site from Google Street View, in order to create a skybox providing an immersive background within the Virtual Reality environment. The final virtual experience was optimised for use with the *Meta Oculus Quest 3* headset, thereby providing users with a fully immersive archaeological exploration.

Graphical User Interface (GUI)

The graphical interface (GUI) of the VR application has been crafted to ensure users have a seamless and informative interaction with the displayed archaeological heritage. Upon launching the app, users are prompted to select between two modes: one tailored for experts and the other designed for general audiences (Fig. 2). All menu interactions are managed via the Quest controllers using a ray-casting interaction method.

Upon entering the application, users are situated at the northern side of the Temple of Juno, positioned on the altar. A concise tutorial video presents the controls and guides users through navigating the virtual space.

n "Professional" mode, users are prompted with a pop-up menu, which allows them to select an excavation site and, if relevant, the specific SU they wish to explore, while in the general mode, instead of choosing an excavation site, users can select a "historical-artistic theme" related to the Valley of the Temples to further explore. This interface facilitates straightforward navigation through the excavation areas, enabling users to focus on specific archaeological details. Additionally, it provides the option to modify the transparency of the terrain, which enhances the clarity of the visualisation. All menu interactions are managed via the Quest controllers using a ray-casting interaction method.

The user is teleported to a designated location within the virtual environment; alternatively, free navigation can be selected (see subsequent Navigation System section). As the user progresses through the designated area in the expert mode, an additional panel is automatically generated, displaying detailed information about the corresponding SUs. This includes photographic images, descriptions, materials, dimensions, and accurate locations, enabling researchers to categorise each excavation and conduct a comprehensive analysis of the findings within the digital environment (Fig. 3). In the general mode, after being teleported, the user can access specific multimedia

Fig. 5 - Interactive hotspot (left) and his multimedia content (right).

content related to the selected historical-artistic themes.

Visualization

The application utilizes transparency effectively, allowing users to see through the various layers of an excavation and facilitating a greater degree of clarity and comprehension regarding the various stratigraphic units (SUs). By modifying the transparency value associated with the materials in the system's backend, users can alternatively view the present-day terrain, complete with excavations coverage, or activate a transparent mode for detailed examination of each SUs. This flexibility allows for a dynamic and customisable view of the archaeological site, enabling users to modify the visualisation according to their specific exploration requirements.

The three-dimensional reconstruction of the original temple, as observed in Fig.4, is presented with a fixed degree of partial transparency that remains unaltered throughout the experience. This model serves as a pivotal spatial reference point within the application, offering users a clear visual context for the site's layout.

For those following the "general audience" pathway, the application affords the opportunity for interactive exploration of the virtual site. As users progress through the environment, they can interact with various hotspots, represented as spheres (Fig. 5), situated at significant locations. These hotspots allow the user to access supplementary content, including text, images, and videos, which provide a more comprehensive understanding of the historical importance of each area. This interactive design encourages engagement and facilitates a more immersive comprehension of the site's past as users navigate through the virtual environment.

Navigation System

The project integrates a user-friendly navigation system designed to offer seamless exploration of the virtual environment, leveraging the Oculus Meta Quest 3 controllers. Users can move through the virtual space using the thumbsticks, allowing for smooth and precise movement, while selecting or interacting with objects by pressing the trigger buttons on the controllers. For additional ease, a teleportation option is also available, allowing users to instantly move to different areas within the environment for quicker navigation.

The navigation system has been developed in accordance with ergonomic guidelines and user experience principles, considering factors such as comfort during extended periods of use and ease of interaction, with the objective of ensuring that the system responds in a fluid manner to user inputs. The incorporation of customisable movement speed and adjustable controller sensitivity enables the adaptation of the system to individual preferences. The result is a highly immersive and accessible virtual environment, which allows users to focus on exploration and interaction without experiencing any discomfort.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The archaeologists participating in this project regard the VR system as a groundbreaking tool for organizing the extensive documentation produced during excavation efforts and artifact analysis. They recognize its capability to consolidate all data generated from archaeological digs into a single, accessible virtual platform. Users can navigate individual stratigraphic units (SUs) while retaining a comprehensive understanding of the site's overall topography. Each SU, reconstructed through photogrammetry, is intricately linked to its corresponding excavation location and related documentation. This method provides a means to address the irreversible aspects of stratigraphic excavation by offering a virtual reconstruction that aids in historical analysis.

Although the current iteration of the system is a prototype centered on a specific case study, its potential for broader application in various archaeological contexts is considerable, pending further enhancements. One potential improvement could involve creating authoring tools tailored for archaeologists. Such tools would empower field specialists to independently contribute to and update SU data, thus streamlining the documentation workflow. Additionally, an automated georeferencing system would represent another significant advancement, allowing 3D scans of each SU to be accurately positioned with minimal manual intervention, thereby enhancing both precision and efficiency.

The broader significance of this VR system extends beyond archaeological research. Its capacity to simplify complex technical information makes it invaluable for public engagement and educational initiatives. Utilizing similar visualization and interaction methods, this system could convey a diverse range of content—historical, artistic, and architectural—thus enriching the visitor experience. It not only enhances on-site exploration but also makes archaeology more approachable and engaging for a wider audience. This integration of technology and heritage has the potential to transform how individuals interact with archaeological sites, enabling them to explore history in an immersive and interactive manner.

Looking ahead, the incorporation of Augmented Reality (AR) offers tremendous potential. By utilizing AR, this experience could be brought into real-world visits, providing the same extensive information directly in the physical environment. This would allow the public to participate in AR-enhanced tours and give archaeologists real-time access to digital records superimposed on their actual surroundings. A precise localization or tracking system would facilitate this transition to AR, offering an unprecedented level of engagement with the archaeological site.

Moreover, the VR system opens exciting avenues for remote collaboration and telepresence. By supporting real-time data sharing and interactive involvement from anywhere around the globe, the system can foster a worldwide network of experts who can both contribute to and utilize this digital information. Such collaborative capabilities could expedite research efforts and shorten the timeline for publishing findings, as archaeologists would be able to access comprehensive data without needing to be physically present at the excavation site.

The future direction of this project also hints at the creation of a unified data management platform, which would significantly boost the efficiency of archaeological processes. This platform would enable seamless sharing, analysis, and processing of collected data, thereby accelerating excavation activities and facilitating more thorough and timely research.

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Abstract

The use of Virtual Reality (VR) is becoming increasingly popular in the creation of innovative content archiving and cataloguing solutions. In the field of archaeology, the utilisation of VR for both professional and non-specialist applications remain a relatively unexplored area. To address this gap, we present a VR application designed to streamline the storage and access of critical data for archaeological studies, while facilitating the presentation of these studies to the public. The application interface facilitates direct interaction with 3D models generated through photogrammetry and modelling techniques, facilitating two distinct yet complementary objectives: firstly, a detailed examination of the data collected, which in turn improves research activities; secondly, it brings visitors closer to the world of archaeological research. We applied this system to the case study of excavations at the Temple of Juno in Agrigento, Italy.

Keywords

Virtual Reality, Archaeology, Data Archiving, Photogrammetry, Reconstruction

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