An immersive workflow of co-creating virtual reconstructions of archaeological sites as an act of trans-disciplinary research

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Abstract
The paper presents a novel type of collaboration between two research teams, the Virtual Environments Lab at The Cyprus Institute and the French Archaeological Mission at Khirokitia, with the aim to use immersion and Virtual Reality (VR) interfaces to create a collaborative 3D modelling environment to be shared by the many disciplines occupied with archaeological enquiries. The results of this collaboration enabled the modelling of an accurate (as much as archaeologically possible) reconstruction of one of Cyprus' World Heritage sites, i.e., the Aceramic Neolithic site of Khirokitia dating back to the 7th millennium B.C. The paper presents how the objectives of employing immersive technology which were both research-driven and educational were implemented. Specifically, this approach to the use of VR in archaeology was developed to test live (in real-time) the interpretations suggested by the archaeological research and contribute new ones, as well as to create a public virtual tour of the Neolithic village, that would introduce visitors to the core aspects of this important settlement in the Eastern Mediterranean.

Keywords
Virtual Reality, virtual reconstruction, immersive environments, Khirokitia, Aceramic Neolithic

1. Introduction

The use of visualisation has long been explored in archaeology for assisting scientists and experts in better interpreting their excavation finds and information collected [1]. Digital representations of three-dimensional information have been used in interpreting spatial relations of building fragments, reconnecting missing architectural parts and removed components that have been stolen, expatriated or destructed, assessing the topography of sites in implementing energetics in simulations, assessing the legibility of functional architectural configurations and geometric compositions, like size and location of windows for interior lighting needs [2]. Significantly, these applications were largely concerning static representations or pre-designed sequences of images (so-called animations) mostly used in testing a hypothesis, disseminating results in publications and communicating complex knowledge to the public.

At the same time, computer graphics have extensively contributed to the dissemination of historical and archaeological research in educational settings, such as museums [3], and for raising awareness about heritage preservation [4]. Most of these cases rely on static illustrations or video animations. Since the 2010s the commodification of Virtual Reality technology (VR), due to technical developments and accessible hardware and software tools, has introduced in many fields new

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opportunities by enabling researchers to experiment with the impact of immersion for a more human-centred, realistic experience of the information represented. In the last few years, large museums with international presence have embraced the use of immersive technologies in their operations, arguably in temporal exhibitions [5]. Literature suggests that virtually reconstructing information in an archaeological enquiry usually comes at the end of the investigation, while hypothetical reconstructions are typically more accepted by non-experts and the public in museums rather than archaeologists [6]. Virtual reconstruction refers to the process of representing missing information which may be known about or oftentimes regards the introduction of a hypothesis about the conditions of the missing artefacts — a process that entails uncertainties in the decisions of the archaeologist. In this context, virtual reconstruction has widely been used for the presentation of existing conditions of a site rather than for scientifically accurate reconstructions [7].

One of the most celebrated potentials of said technologies of immersion though is new opportunities for better processing of complex (geometric, representational) information by the human brain of the user offered by cognitive processes related to proprioception, sensory motor interactions and stereoscopy [8]. Recognising the value of immersion, fields related to engineering have recently adopted these technologies to handle complex interactions with digital representations as well as in training operators, workers, professionals, etc.

In archaeological enquiries, a virtual reconstruction created to be accessed through immersive interfaces with the support of VR technology, relies on a methodology that involves remote sensing (topographical survey), 3D documentation, data processing and 3D visualisation of spatial reconstructions, a step that includes interpretation actions [9]. This paper is occupied with the way the authors addressed key steps in the above workflow, specifically for enabling expert interpretation of inaccurate information about an archaeological site by means of VR. Literature in the field is occupied with the use of VR for accessing excavation data, as an interface to enable revisiting the destruction process of excavation [10], or with the formalization of a pipeline of virtual reconstruction that ends with interactive visualisation, as well as for educational purposes in the context of museum dissemination activities [11]. Rarely research in the field [12] has focused on operations wherein VR-enabled spatial cognition has facilitated more accurate data interpretation in a demonstrated way, as in revisiting visual hypotheses to correct erroneous descriptions produced in the past due to the lack of archaeological evidence. Aiming to contribute to this enquiry, the paper presents an innovative methodology that proposes the use of immersion in enabling the archaeologist to co-design and assess in three dimensions, together with technical VR experts and collaborators with various disciplinary backgrounds, a virtual reconstruction of the site under study, the Neolithic site of Khirokitia.

2. Challenges of the virtual reconstruction of the village

Cyprus Neolithic starts around the beginning of the 9th millennium, if not before, with the installation on the island of agro-pastoralist communities showing clear affinities with the Levant. Later, the island seems to follow a distinct trajectory until the emergence, during the 7^{th} mil. B.C., of an original civilisation, the Late Aceramic Neolithic, so-called 'Khirokitia Culture', and its collapse during the 6th mil. B.C. The most distinctive features of this culture are the persistence of circular plan architecture. Khirokitia settlement has been the extensively investigated between 1936 and 1946 by Department of Antiquities of Cyprus, under the direction of Porfyrios Dikaios and later, between 1976 and 2009, by a French team (C.N.R.S - Ministry of Foreign Affairs), under the direction of Alain Le Brun. Situated within about 6 km of the present southern coastline of the island, the village spreads over the sides of a hill partly enclosed by a meander of a river. Its long occupation that spans almost a millennium, its very large size, almost 3 ha, and its exceptionally well-preserved remains, together with extensive excavations and multidisciplinary research programs[2], have provided the richest cultural, environmental and anthropological documentation on the Late Aceramic Neolithic of Cyprus.

The first step of reconstructing the village for the authors was to agree on the project's framework and specifications and assess the feasibility of this project given the available archaeological data and the possibilities of immersive innovative technologies. As it is generally the case with archaeological data, the constraints were those resulting from the preservation of architectural remains, the limited extent of the excavated area and the excavation regulations, specifically:

- only part of the village has been investigated,
- due to erosion of the hill slopes, documentation on the very end of the village occupation (6th millennium) is rather incomplete,
- excavation regulations prevent the dismantling of architectural remains. Therefore, only occupation levels around the end of the 7th mil. have been extensively excavated (the early levels have only been identified in test-trenches); and,
- due to the destruction, reconstruction or remodelling of habitations during the occupation, the buildings are preserved to a maximum height of around 1 metre, enclosure walls to a maximum height of 4 metres).

3. Methods

The research presented proposes a new approach to the way real-time data visualisation tools can help archaeologists interpret and analyse complex spatial datasets more accurately than typical methods of representation. This novel method aids in understanding the spatial relationships and patterns within archaeological sites. By crafting accurate 3D models and overlaying them with contextual data, researchers can walk through ancient sites, interpreting more accurately how spaces were occupied in the past.

This research draws on the value of real-time immersion in the context of 3D object research and its applications in various fields. Stereoscopy, the technique of presenting two slightly different images to each eye, enables depth perception in immersive environments. In research involving 3D objects, this enhances the ability to analyse shape, size, and spatial relationships accurately [13]. By providing a sense of depth and distance, stereoscopy allows researchers to assess the relative positions of 3D objects and structures on site (e.g., visual access and connection with topography, light and shadow casting in relation to a built structure's dimensions) in a manner not possible with 2D representations like drawings and sketches. This has significant implications for fields such as spatial configuration of geometric structures and objects in archaeology, where researchers can examine artefacts in unprecedented levels of relationships of assemblages of objects.

Furthermore, spatial cognition refers to the mental processes involved in understanding and navigating the physical world. In the context of 3D object research, real-time immersion enables the creation of virtual environments where participants can explore and interact with 3D objects, fostering a deeper understanding of spatial relationships. This is particularly valuable in architecture and archaeology, where the study of spatial layouts is essential. Researchers can investigate the

[2] Archaeozoology, paleobotany, anthracology, palynology, geoarchaeology, physical and biological anthropology (paleo -pathologies, parasitology) and experimentation (use-wear analysis, architectural practices).

impact of choices of dimensions, form and scale, and evaluate the effectiveness of spatial configurations in real-time, leading to more informed decisions. In addition to this, proprioception, the sense of one's body position and movements, plays a crucial role in research involving the manipulation of 3D objects.

In other fields of practice, collaboration activities and co-design traditionally require meetings, surveys, and workshops to gather input from engaged stakeholders and participants [14]. Interactive visualisation of spatial data through VR and Augmented reality has recently been promoted as a new method of accessing information and enabling collaboration in co-design processes. This presents a significant opportunity for archaeological research and heritage science by transforming the way VR is used [15]. Positioning the presented research in this technical framework, the authors developed an innovative methodology that proposes the use of VR technology in enabling the two research teams, the Virtual Environments Lab at The Cyprus Institute and the French Archaeological Mission at Khirokitia to collaborate in co-designing and assessing, in a three dimensional immersive environment, together with technical experts from various disciplinary backgrounds[3], possible accurate archaeological scenarios for the site under study, the Neolithic site of Khirokitia.

4. Visualising archaeological interpretations of rituals, everyday life, construction techniques and tools in the virtual environment

The available data, provided by the archaeologists, mainly vectorized plans (topographic surveys, plans and catalogue drawings from the various excavation periods, 1977-2009) and aerial photos from a kite (2007-2008) were integrated with a 3D reality capture terrain model produced by the CyI team [16] to assist the reconstruction of the topography, but the reconstruction of the whole village faced a major challenge due to the fact that it is excavated only partially (fig. 1). A computationally simulated study of the spatial configuration of the whole village was tested to provide to the authors possible directions of exploration for the fabric of the village [17] based this fragmented evidence before focusing on a limited area of the settlement for the detailed reconstruction, as presented below.

Figure 1: Reality captured 3-dimensional point cloud model of the archaeological site of Khirokitia. [The Cyprus Institute]

4.1. Reconstructing the hill and its surrounding

The first step of the reconstruction process involved an aerial photogrammetric documentation method to capture the entire settlement hill for the creation of a textured mesh from the resulting

[3] Archaeology, architecture, archaeozoology, paleobotany, geoarchaeology, anthropology and more.

3D point cloud[4] (fig. 2). The resulting 3D representation of the hill was lacking the terrain of the surrounding environment, and thus it was deemed necessary to virtually extend the environment to create a more realistic view of the site. This was achieved by assembling height maps[5] sourced from online platforms such as the Earth Explorer geospatial service[6]. The actual terrain's elevation data (collected by means of a topographic survey) was used to adjust these maps to accurately reflect reality. Further to this, a 360-degree HDR panorama of the environment was created from on-site photographic documentation of the view of the horizon. This sequence of photos was used in implementing an HDRI workflow, i.e., High Dynamic Range Imaging[7]. The resulting HDR panorama image was then used in the interactive rendering software Unity3D as a 360-degree panoramic ‘environment map’ (fig. 3).

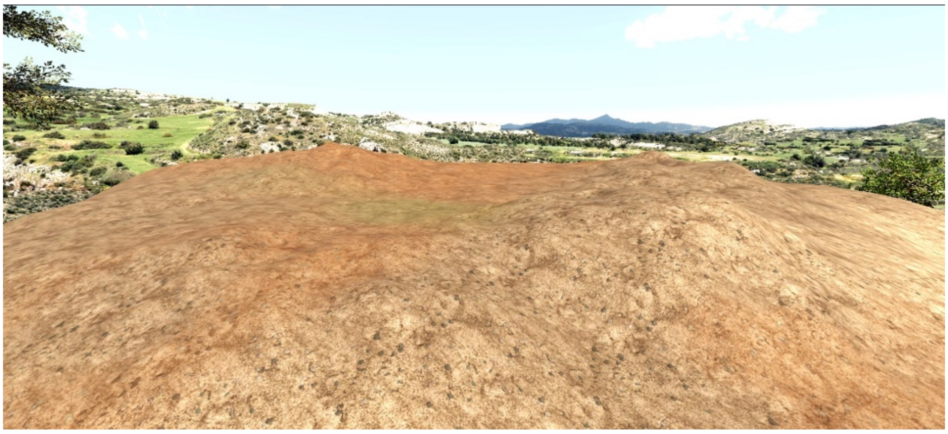

Figure 2: Textured mesh of the terrain. [The Cyprus Institute]

Figure 3: A panoramic HDR photo, created from combined photos taken from a spot above the settlement, was used to enhance the realism. [The Cyprus Institute]

4.2. Reconstructing the Neolithic village in its natural environment, over the course of its occupation

Given the archaeological constraints mentioned above, the digital reconstruction focused on an area of the settlement for which archaeological documentation was the most complete: the hilltop saddle,

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[4] A 3D point cloud is a collection of data points in three-dimensional space that represent the external surface of an object, environment, or scene. These points are typically captured using sensors like LiDAR, 3D scanners, or photogrammetry techniques.

[5] A height map is a grayscale image where the darkest areas represent the lowest points of a 3D mesh, and the lightest areas represent the highest points.

[6] https://earthexplorer.usgs.gov/

[7] This involves capturing multiple photos from the same angle with varying exposures, ranging from very dark to overexposed. When these photos are combined into a single HDR image, the light emitted from it can be controlled, affecting the 3D scene's (i.e., the virtual representation of the site) lighting accordingly.

methodically excavated and systematically recorded by the French Archaeological Mission between 1976 and 2009. Research carried out there provided an accurate picture of the history of the village occupation, marked by a series of events clearly evidenced by variations in the spatial extent and organisation of the village fabric, the construction, destruction, reconstruction or remodelling of the habitations.

Figure 4: [Top] The virtual visitors can time travel through the stratigraphy 'room' to explore different periods of the village. This is an interface that allows them to stand in the same space as they travel in time. [Middle & bottom] A simplified model of the hill with the settlement helps the visitors to better observe and understand the spatial transformations of the village through the centuries. [The Cyprus Institute]

Clinging to the sides of a hill, the village was a closed space, surrounded since its foundation by an imposing enclosure wall, around 2.5 metres thick and preserved to a maximum height of 4 metres. The function of this wall was most likely to emphasise the cohesion of the community rather than to ensure the defense against enemies, human or animal, of which there is no evidence. Communication between these two worlds was ensured by a complex structure, conceived to allow traffic as well as to control it: a narrow and tortuous staircase invisible from outside constructed into a massive stone structure against the enclosure wall. Out of the twelve main stratigraphic levels in the sequence of the chronological transformation of the settlement, three successive and most significant levels were selected to illustrate a key period characterised by a major event. This was an outstanding shift of the built area and the construction of a new enclosure wall, along with a significant change in vegetation cover and animal exploitation, which occurred towards the end of the seventh millennium BC, i.e. a period marked in the Near East by a climatic event in 6200 B.C. and the installation in Cyprus of present-day climatic conditions.

In the virtual reconstruction, when entering the Khirokitia, visitors are immersed within the so-called 'stratigraphy room' (fig. 4 [top]), a novel concept of an interaction interface for said applications in archaeology that was inspired by the complex reality of the archaeological palimpsest of the settlement's occupation. In there, an interactive virtual model of the hill has been created for the visitors to visualise the major changes that occurred during the village occupation in terms of the extent of the settlement built up area, the enclosure wall layout, the entrance location as well as the plant and animal environment. When found in this room, visitors are invited to select, with a hand icon, the period they want to experience, i.e., the early village (levels C and B), or the late village after the shift (level III) (fig. 4 [middle, bottom]). This hand icon has been introduced in the virtual environment to stimulate visitor's curiosity and encourage interaction, as supported by extensive user testing sessions conducted in the Virtual Environments Lab.

4.3. Reconnecting missing architectural parts

Understanding and visualising the entrance to the second phase of the settlement, which was meticulously excavated and remains in excellent condition today, contrasts with the uncertainty surrounding the entrances to the earlier settlement. One of the main challenges of interpretation the co-design team of 3D modellers and experts in arachaeological sciences faced was this of the reconstruction of the terrain around the entrance to the village. When the 3D modelling team received the plans from the French Mission, several aspects of these inaccessible structures remained unclear. This was largely due to the significant disruption caused by the excavation conducted in the 1930s, which dismantled much of the early entrance area. Despite these uncertainties, the 3D modelling team proceeded with a reconstruction of the entrance corresponding to level C1 based on assumptions and interpretations devised by the archaeological documentation drawings (fig. 5). Reconstructing three-dimensionally the terrain around the entrance and near the structures of houses to the inside of the enclosure wall required extensive testing based on knowledge sourced from dry stone wall making processes. Once the archaeologist visited the entrance reconstruction in VR, which allowed for stereoscopic viewing, it became apparent that the design was too steep and could not have accommodated the movement of the inhabitants of the settlement through it, while the terrain surface on top of the wall would have to be constructed by stones rather than earth. After a thorough design review, it was decided that the original entrance geometry should be revised to more closely align with the newer well-preserved entrance, incorporating modifications, which were primarily necessary due to differences in the placement of the structures atop the wall and near the space occupied by the entrance. This approach was employed to the reconstruction of the later entrance corresponding to levels B5 and B4, which also belong to the first phase of settlement, further enhancing this iterative, co-modelling process of the 3D reconstruction of the site.

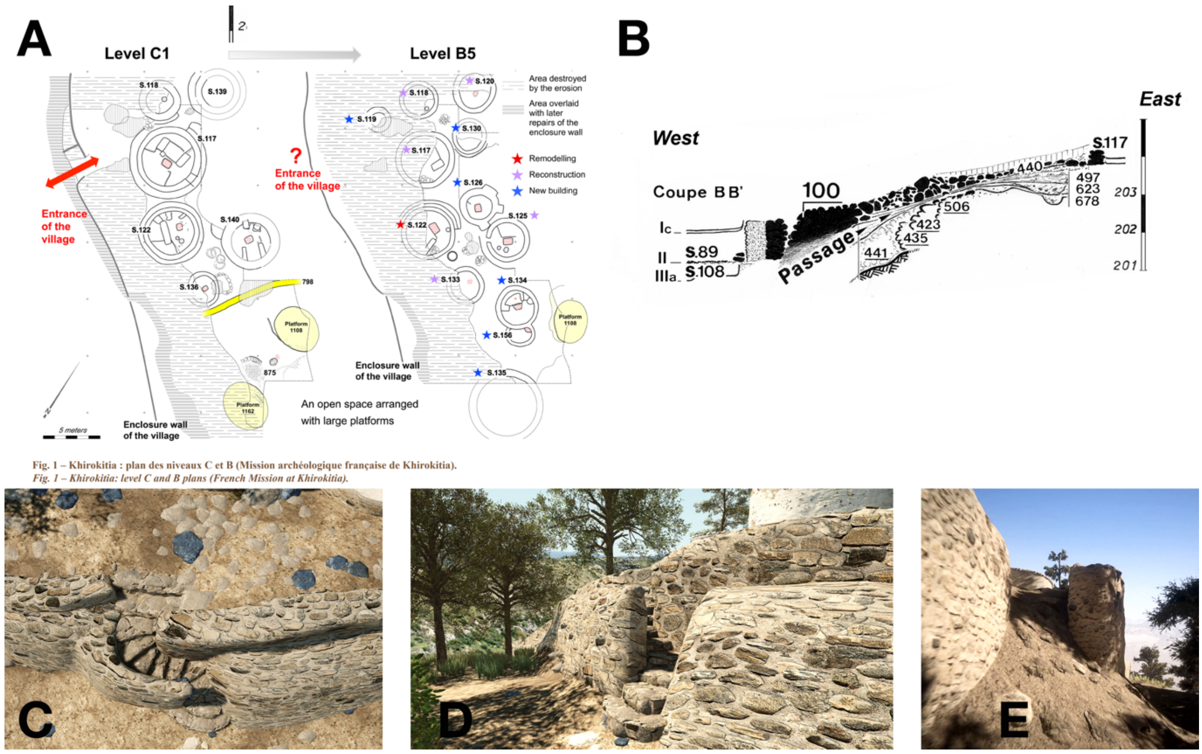

Figure 5: Plan [A] drawings of two exemplar phases of the entrance (Level B5 and older Level C1) and and section [B] of Level B5 (note "Passage" mark), published by Alain Le Brun, Mission Archéologique Française-Khirokitia [19]. 3D reconstructing the earlier versions of the entrance and enclosure wall based on these drawings became a close collaboration opportunity for the team of VR modeler and archaeologist. In this iterative co-designing operation, the terrain underwent several rounds of remodelling until it would represent accurately the process through which it could have been constructed out of river rocks and aggregates on the bedrock of the hill. [A, B: Mission Archéologique Française-Khirokitia; C, D, E: The Cyprus Institute]

4.4. Reconstructing the habitations

Inside the settlement, a house consisted of several circular constructions around a 'courtyard' equipped with a grinding installation. The walls were built with rough stones, or stone and mudbrick. The roof was flat, made of three layers of earth lying on two crosswise laid layers of reeds resting on a wooden framework. For digitally reconstructing the habitations, the authors relied on a solid set of data from both the excavations and an experimental program on building practices and techniques carried out by the Department of Antiquities of Cyprus with the collaboration of the French Mission (1994-1995).

The appropriate choice of texturing was essential for minimizing latency while simultaneously achieving high-fidelity graphical representations. Utilizing Physically Based Rendering (PBR) materials and selecting the proper texture size helps reduce the need for complex 3D geometry. The optimal method for texturing various assets within a 3D scene involves UV unwrapping each one. A UV map is a square area where the mesh of an object is laid flat, allowing for the application of textures as if painting on a canvas. Given the size of the structural elements (walls, roof layers, foundation, etc.), UV maps were set to 8K resolution (8192 x 8192 pixels). This ensured that all unwrapped parts of a structure maintained sufficient size and quality. Additionally, minimizing Unity 'draw calls' (i.e., how many 3D objects are being drawn to the computer screen) is crucial; this can be achieved by grouping objects with the same material into a single 3D object.

5. Results

The presented investigation focused on two main points: the shape, dimensions and position of the entrance of the early village in relation to the layout of the village's spatial fabric [18] and the openings, doors and windows of the habitations. Their reconstruction was based on the consideration of the overall permanence throughout the sequence of the main construction techniques and the village layout even after the village underwent a major shift (level III); it remained basically the same, houses still organised as closed spaces, a new enclosure wall and a new entrance keeping the same axial location (fig. 6). The well-preserved entrance of the late village (level III) was used as a model for the reconstruction of the early village level C entrance which had been located but could not have been uncovered. Regarding level B entrance, for which the only indication was that the village entrance had been moved [19: p. 230], a scenario for its possible location was elaborated and subsequently tested and assessed.

In addition, the careful reassessment of the openings uncovered, whether complete or not, revealed the existence of a model which, when applied to habitations, made it possible to reconstruct each compound constituting a house, i.e., to reconstruct lay out of the built-up space from a single element, door or window.

Figure 6: Visualisation of the transformation the village underwent through the centuries. [The Cyprus Institute]

Finally, a typical example of an undetected anomaly, or more likely one that was overlooked, is that of circulation within the village. Real-time data visualization tools aid in understanding the spatial relationships and patterns within an archaeological site and, through interactive data visualisation, researchers can identify trends and anomalies that might not be evident through traditional tabular data or 2D plans. In the presented case, a typical example of an undetected anomaly, or more likely one that was overlooked, was that of circulation within the dense fabric of the village. 'Circulation within the village should not have been very easy, the density of buildings forcing one to squeeze through the spaces left free" [20: p. 422). While it is easy to rely on this simple observation, made by the mere reading of a plan, obstacles arise, unexpected or rather ignored, as soon as the archaeologists decide to move virtually between the houses to reach a precise point in the village (fig. 7).

Figure 7: Image fidelity of the real-time visualisation of the reconstruction of the settlement with its house compounds in place based on the archaeological findings surrounded by the natural environment as it must have been at the time. [The Cyprus Institute]

6. Discussion

The use of the results of the research presented in the museum space confirmed a strong contribution to new approaches to visitor engagement in knowledge dissemination across varied demographics. More specifically, the virtual reconstruction presented above was featured at the Fitzwilliam Museum, University of Cambridge, UK, as part of the international exhibition 'Being an Islander' [21] (fig. 8). During the series of sessions that were included in the agenda of public events of the exhibition, the authors observed a significant visitor engagement in interactions with virtual objects. This observation underscores the imperative for creating additional interactive activities akin to the vessel creation experience (fig. 9).

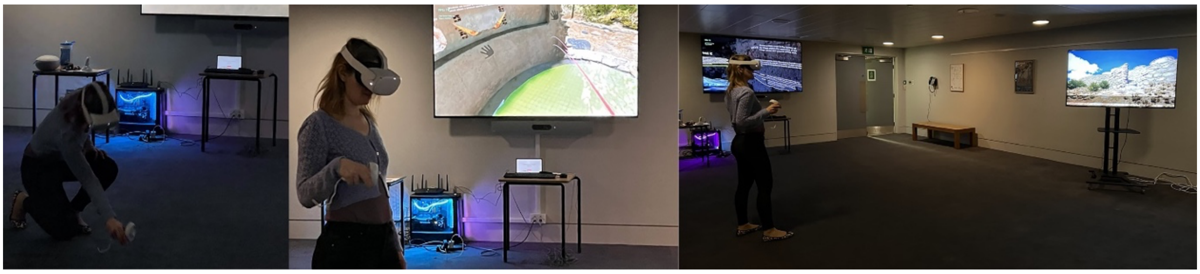

Figure 8: The virtual experience installation, a part of the 'Being an Islander' international exhibition at the Fitzwilliam Museum, University of Cambridge, UK (2023), was located in a dedicated hall that allowed for the visitors who signed up for this to queue and to watch the action in the virtual environment before wearing the VR goggles through a video projection on the wall. [The Cyprus Institute]

The virtual reconstruction experience was fully embedded in the design of the exhibition including the provision of trained invigilators, fully conducted health and safety plan and announcement of the sessions through the booking system of the museum. The survey results of the exhibition session provided significant visitor feedback. 82% of the 77 visitors who responded to the survey conducted, they agreed or strongly agreed that "the gamified content (e.g., "house abandonment ritual" and "stone vessel creation") was helpful to understand the culture of Khirokitia". The 80% of the responders agreed or strongly agreed that they would like to continue exploring the reconstruction in VR to learn more about the settlement and its inhabitants, while 75% of the responders would like to interact with more objects in the virtual environment. 65% of the responders thought that the use of textual means for communicating complex information in the virtual environment was not breaking the immersive experience. 71% did not feel any negative feelings or motion sickness during the interaction with the VR interface. Notably, more than the 84% of the responders to the survey were confident in using the interface and navigating in the virtual space although 78% of them were not experienced with Virtual Reality Systems, while 71% were not experienced with video games at all. The 52% of the responders were female, 77% of the responders held a higher education degree and 27% of them were under 35 years old. Interestingly the nationality of the responders was diverse and included UK, USA, Ireland, Spain, Germany, Poland, Lithuania, Chile, France and Colombia.

The significant user engagement observed in interactions with virtual objects underscores the imperative for creating additional interactive activities akin to the vessel manufacturing experience. Considering the above feedback, integrating gamification principles is crucial to enhancing engagement and appeal, particularly among younger audiences. Proposed activities could include grinding grains to produce flour, flint knapping, burial rituals, and textile manufacturing. Each task could incorporate a point system to indicate its completion, accompanied by enhanced audiovisual elements such as sound effects and voice overs to guide and motivate users throughout their exploration.

Figure 9: [Top] Floating tablets display photographs of the architectural remains as they were excavated, accompanied by short textual explanations inform visitors of the VR reconstruction in the case of disseminating the results of the reseach in museum spaces. [Bottom] Representing the stone vessel production located inside the reconstructed workshop was developed through collaboration with experts in stone making techniques [The Cyprus Institute]

7. Conclusions

It is widely acknowledged that VR can create a more engaging experience, one that enables humans to immerse in an experience that can lead to a deeper understanding of complex, big, historical data, finds and hypothetical reconstructions, enabling new interpretations, insights to complex assemblages of spatial and 3D represented information. Beyond the use of immersion in education and cultural settings wherein VR has been embraced in the last decade, this paper presented new affordances of emerging technologies for spatial presence, immersion in situated information and big data interaction in virtual environments through the use of VR for interdisciplinary collaboration.

The paper analysed how this approach to the use of VR can strengthen multi-disciplinary discoveries and collaborations in archaeological enquiries. Researchers from various fields, such as archaeology, architecture, archaeozoology, paleobotany, geoarchaeology, anthropology, can collectively contribute to the study of heritage sites, bringing their unique expertise together through a virtual stage provided by VR technologies. New solutions to previously identified archeological questions on Khirokitia were formed through this interdisciplinary approach to VR-enabled collaboration between the two research teams of 3D visualisation experts and archaeological sciences. This contribution of real-time immersive data visualisation to the incomplete big archaeological data was decisive for the archaeologist of Khirokitia, as 3D modelling within a virtual environment forces researchers to reflect on their data with greater spatial accuracy in order to propose possible design scenarios and solutions for reconstructing their site of study. The paper illustrated how VR reconstruction can act as an immersive stage for interdisciplinary reflection and by doing so can generate a better understanding of the dimensions of structures, their position in space and their spatial-geometrical interrelations. Arguably, this contribution adds new evidence of successful interdisciplinary science and technology practices to the literature about the use of VR in archaeological research [22]. The presented interdisciplinary practice offered new knowledge to archaeology as proven by the updated publications about this most valuable UNESCO World Heritage Site of Khirokitia [20] that draw on conclusions offered through the virtual reconstruction presented above.

Figure 10: Inside the houses visitors are guided to observe diagrammatic information projected on the virtual walls and follow instructions that help them interact with virtual objects in the way that they were used to perform daily activities. [The Cyprus Institute]

Adding value to the results of this successful interdisciplinary collaboration, the paper briefly presented how these results were re-used to create a public virtual tour of the Neolithic village that would introduce museum visitors to the core aspects of the settlement, its history, the natural environment, subsistence strategies, craft activities, architectural practices, social organisation and rituals. In this effort, virtual reconstructions were enriched with signs of occupation drawn from archaeological data so that the museum visitors can enter the house structures and interact with the objects laid in the interior space. These archaeological finds were carefully chosen by the team after several rounds of testing in the VR to illustrate daily life activities such as preparing and cooking food, manufacturing objects and tools (flint knapping, stone vessels, bone tools, textiles or basketry manufacturing), building and repairing constructions, as well as performing rituals (funerary rituals or ritualised procedure for condemning a building). ‘Inside’ a house, that is, in the open-air courtyard surrounded by the compound of circular structures, visitors are guided to observe information displayed on the walls (fig. 10). As shown by the results of the user evaluation in the case of the exhibition at Fitzwilliam Museum, this approach to spatially distributing archaeological information about intangible aspects of cultural heritage was proved to be successful in engaging museum visitors to the archaeological narratives and to help them better relate to the exhibition’s context.

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Declaration on Generative AI

The authors have not employed any Generative AI tools.

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