

CYPRUS UNIVERSITY OF TECHNOLOGY
FACULTY OF FINE AND APPLIED ARTS



Master Thesis

VISUALIZING AND ASSESSING HYPOTHESES IN MARINE ARCHAEOLOGY IN A VR CAVE ENVIRONMENT

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Limassol 2013

CYPRUS UNIVERSITY OF TECHNOLOGY
FACULTY OF FINE AND APPLIED ARTS
DEPARTMENT OF MULTIMEDIA AND GRAPHIC ARTS

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by

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APPROVAL FORM

Master Thesis

**Visualizing and Assessing Hypotheses in Marine
Archaeology in a VR CAVE Environment**

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Cyprus University of Technology

December, 2013

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PREFACE

This dissertation is the original, unpublished, independent work by the author, I. M. Katsouri.

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ABBREVIATIONS

VR: Virtual Reality

GIS: Geographical Information System

ARU: Archaeological Research Unit

ICT Lab: Immersive and Creative Technologies Lab

VR: Virtual Reality

VR CAVE: Virtual Reality Computer Automated Virtual Environment

ABSTRACT

The understanding and reconstruction of a wreck's formation process can be a complicated procedure that needs to take into account many interrelated components and has not been adequately and precisely investigated in the past. The Cypriot archaeologists investigating the 4th century BC, Mazotos shipwreck are unable to interact easily and intuitively with the recorded data, a fact that impedes visualization and reconstruction and subsequently delays the evaluation of their hypotheses. An immersive 3D visualization application that utilizes a VR Cave is developed, with the intent to enable researchers to mine the wealth of information this ancient shipwreck has to offer. Through the implementation and evaluation of the proposed application, this research seeks to investigate whether such an environment can aid the interpretation and analysis process and ultimately serve as an additional scientific tool for marine archaeology.

1 Introduction

1.1 Nature and scope of thesis

The important discovery of the ancient Mazotos shipwreck prompted the development of marine archaeology in Cyprus, as well as the first Cypriot underwater archaeological project, undertaken by the Archaeological Research Unit (ARU) of the University of Cyprus, under the direction of Dr Stella Demesticha. One of the project's prime research objectives is the understanding and reconstruction of this wreck's formation process.

The methodology currently employed presents limitations in stratigraphy, the documentation of finds and in reconstructing the site formation process, which were reported in a recent paper (Demesticha, Skarlatos, Neofytou, 2013) and further discussed with members of the archaeological team.

The excavation work is conducted vertically and in small sections, which impedes data being spatially correlated, obstructs the archaeologists from forming a general impression of the site and from pinpointing obvious (to the trained eye) interrelated artefacts. This consequently slows down the process of data analysis and interpretation.

Difficulties inherent within marine archaeology hinder the researchers from forming and assessing research questions during the excavation process (before artefacts and evidence are lifted), and certain remaining limitations of the documentation data and the employed methodology prevent them from interacting easily with the information gathered.

Even though they share the same methodology and principles, underwater archaeology is more complex than land archaeology. Underwater sites are inevitably hazardous and difficult to access, which results in the excavation process becoming very time consuming and demanding in human resources and specialized equipment.

During an underwater excavation, all physical artefacts are permanently removed from their original position and context. Consequently, meticulous mapping and recording is of vital importance, in order to ensure the accurate and thorough documentation of the site and the possibility of its future reconstruction. Once recovered from the underwater site, artefacts require special care, stabilization and conservation.

The Mazotos wreck can be accessed by divers but only for a limited 20 minutes of productive time, before they start their decompression sequence. Work can be hindered further by many other factors such as: narcosis, low visibility conditions, the dynamic nature of the environment and weather conditions. Furthermore, the involvement of non-experts, such as students and volunteers, also presents operational difficulties.

Underwater sites can be difficult -if not impossible- to be experienced first-hand by the majority of other archaeologists, experts from different fields, or the general public. Results of the archaeological research are also difficult to access and their presentation typically relies on publication through books, article in specialist journals, websites and electronic media.

This thesis intends to:

- Investigate whether and how, the VR CAVE can be used as an additional scientific tool for marine archaeology, to aid and direct archaeological research.
- Investigate how the data produced for archaeological documentation purposes can be further utilized to form a virtual environment that facilitates the process of interpreting the site and its formation.
- Explore whether such visualizations can lead to new evidence, new ways of investigation and unanticipated discoveries.

The thesis will seek to answer the aforementioned research questions through the design, development and implementation of an immersive application with the use of a VR CAVE.

Due to the complexity of implementation, a fully developed virtual environment that accommodates all the acquired data is beyond the scope of this research. This research will instead be focusing on two current hypotheses/research questions, regarding the wreck formation process the archaeologists wish to evaluate, and to facilitate in the testing of these hypotheses.

1.2 Road map

This thesis is organized as follows: Chapter 2 gives an overview of related work, while Chapter 3 explains the research methodology. The background information relating to the Mazotos archaeological site is presented in the first section of Chapter 4, followed by the

hypotheses regarding the site formation process, leading to the definition of user requirements. Moreover, the design and development of the application is presented in Chapter 5, while the evaluation process is described in detail in Chapter 6. The results of the formative evaluation process are presented in Chapter 7, followed by a focused discussion of the results in Chapter 8. Finally, Chapter 9 will present the conclusions and ideas for further work.

2 Related work

Archaeology employs procedures that are destructive in their nature. It is due to this key characteristic that archaeologists obsessively record and document sites with as much accuracy and detail as possible. It is common practice for archaeologists to use the documentation process deliverables to understand and be in a position to reconstruct the site at a later stage. Such a reconstruction derives from their need to interact with the produced data in order to explore the site and to understand the relationships between the elements that compose it and the stages of its transformation (Drap et al., 2012; Frischer & Dakouri, 2008).

Pansiot et al. (2004) note that “It may be disappointing and quite frustrating for archaeologists to spend time and money in order to collect a large amount of data, but finally not be able to sort and represent it at a level similar or even better than its original quality”. The implementation of an effective immersive visualization tool that will further assist the scientific process of analysis and interpretation has been an obvious conclusion for many researchers (Allen et al., 2004; Acevedo et al., 2001; Demesticha et al., 2013; Barcelo, 2001).

2.1 Visualization

Visualization and computer reconstruction are widely accepted to be of great importance in the process of dissemination and presentation (Bernardes et al., 2012). This is not the case with other processes and phases in archaeological research, with many archaeologists preferring to use more traditional means for visualization purposes. This reservation to use modeling and newer visualization methods for research and analysis is also evident in the work of other authors, such as Frischer & Dakouri (2008). In contrast to this view, certain authors argue that through the use of such methods, the process of interpretation and analysis is facilitated; complicated and intricate data are presented visually and are made more easily comprehensible, permitting the testing of the validity of the reconstruction (Barcelo, 2001; Forte, M. & Guidazzoli, A. as cited in Pansiot et al., 2004). Barcelo goes on to state that: “The main reason for visual models is to help to see what the data seem to say and to test what you think you see”. He adds that by building artificial objects and using them to act out scenarios, archaeologists gain improved insight into the data and “learn by doing”.

There is an evident reluctance on the archaeologist's part to make assumptions and to reconstruct the history of excavated sites. There is a sense that this activity does not achieve a high level of accuracy and archaeologists are fearful of unfavourable criticism by their peers (Ginsberg, (n.d.)). This is precisely why, the presence and expertise of the archaeologist is of paramount importance during this process and even then it proves a challenging task as many different interpretations and hypotheses need to be presented and evaluated (Roussou & Drettakis, 2003).

2.2 Advantages of Virtual Reality

According to Martha Joukowsky, an archaeologist at Brown University, "In order to truly understand a site, one has to be in it. You have to walk around and see the relationships of everything yourself" (Vote & Joukowsky, 2001).

Virtual reality can provide such an environment with realistic, 3D representation of data and can facilitate the exploration of varying perspectives and interpretations (Knabb, 2008).

Furthermore, the VR environment can be accessible to everybody, experts and the general public alike, in a relatively easy way when considering the difficult and demanding conditions that prevail, particularly underwater (Chapman et al., 2006; Allen et al., 2001).

Apart from an intuitive interaction, a virtual environment can also permit a greater degree of movement for the user. Through the use of VR, data can become easier to understand, remember and reference. User actions or observations, whilst immersed, can form a narrative for the user, thus enhancing the ability to recall data (Jacobson & Vadnal, 1999). User commands and inputs can instantaneously modify the virtual world and depict the effects of each change, thus creating a dynamic model. Real time interaction is a key feature of virtual reality and archaeologists can use this to form hypotheses, perceive patterns, relationships etc. more quickly, than by using maps, drawings or photos alone (Barcelo, 2001).

Archaeology's focus is to understand not only objects but events, the development of features and the transition from one stage to the next (van Dam et al., 2002; Barcelo, 2001) and virtual reality may be an ideal vehicle for this.

2.3 Application examples

This review of related works concludes with an overview of three examples of virtual environments for visualization, used specifically as scientific tools for archaeologists.

The ARCHAVE (Vote & Joukowsky, 2001), a GIS-based archaeological system that uses a VR Cave, provides researchers access to the excavation data of the Great Temple site in Petra, Jordan. This application's goals were to help archaeologists interact with the data in order to perform research and analysis, develop ways for them to conduct queries and to assess the hypothesis that an immersive VR system would allow them to realize the potential of their documented data.

The only virtual reality example found relating to marine archaeology is the VENUS project (Chapman et al., 2006) which aims to improve the accessibility of deep underwater sites by developing virtual and augmented reality, immersive visualization tools for archaeologists and the general public. The archaeologists can improve their data understanding through an online 3D model whilst the general public, using the same model can experience simulated dives.

The system implemented in a Cave-like environment by Pansiot et al. (2004), utilizing a database alongside an interface for navigation, developed an impressive assortment of widgets such as stick fields, density map, compass, rotative billboard, crop-marks and terrain that could be draped with different textures that enabled intuitive ways of understanding the environment. The system's objective was to facilitate the visualization of archaeological datasets in a range of representations through the interactive immersion of the user.

2.4 Contribution

To the best of the authors' knowledge, no similar work has been carried out regarding the use of the VR Cave and its potential as part of the marine archaeology methodology. This research also wishes to investigate another area that seemingly remains unexplored, which is how developing visualizations as scientific tools may assist in data interpretation and the assessment of hypotheses concerning site formation processes.

3 Research methodology

Whether and how the VR CAVE can be used as an additional tool to aid the Mazotos research team in their work, is a question not easily answered when the ARU researchers are neither very knowledgeable about virtual reality nor have used a VR CAVE prior to this research. This made it difficult to ascertain what their user requirements or ideal working process would be and so it was necessary to design and develop a prototype application to serve as an introductory experience.

Furthermore, through a working prototype, the author will be in the position to investigate the remaining two research questions posed in the beginning of this thesis, how the ARU documentation data can be further utilized to visualize and assess present hypotheses and whether such visualizations can lead to new lines of investigation.

Discussions with key members of the ARU helped to clarify their research process, become familiar with the Mazotos artefacts and documentation data and helped the author understand their present hypotheses/research questions that were subsequently used to form the basis of the application.

Once the first prototype was ready, a heuristic evaluation was conducted by two experts in usability, human computer interaction and user experience design in order to pinpoint issues prior to formative evaluation sessions with representative users.

The evaluation of a virtual environment is a difficult task to perform correctly, as many aspects need to be considered in advance, such as physical environment issues, evaluator issues and user issues.

The following process of evaluation was selected by taking into account three characteristics: the involvement of representative users, the context of evaluation, and the types of results produced (Bowman et al., 2002; Hix & Gabbard, 2002).

The user interaction was assessed through a formative evaluation, which is typically conducted during the development or improvement of an application. Users were introduced to the virtual environment and asked to use the application and more specifically to try out two Task-scenarios. These Task-scenarios are based on the two ARU hypotheses and so the potential contribution of the application and the VR CAVE by extension could be evaluated appropriately.

The observational nature of a formative evaluation yielded important qualitative information such as user reactions, comments and unexpected incidents. Further information, opinions and insight were gathered through semi-structured interviews with the users.

It was also imperative to conduct these user studies, in order to investigate the types of analysis actual users can perform in the virtual environment and the merits of the developed application as a scientific tool, enabling them to generate visualizations and assess their hypotheses/research questions.

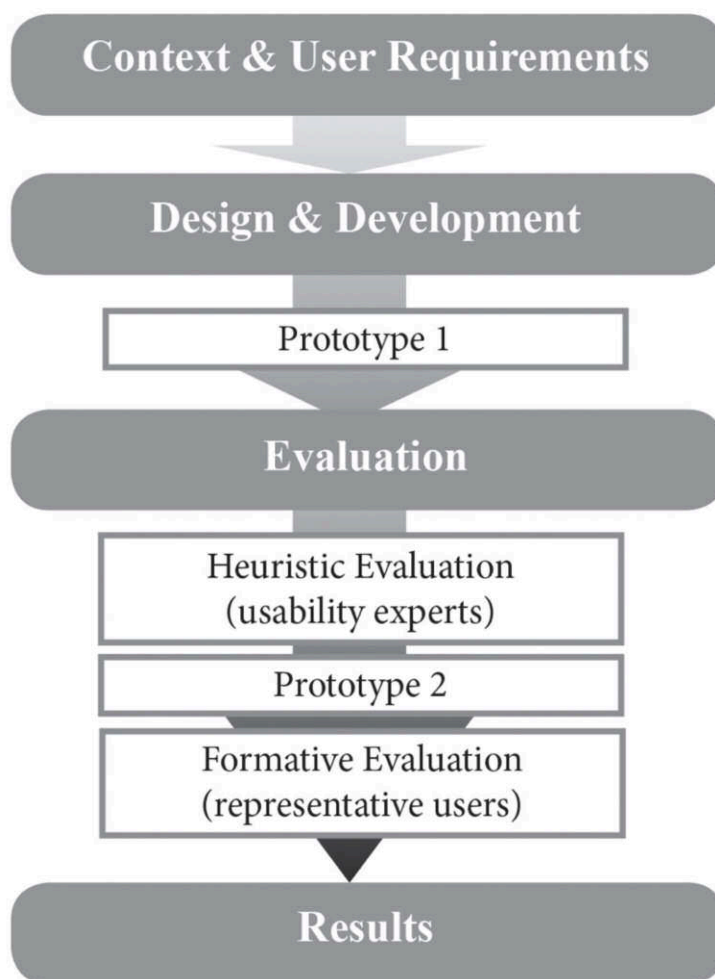


Figure 1: An overview of the research methodology

4 Context and user requirements

4.1 Mazotos shipwreck: The study area

The thorough study of published work regarding the Mazotos project (Demesticha et al., 2013; Demesticha S., 2011; Skarlatos D., Demesticha S. and Kiparissi S., 2012) and a number of meetings with members of the ARU team helped to direct this thesis.

4.1.1 General information

The Mazotos underwater site of the wreck of a 4th century BC merchant ship, carrying wine amphorae mainly from Chios, has been investigated since 2007 by the Archaeological Research Unit (ARU) of the University of Cyprus, under the direction of archaeologist Dr Stella Demesticha, in collaboration with the Department of Antiquities of Cyprus and the THETIS Foundation.

Off the coast from Mazotos village, the wreck lies at a depth of -44m, on an almost flat sandy seabed and stretches over an area of 17 x 7m. It comprises of an oblong concentration of at least 800 amphorae, which almost forms the silhouette of a ship, with its south end pointed (the bow area) and the north one almost squared-off (the stern).

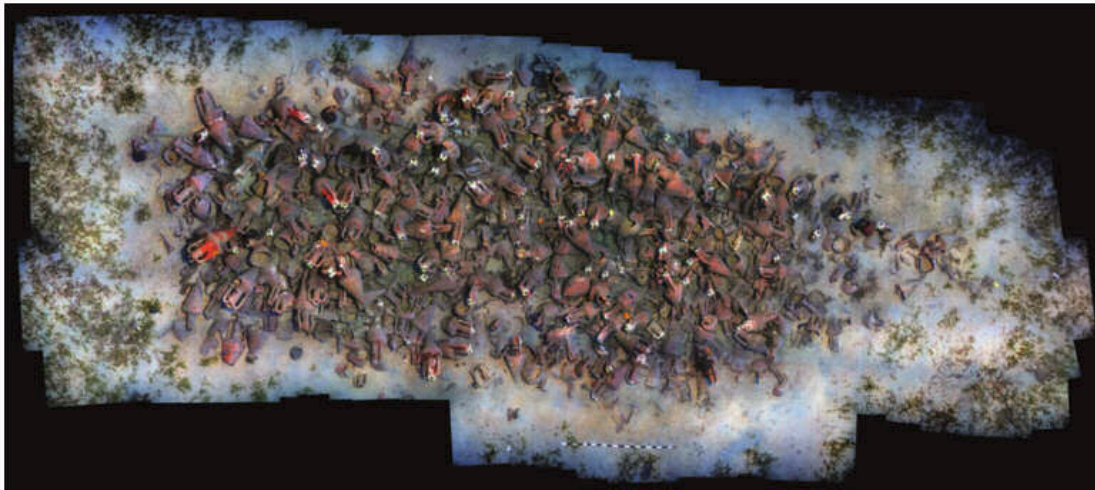


Figure 2: The photomosaic of the wreck.

Reprinted from *The 4th-Century-BC Mazotos Shipwreck, Cyprus: a preliminary report*. *International Journal of Nautical Archaeology*, 40(1), 39-59 by Demesticha, S. (Copyright 2011 by University of Cyprus, ARU).

The site is a rare example of a coherent pre-Roman shipwreck, seemingly having preserved its upright position (slightly tilted to its starboard side), maintaining most of its cargo amphorae in their upright position and with limited disturbance of the spatial arrangement of the ship's material occurring after the wreckage.

Prior to the systematic excavation of the shipwreck, which began in 2010, the site was photographed and documented through drawings (2007) and a geophysical survey was conducted (2009) to investigate the extent of its non-visible sections. The 2010 and 2011 excavation seasons focused on the southern part of the assemblage (ship's bow) which apart from Chian amphorae, revealed the remains of 3 anchors (their lead stocks), a large number of olive pits, part of the hull and the planking of the ship. The 2012 season which focused on the northern side of the assemblage (ship's stern), brought to the surface, among the amphorae, the ship's secondary cargo of wine jugs and small fineware pottery which was probably used by the crew. The keel at the stern and an important part of the ship's planking was also revealed, indicating that most of the keel is preserved under the amphora concentration. All recovered materials were transported to the Larnaca District Museum, for their desalination and conservation.

4.1.2 Archaeological significance

The Mazotos project is of obvious significance in respect to issues concerning trade, sea routes, trade relations in the Aegean and South Eastern Mediterranean and the role of Cyprus in the shipping routes during this period.

What is less known, is the fact that it is the first late-classical, Southeast-Mediterranean shipwreck, carrying Chian amphorae that has been found at a depth where divers can work.

The wreck's good state of preservation may allow researchers to gain valuable information with regards to amphorae stowage on ships. Artefacts can also yield information regarding the living conditions on-board the ship, such as the large numbers of olive pits found during the excavation, which may have been part of the crew's food supply.

The discovery of sections of the keel is of exceptional importance and ranks the Mazotos shipwreck among the very few shipwrecks in the Mediterranean region that can provide data regarding shipbuilding during the classical period. Additionally, sailing equipment, such as the parts of 3 anchors of varying sizes that were found, shed light to seafaring practices in antiquity.

4.1.3 Learning significance

Over time, Cypriot volunteers gained experience in this field, as they were given the opportunity to train in underwater archaeological excavation, as well as in the preservation of archaeological artefacts. The Mazotos project has served as a training centre for many students from the University of Cyprus, who took part in the project at various stages, offering them the possibility of direct participation and practical training experience.

Volunteers and researchers, coming from different academic background and specialization, have created a fertile ground for interaction of knowledge and experience. This aspect has also helped in the development of scientific research in various disciplines.

It can safely be said that the Mazotos project constitutes the birth of Cypriot underwater archaeology, as it is the first of its kind to be conducted exclusively by Cypriot organizations.

4.2 Site formation process

The terms, site formation process or wreck formation process, describe the many changes of state that occur to a ship, before reaching the seabed and what happens to it subsequently for the time it remains underwater, until it reaches an equilibrium with its new environment. The transformation of a shipwreck site is determined by natural forces as well as physical, biological and chemical processes that act upon it for long periods of time. As Gibbs (2006) states, “No two wreck-site formations are the same, since the complex and interacting variables that constitute the environmental setting, the nature of the ship, and the circumstances of its loss combine to create a unique set of attributes.”

4.3 Requirement specifications

The archaeological team is looking for an environment that will allow the simultaneous and manageable viewing and comparison of the documentation process deliverables, which come in many different file formats and sizes. They are also searching for ways to practically and effectively use the deliverables, to enable and initiate the reconstruction of the site formation process. The need arises for an environment that will permit a more “hands-on” and easy interaction with the recorded data and can assist archaeologists in generating, visualizing and assessing their hypotheses concerning wreck formation processes. It is possible that such an

environment may also allow archaeologists to examine the acquired data and assess their methodology as the excavation progresses.

In order for the application to be a valuable scientific tool, it must maintain a high level of accuracy and authenticity; this consideration has prompted the use of the original deliverables from the Mazotos shipwreck. The application will also attempt to provide an intuitive environment for the users to work in, aiming to enhance their feeling of immersion.

The aforementioned overview of general requirements for the application was the result of discussions with members of the ARU. The researchers also provided details regarding two present hypotheses/research questions that they have, which formed the focus of the application.

4.3.1 Hypothesis/research question A

The Mazotos researchers are interested in examining the changes in seabed levels occurring at different stages of the site formation process. Data that may provide clues include: white traces found on amphorae, the anchor-cores final position and the documented superposition of shells and fragments of foreign artefacts found.

They wish to begin examining the distribution and correlation of such clues and to hypothetically divide the virtual environment into layers. For this first hypothesis they will need to be able to select an amphora, drape it with a texture created from the cleaned-up photographs and mark it where the white traces appear on the artefact. Furthermore, they will have the added ability to expand these markings to create new or additional surfaces and check whether other artefacts' white traces are situated on the same level, which could imply a previous seabed.

4.3.2 Hypothesis/research question B

The second research question concerns the amphorae that lie in the centre of the bow area, described as “found broken in situ, in a disturbed but not entirely disordered position and may indicate a wreckage episode or a phase of the deterioration of the ship’s hull” by Demesticha et al., (2013). At least four layers of amphorae seem to preserve their initial stowage position, which the researchers find extremely interesting.

For the investigation of this research question, users will need to be able to recreate an amphora based on its fragments and to move it to new positions. These initial requirements

were extended by the author during the design process, in order to make the function easier and more helpful for users.

5 Design and development

5.1 Original documentation data

Documentation data, mostly relevant to the bow area and the two Hypotheses/research questions, were received from the ARU for the purpose of this application. These included: photographs regarding amphorae: 001, 137, 151, 159, 256, 259, 260, 263 taken at various stages of their excavation process, an Excel spreadsheet of all information relating to the documented finds for the period 2010-2011, point clouds for the years 2008-2012 and 3D models created in Rhino, of individual amphorae (for the abovementioned amphorae) and of the entire reconstructed site to date.



Figure 3: Photographs of amphora 259 from various stages of its excavation process (Copyright University of Cyprus, ARU).

5.2 Optimizing data

5.2.1 Point clouds

From the numerous (42) point clouds made available by the ARU, covering the years 2008-2012, four point clouds were selected to be included in the prototype because the two hypotheses/research questions involved artefacts investigated during the 2010 and 2011 excavation periods.

Two point clouds corresponded to the beginning (2010-6-11-4) and end (2010-5-9-3/4) of 2010 and two to the beginning (2011-5-25-5) and end (2011-6-21-2) of 2011 excavation period. These specific four point clouds were chosen, due to the fact that they were some of the better examples of the 2010 and 2011 photogrammetry results, but also because the author felt that it would be interesting to compare and examine two data files with an obvious

time gap between them, alongside the 3D scene, as a form of excavation timeline for each period.

The selected point clouds had to be reduced in amount of vertices by 50%, using Meshlab to make each file manageable for the hardware devices used and in order to be exported as one file to EON Studio 8. Once reduced they were exported as an obj file to Autodesk Maya to check how they were automatically placed in relation to the 3D scene (point clouds are geo-referenced, so the author did not manipulate them in any way so as not to alter their coordinates).

It would be ideal to include all the photogrammetry data but the four point clouds were used as a starting point. Including more than four point clouds in the VR environment would make the application very heavy to run and slow to load. As previously mentioned, this prototype serves as an introduction of what can be achieved with this technology. Future development of the application would have to use a different method, perhaps by dynamically loading these information rich and heavy data files from a database, or an external source.

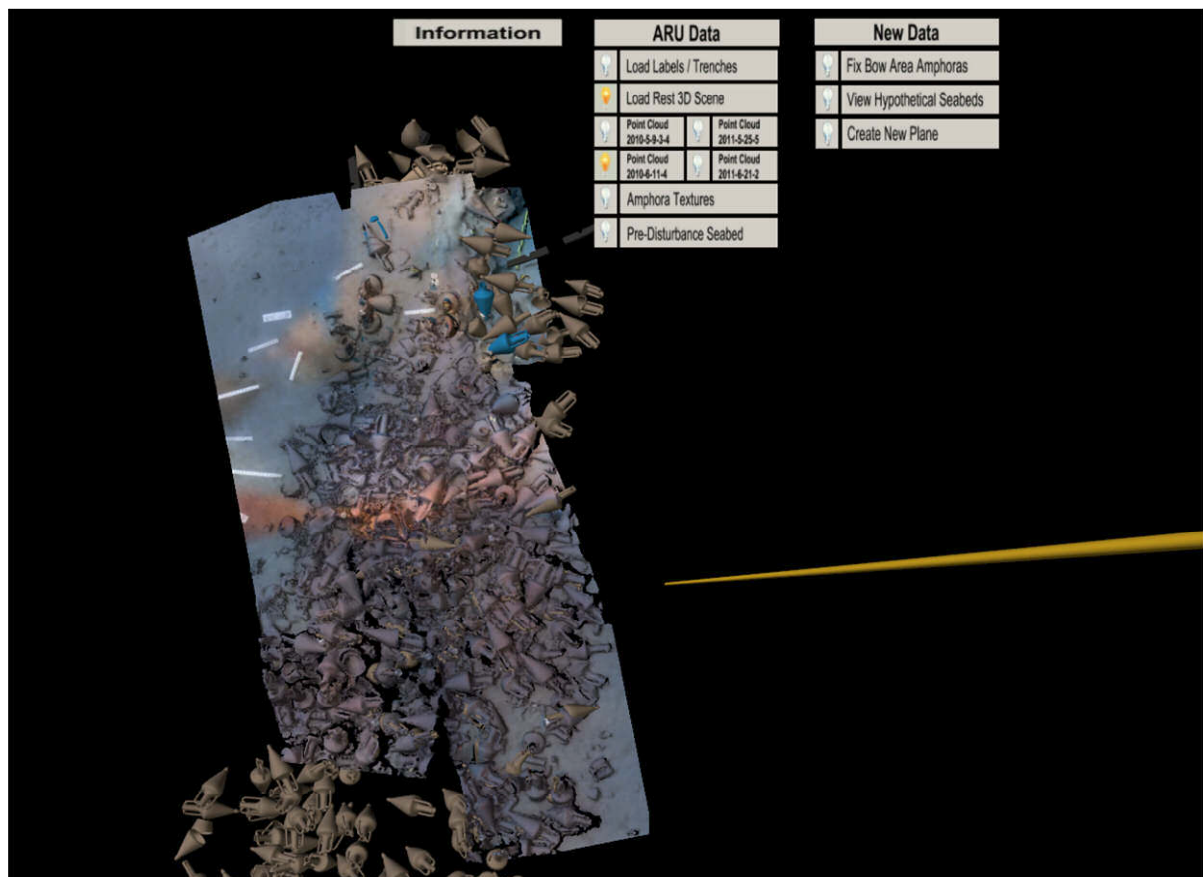


Figure 4: The 2011-6-21-2 point cloud, as it appears in the application

5.2.2 Information and photographs

The information panels went through many iterations. They were originally created as 2D images (bmp files) but this method was problematical for several reasons:

1. All 2D information in EON Studio 8 is always placed above any 3D mesh, making it impossible to place the 3D previous and next photograph buttons on the information panel.
2. Creating the previous and next photograph buttons as 2D buttons to be placed on the 2D information panel was also not a solution as 2D buttons could not be activated by the laser beam.
3. All 2D information (text or images) appeared in all screens, which meant the same information panel was visible four times to the user and always in front of the 3D scene, which was unnecessary and not ideal.

For these reasons all information panel images were instead attached as a UV map/texture to a mesh in Autodesk Maya and placed as a 3D object in the virtual environment.

Information regarding the artefacts was extracted from the ARU Excel file and through the use of Adobe Photoshop were used to create information panels. In addition to the description, material, date lifted and dimensions, each information panel presented the selected photographs corresponding to each artefact, ranging from it being undisturbed underwater, to its process of excavation, lifting and clean-up at the museum. Each photograph meant the creation of an image file, so for instance, the information panel for amphora 001 had 67 photographs resulting in 67 image files. It was made clear during meeting with the Mazotos research team, that artefact photographs from different stages of the excavation process would be necessary for the user to perform the tasks and indeed any process of analysis or interpretation.

5.2.3 3D models

The 3D models and scene created by the ARU in Rhino had to be exported as an obj file for further work in Autodesk Maya. A group of amphorae were coloured in blue (001, 137, 151, 159, 256, 259, 260 and 263). These amphorae were the ones to be examined more closely for the Hypothesis/research question A. Another group of amphorae were coloured in dark brown and cream to make them clearly identifiable to users that they would be used for Hypothesis/research question B.

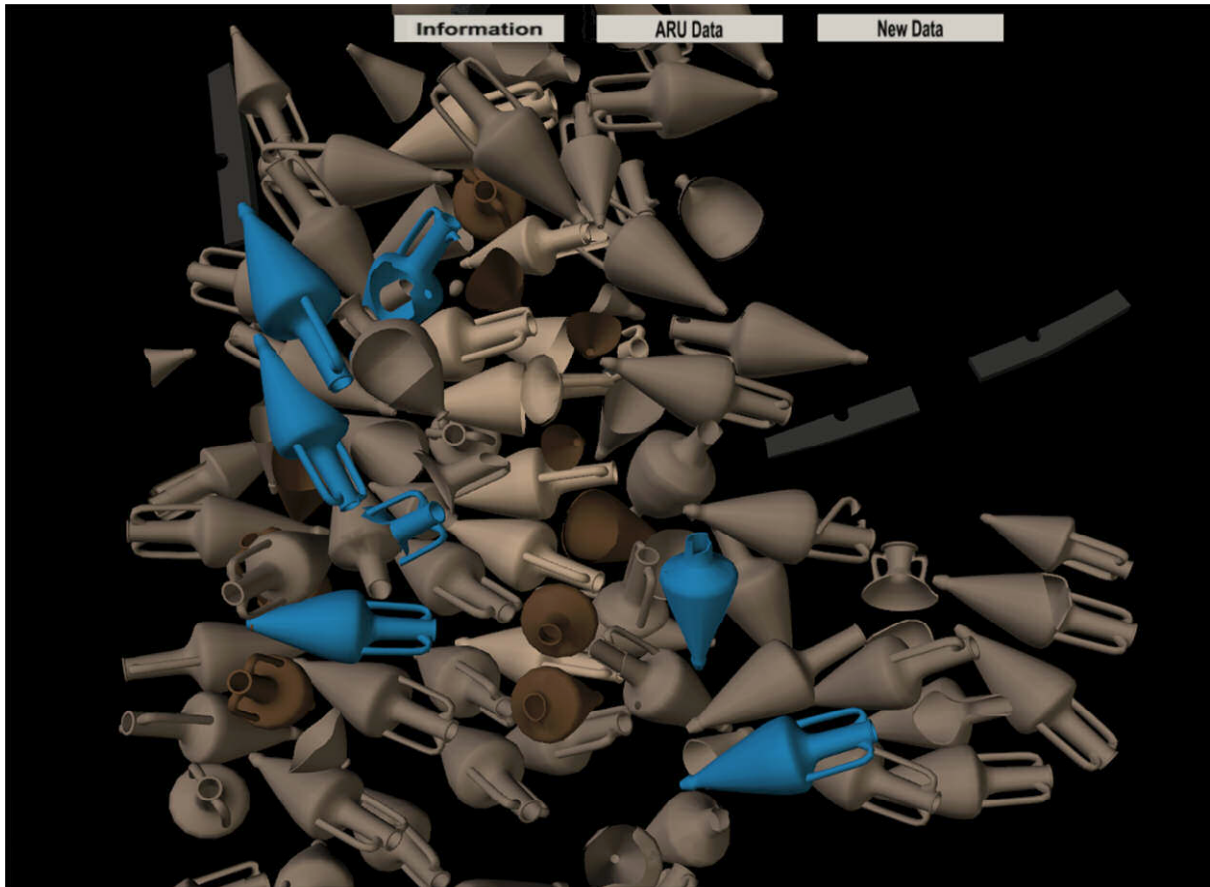


Figure 5: The amphorae that will be specifically investigated with regards to the two Hypotheses/research question are coloured differently to the rest

Apart from the artefacts contained in the Rhino file, the artefact labels and excavation trenches were also exported, this time as vectors and brought into Autodesk Maya to be transformed into a 3D mesh. This process was necessary due to the same difficulties experienced with the information panels, as previously described.

Even though the hypotheses/research questions explained by the ARU involve predominantly the bow area, the option to view the rest of the 3D scene is also available for the users to activate.

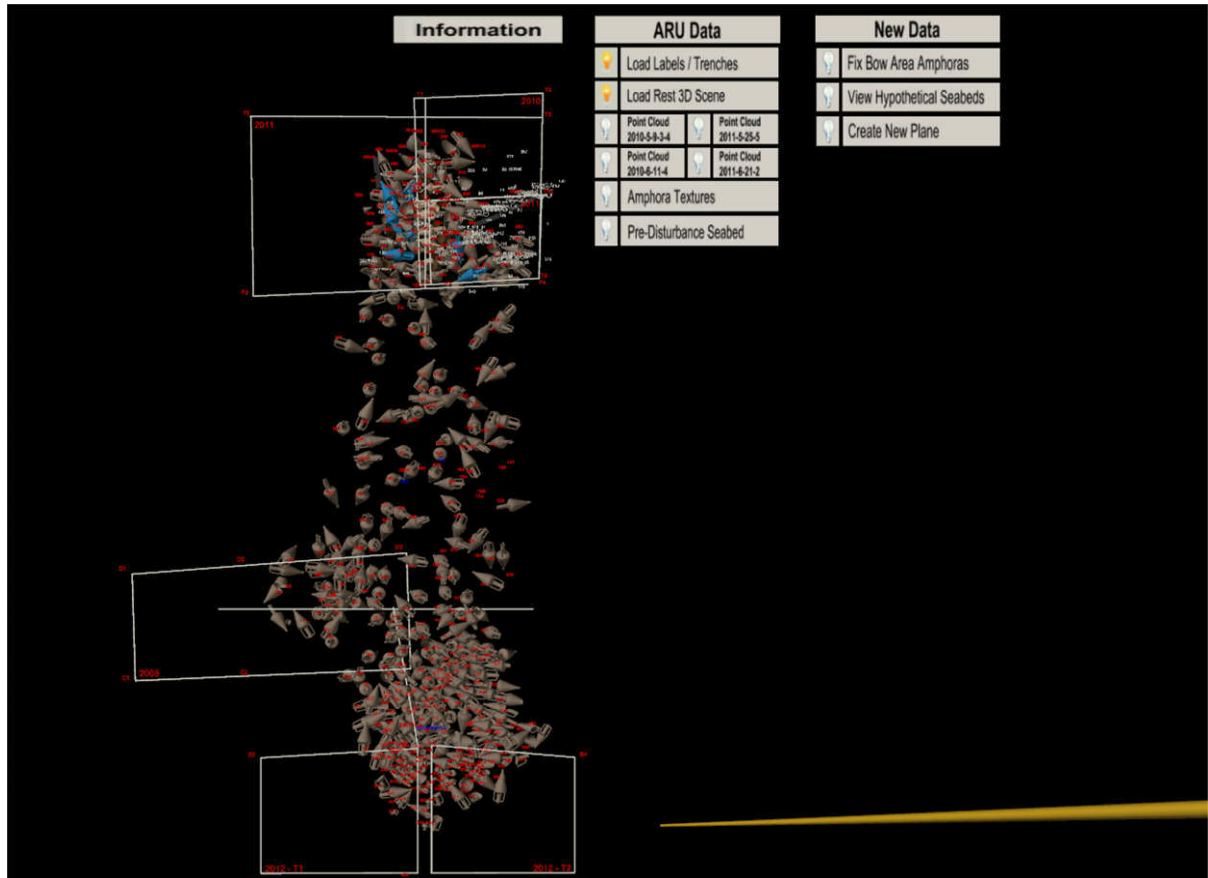


Figure 6: The full 3D scene, labels and trenches as they appear in the application

5.3 Creation of new data

5.3.1 Interface

The interface of prototype 1 comprises of 3 menus named Information, ARU Data and New Data. The first menu contains the information panels for the 8 blue amphorae (001, 137, 151, 159, 256, 259, 260 and 263). Through the ARU Data menu, data received from the ARU can be activated/viewed when their corresponding button is pressed (labels & trenches, 3D scene, the 4 point clouds, amphorae textures and the pre-disturbance seabed). Finally, the New Data menu contains the buttons for fixing the bow area amphorae, viewing hypothetical seabeds and creating a new plane, which are all hypothetical data created for this application in order to facilitate researchers in visualizing and assessing their hypotheses, discussed during our meetings.

As a way of indicating which button is active, white, light bulb icons are placed next to them, changing to yellow when they are activated. The menus can be maximized or minimized so as not to obstruct the user's view or take up too much of the front screen's space.

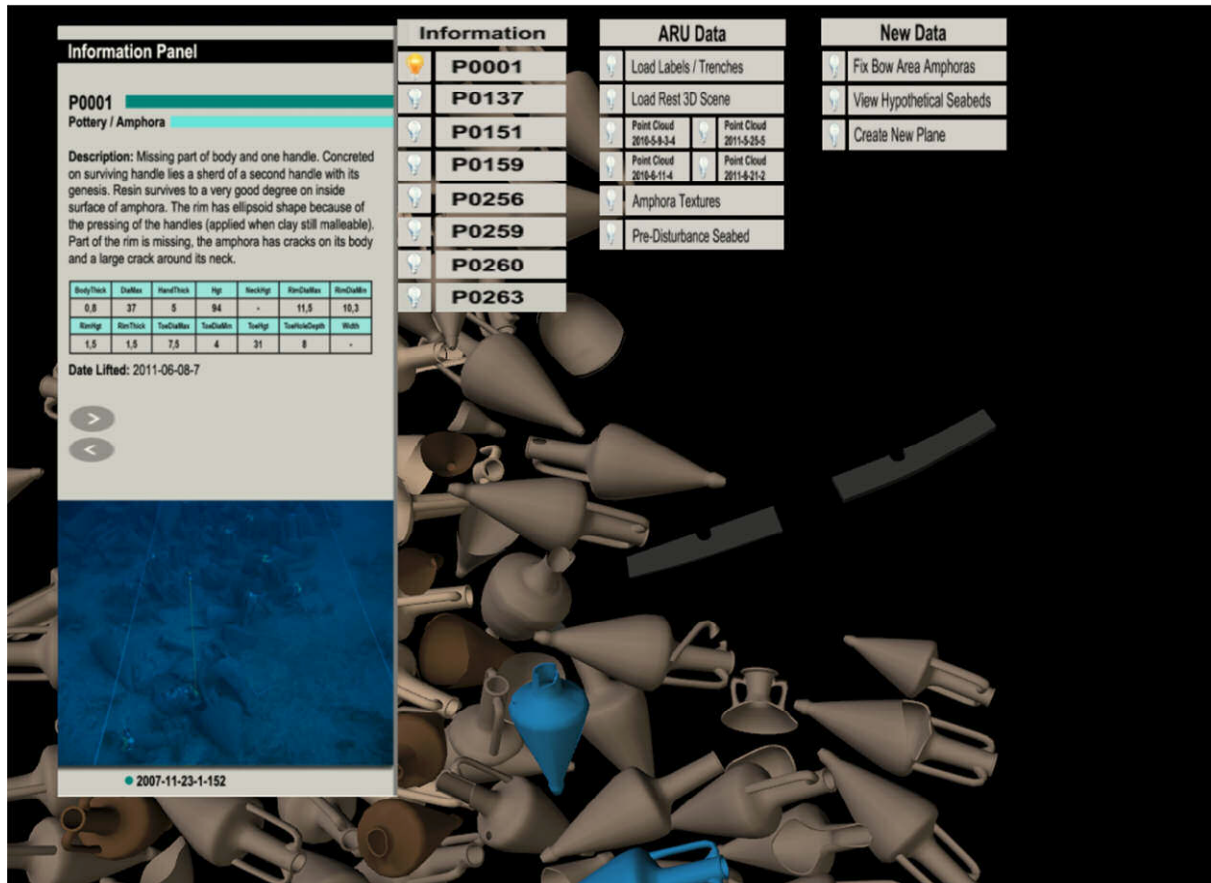


Figure 7: The 3 menus, buttons and information panel that make up the application's interface

5.3.2 Amphorae textures

The individual obj files for amphorae (001, 137, 151, 159, 256, 259, 260 and 263) were opened as 3D objects in Adobe Photoshop where texture maps for each amphora were created using the cleaned-up photographs taken at the Larnaca museum. When photographic information was missing for a certain part of the amphora (for example, the inside part of the amphora handles), the texture map was coloured blue so as to relate this fact to the users.

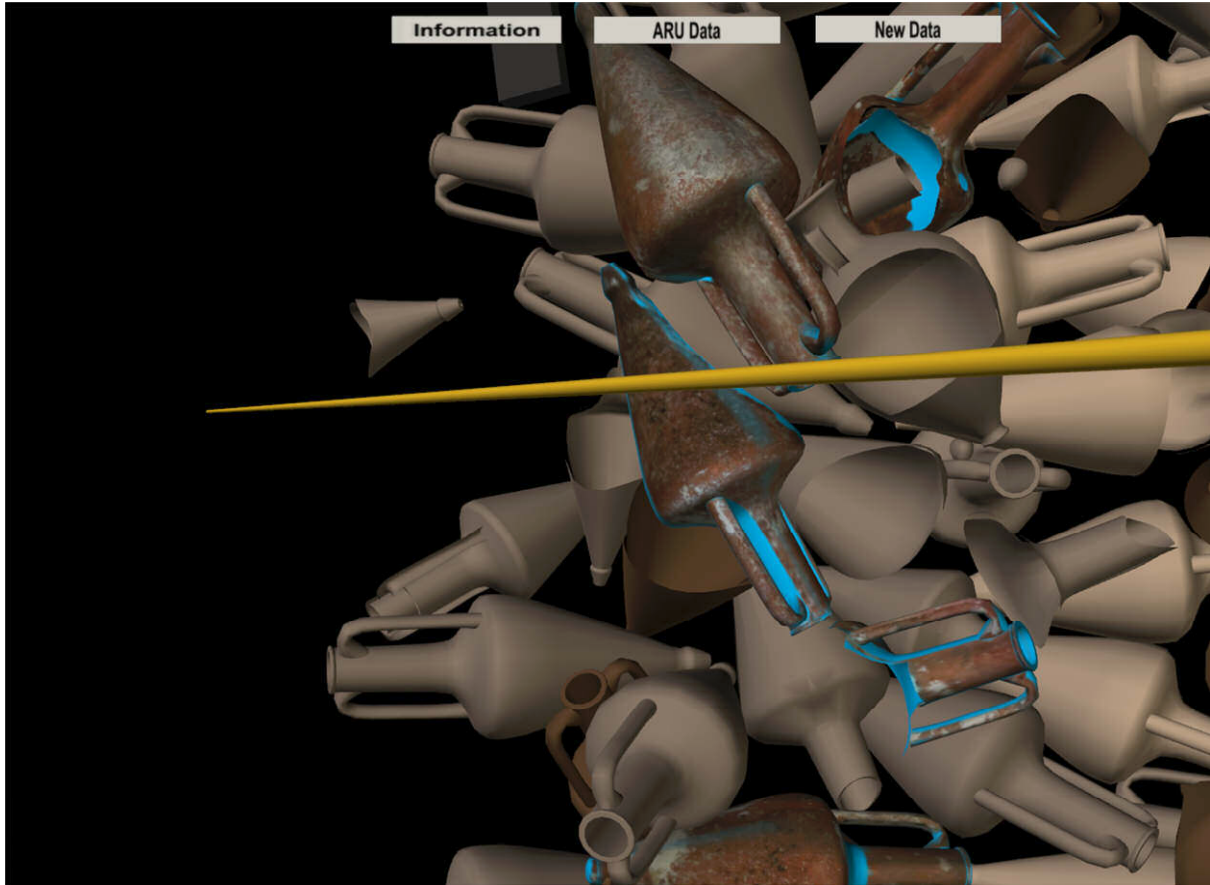


Figure 8: The textured amphorae as seen in the application

5.3.3 Hypothetical seabeds

Once the cleaned-up photographs were attached to their corresponding blue amphorae, it was easy to see where the white traces appeared on their body. From this information, planes were created in Autodesk Maya (since they are hypothetical, they were depicted in light blue and semi-transparent) to indicate what hypothetical seabeds they would form if projected. The same type of plane was created and placed on the anchor cores, found in the bow section of the ship as well, since they also might indicate a hypothetical seabed. When using the application, the researchers have the ability to move these semi-transparent planes, expand or contract them to visualize hypotheses regarding the site formation process.

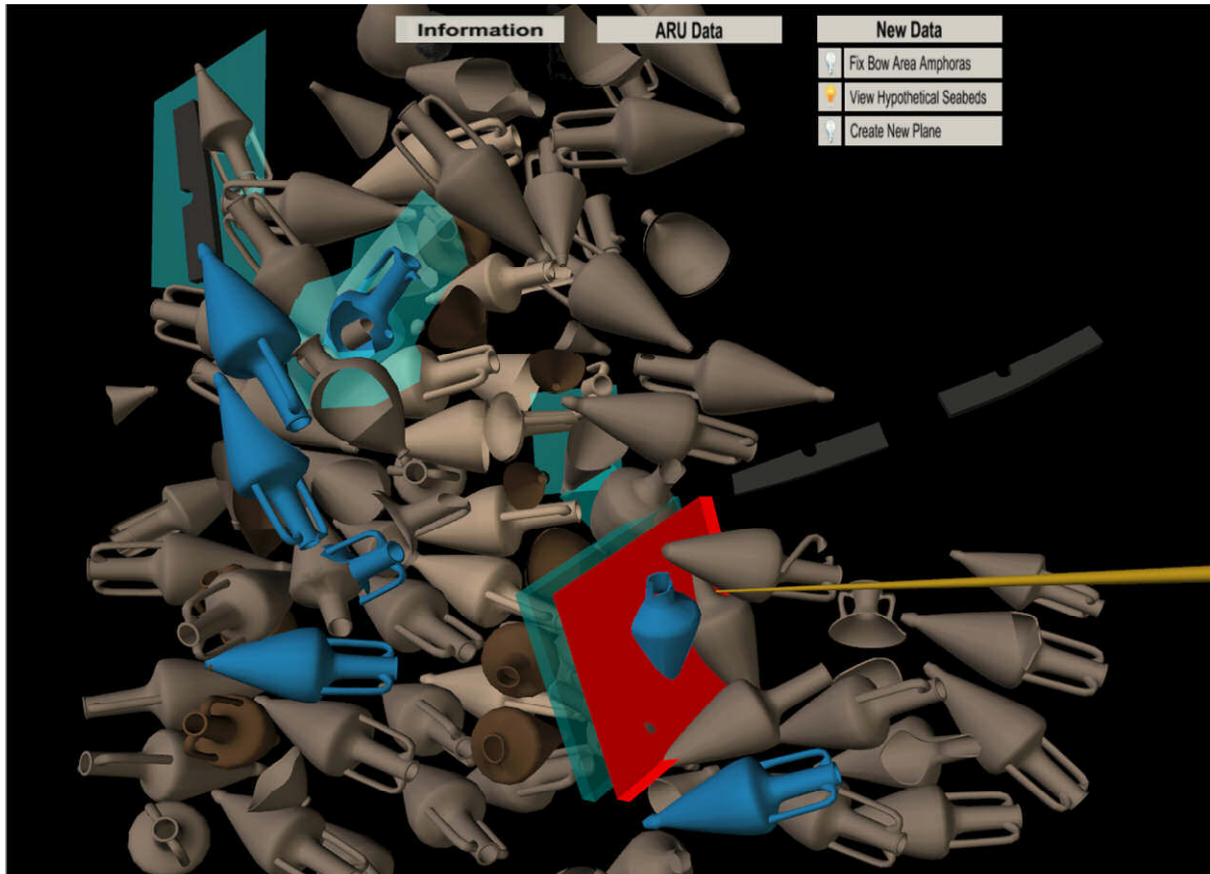


Figure 9: One of the hypothetical seabeds is highlighted in red as the laser-beam hovers over it

5.3.4 Pre-disturbance seabed

The application will indicate which artefacts and what parts of their bodies were found buried through the visualization of this newly created piece of information. It is a semi-transparent mesh, placed according to the artefact photographs.

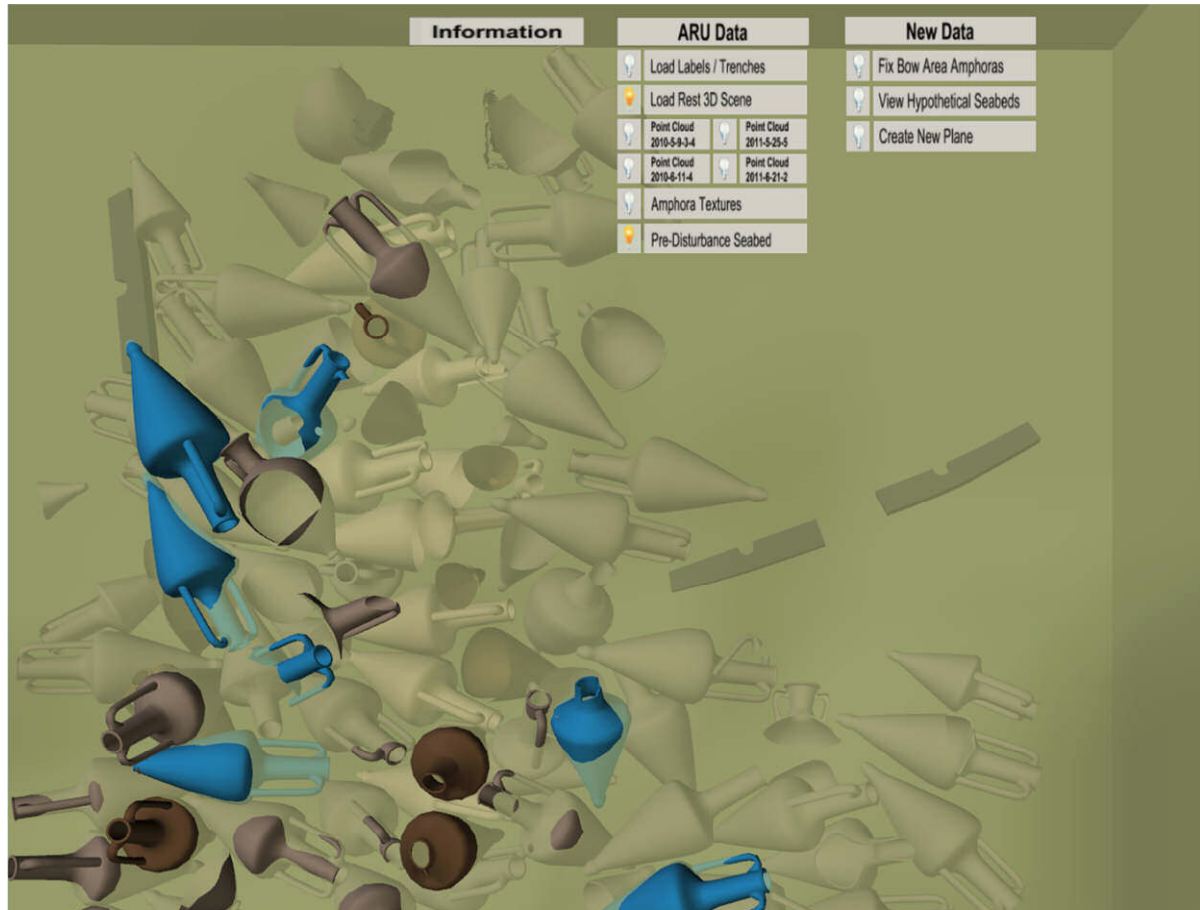


Figure 10: The pre-disturbance seabed is used to indicate how the assemblage was originally buried

5.3.5 New plane

Users are able to create a new semi-transparent plane while in the VR environment, which they can manipulate similarly to the hypothetical seabeds. What distinguishes this plane, is that it does not correspond to any specific amphora or white traces.

5.3.6 Fixed amphorae

The amphorae coloured in dark brown (377, 375, 155, 261, 353, 355, 358, 268, 266 and 361) and cream (367, 368, 356, 357, 313, 359, 363 and 348) were duplicated in a light blue colour to indicate that they are hypothetically recreated data. Certain of these were only fragments, from which whole amphorae were recreated in approximation, according to their dimensions.

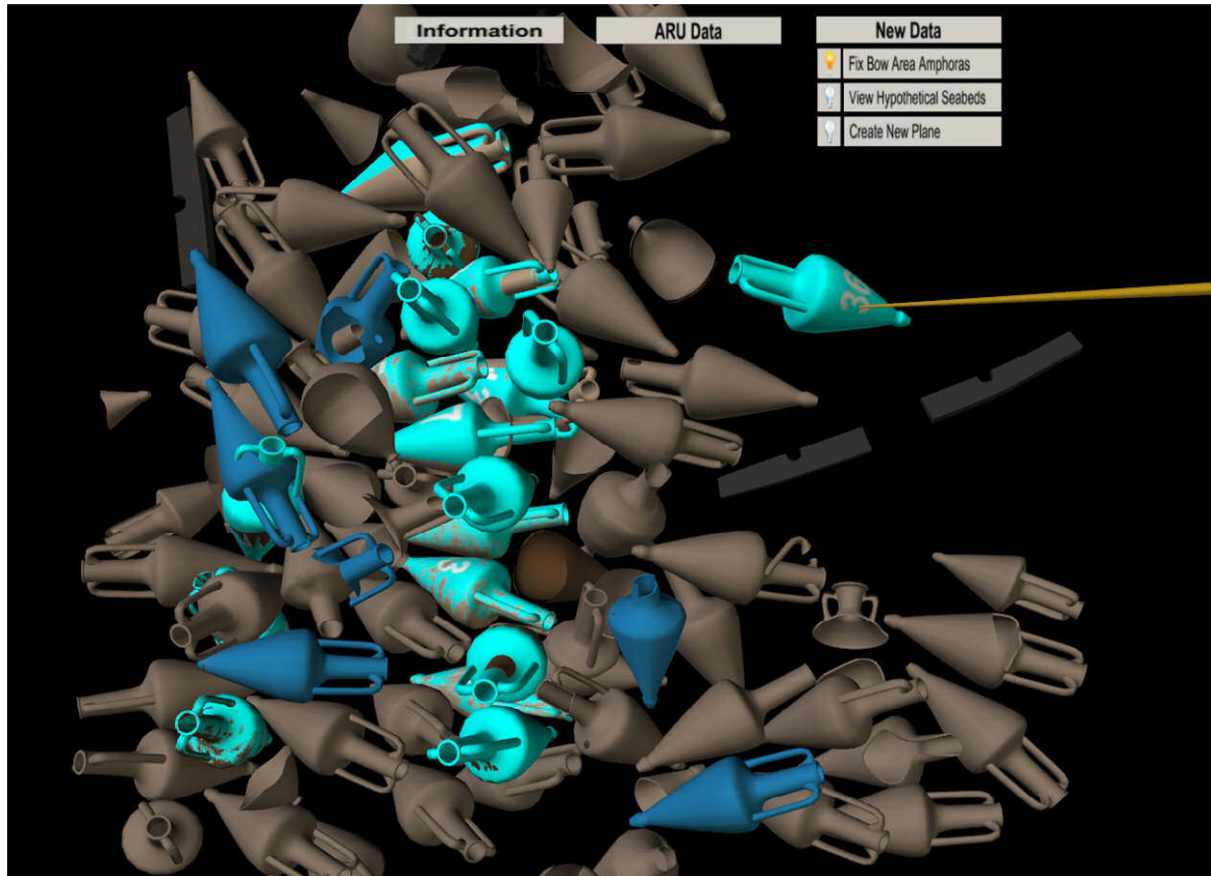


Figure 11: The fixed bow amphorae are depicted using a light blue colour

For the function of permitting researchers to test hypotheses regarding the spatial arrangement of artefacts and the site formation process, the users will have the ability to move these fixed amphorae freely in the VR environment to test out hypothetical positions. Also indicated on their UV texture map is their label number, to help users identify them when they are moved away from their original position in the 3D scene.

5.4 Export to EON Studio 8

Once each 3D mesh was ready, 3D Studio Max was used to export it as an eoz file for EON Studio 8 through the EON Raptor plug-in. The only setting that was changed in EON Raptor options was the EON unit system option so that one system unit in 3D Studio Max would be kept as 1 unit in EON Studio 8, thus maintaining all the original dimensions created by the ARU.

5.5 VR CAVE

The application was developed in EON Studio 8 and runs in a VR CAVE with four display surfaces, three walls made up of rear-projection screens and the floor through a downward-projection screen. The projection systems are very high-resolution due to the need for near distance viewing. 3D glasses allow users to see stereo imagery whilst immersed in the virtual model and for their position to be tracked (through markers attached to them) in order to adjust the stereoscopic display to retain the viewer's perspective. Infrared tracking cameras make it possible for users to see and walk around 3D objects that appear to be floating in mid-air. The use of an Xbox controller, also equipped with markers, enables the navigation through the environment as well as the interaction and manipulation of the data and the 3D models that populate it.

5.6 Interaction in EON Studio 8

EON Studio 8 was the authoring software used to develop the interactive application for the VR CAVE. It provides a library of nodes and prototypes with ready-made functionality, which were used to add interactivity. These nodes and prototypes are then connected between them in the Routes section of the EON Studio 8 environment. A template was used with already configured functionalities relating to the tracking, displays and Xbox controller navigation.

Important nodes and prototypes that were used for this application are presented briefly:

- View Maker Node: By pressing the right and left bumper buttons on the Xbox controller, the 3D scene could be viewed from 10 different saved perspectives.
- Wand Sensor Prototype: The laser beam, activated by the Start button on the Xbox controller, worked as a virtual pointer and when pointed at buttons or objects it triggered this node which enabled the corresponding action.
- Latch Node: this node was used to toggle between 2 states – making elements used in the environment visible or invisible.
- Frame Node: all 3D objects need to be placed within this node in order to be used.

- Switch Node and Counter Node: These nodes were used together by the next and previous buttons to loop through the different photographs available in the information panels.
- zSpaceStylusInteraction Prototype: this node was used when objects could be manipulated by the users. By keeping the A button pressed on the Xbox controller, the user could move objects on all axes, to a location of their choice. By pressing the B button on the Xbox controller, all manipulated objects were returned to their original position and state. According to the objects that were moved, by keeping the Y button pressed on the Xbox controller, the amphorae could be moved only on the y-axis and the seabeds could be expanded or contracted.

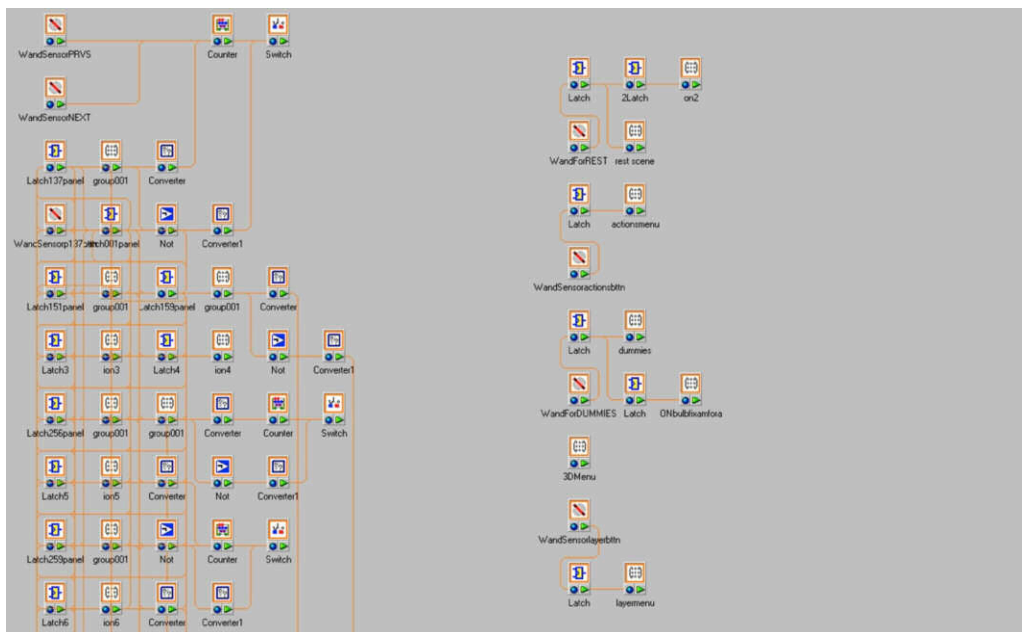


Figure 12: Screenshot of the Routes section, showing some of the nodes used to form the interaction for the Information Panels (left) and the menu buttons (right).

The user can interact with the application’s interface and the objects that populate its environment through the use of the Xbox controller. A diagram indicating all the possible actions that can be performed by the user is presented next.

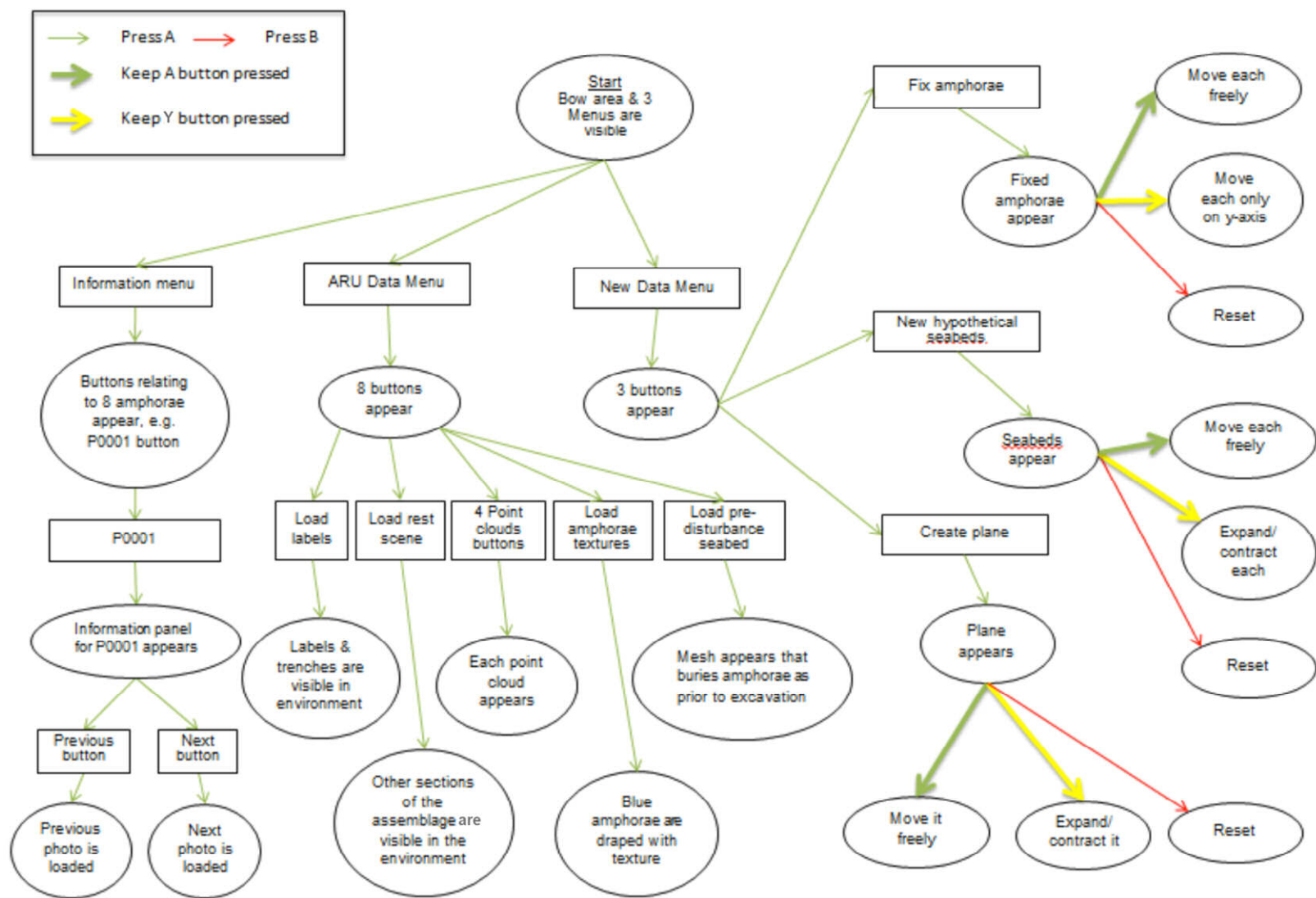


Figure 13: State diagram giving an overview of the interaction available

6 Evaluation

6.1 Heuristic usability evaluation for prototype 1

On the 11th of November, two usability experts were asked to evaluate the prototype, following a set of “heuristics” or design guidelines, such as the ones identified by Nielsen and Sutcliffe (Sutcliffe & Gault, 2007; Nielsen, 1994).

This heuristic evaluation was conducted by two experts in usability, human computer interaction and user experience design and not representative users. The aim of this type of evaluation was to identify problematical elements and other issues concerning the design of the application during the development stage, so that they were addressed and refined prior to evaluations with actual users.

The virtual environment was explored thoroughly twice, and task details were inspected in order to identify problems. It is important to mention that, as anticipated, the heuristic users could not perform the tasks intended for the actual users and found some of the terminology and functions difficult to understand. For this reason, the tasks that would be asked of actual users were performed by the author, while heuristic users identified issues and problems. The first pass was exploratory in nature, with the intention of getting a feel for the flow of the interaction and the general scope of the application. The second pass allowed the evaluators to focus on specific interface elements while knowing how they fit into the larger whole.

The findings were then summarized in a report that ranked the severity (according to the heuristic experts) of each usability issue discovered and resulted in further refinements (that the author felt necessary to address at this point) to be made to the prototype, thus creating prototype 2. These refinements are described in greater detail in the following section.

6.2 Prototype 2

Through the heuristic evaluation process, it was concluded that certain basic improvements needed to be made to Prototype 1, to eliminate some of the issues that would arise during the user evaluations that could cause confusion when performing the tasks and to ensure that the sessions would run more smoothly. These alterations and additions were made within 5 days, so that the programmed evaluation sessions could begin without delay.

6.2.1 Relocation information

Firstly, the Information menu is no longer a separate menu, but has instead become a button incorporated in the ARU Data menu; the Amphora Textures and Pre-Disturbance buttons were relocated to the New Data menu.

In this manner, all the ARU gathered data are grouped together and are kept separate from all the new data created for the purpose of this application. It is believed that this structure will make the interface easier to remember and learn, as well as simpler to use.

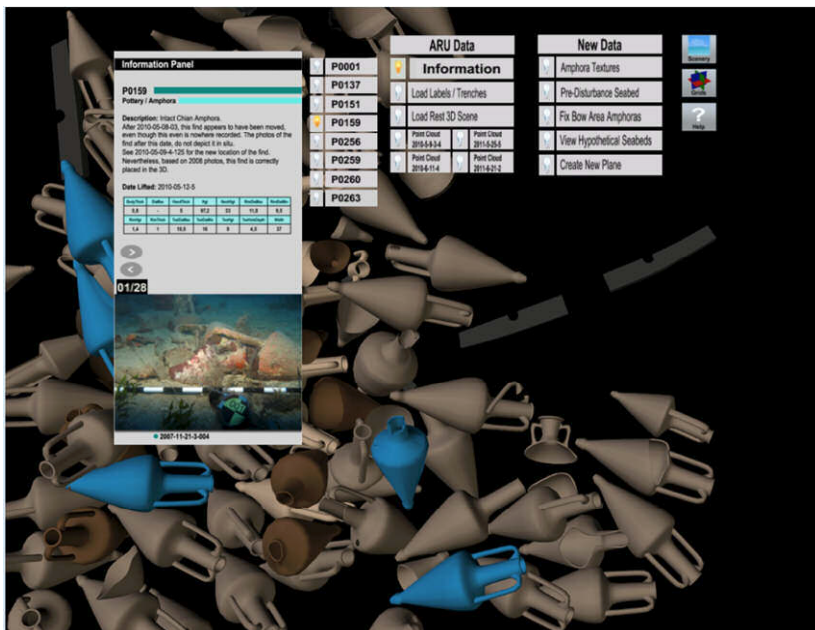


Figure 14: The new interface consisting of only two menus

6.2.2 Addressing issues

Some aesthetic issues were identified during the expert evaluation and were subsequently rectified. Firstly, the smaller white labels, which appeared along with the artefact numbers when the Labels button was activated, were omitted from the application. They could easily be added at a later stage, if needed, but they would be too distracting for the tasks in mind for the user evaluations.

Some View Maker positions caused a change in lighting, which made the menus and buttons much darker than intended and difficult to read.

The hypothetical seabed plane for amphora 001 was remade to match the other hypothetical seabed planes and lastly, the Fixed Bow Area Amphorae were all re-textured so that their identification number would be more readable.

Unfortunately, it was not possible to find a solution to the lag problem experienced when buttons of the New Data menu were activated (View hypothetical seabeds, Fix bow area amphorae, i.e. when 3D artefacts can be manipulated) in the time available.

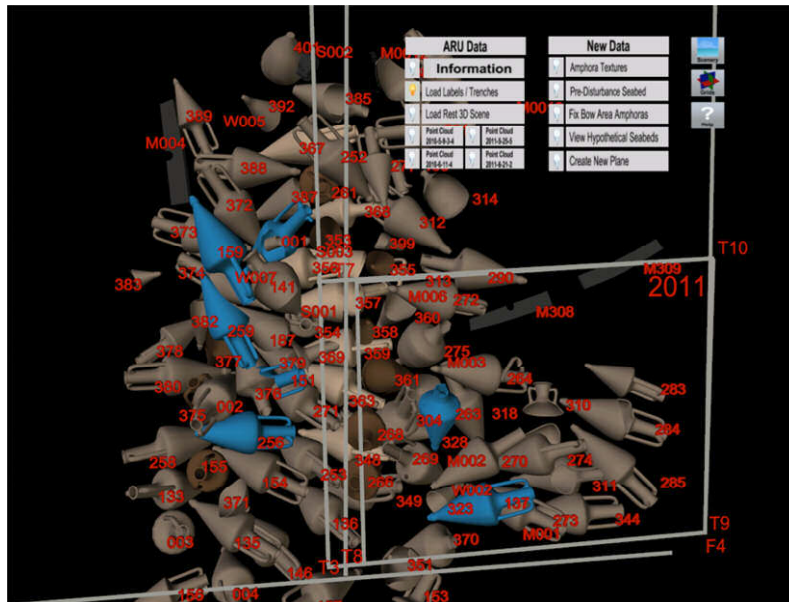


Figure 15: The updated labels and trenches

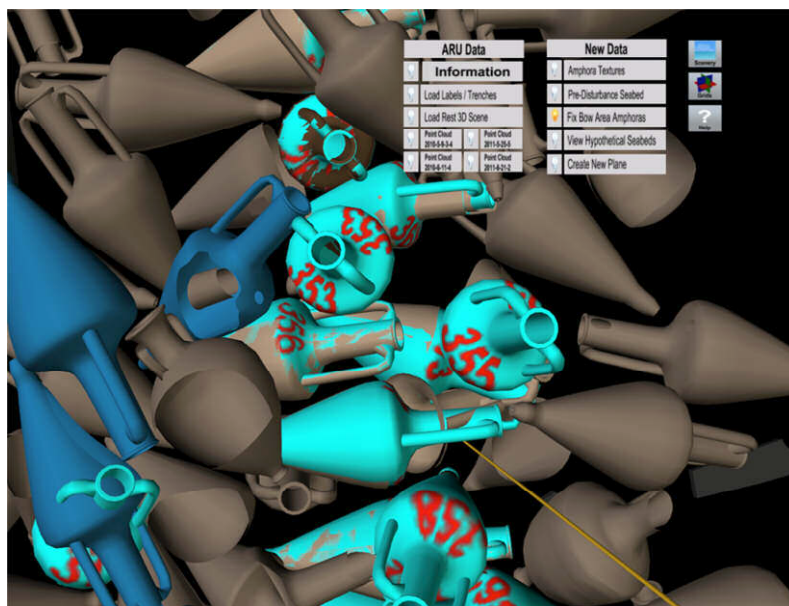


Figure 16: The updated texture maps for the fixed amphorae

6.2.3 New additions

The information panels gave no indication of how many photographs were available for each amphora. This was amended with clear indication of the total number of photographs that the user could go through, as well as the number of the photograph visible at the time.

The addition of scenery at this point, was done only as a way of adding “landmarks” to the virtual environment, to support the user, in case of difficulties, understanding his/her movement, viewpoint and orientation, and not to enhance the sense of presence and immersion. It was one of this project’s objectives to use only real data from the Mazotos site to form the virtual environment and this is why the scenery can be turned on and off with a new Scenery button/icon appearing in the interface. This way, it is up to the user to decide at any given time which environment is easier for him/her to work in as well as accommodate the possibility that some users may not be as familiar with the site as others.

The second button/icon that was added to the interface is that of the Grids, which as its name suggests, activates three grids. Each grid is coloured differently (blue for z-axis, red for x-axis and green for y-axis) and consists of 400 squares (20x20 of 1mx1m). The grids were added so that the user can manipulate objects with more accuracy in the 3D environment, moving and scaling them with reference to something. They were also incorporated in the application to hint at the possibility of adding other information in future versions (such as topographical plans, hypothetical illustrations of what the ship looked like and moving the 3D artefacts in reference to them).

When the user activates the final button/icon, a sequence of help screens appear to inform him/her of the Xbox controller functions, what information can be found in each menu and icon and how to manipulate certain objects. These three screens and functionality were created, in order to make the application easier to learn and understand, for first time users and to support them during its use.

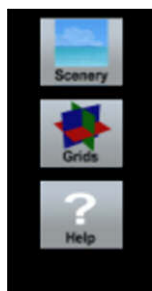


Figure 17: The newly created button icons for the scenery, grids and help

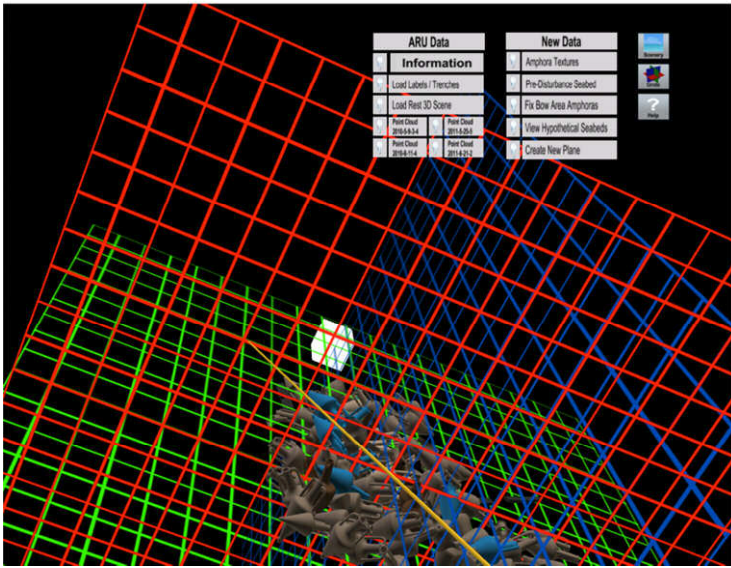


Figure 18: A screenshot of the application with the grids loaded



Figure 19: The first help screen with information regarding the Xbox controls

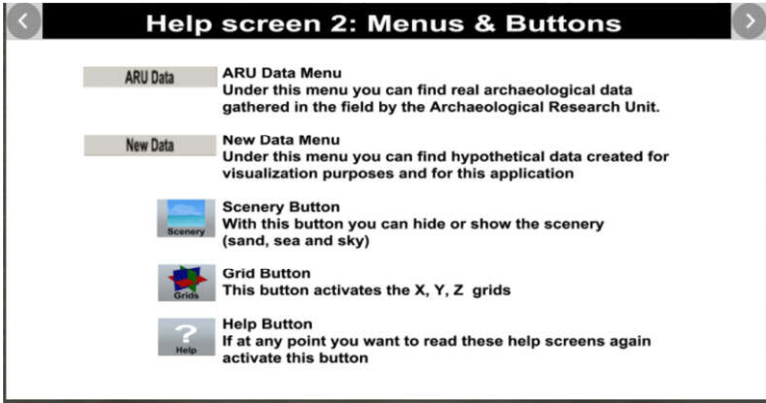


Figure 20: The second help screen with information regarding the menu and icon buttons

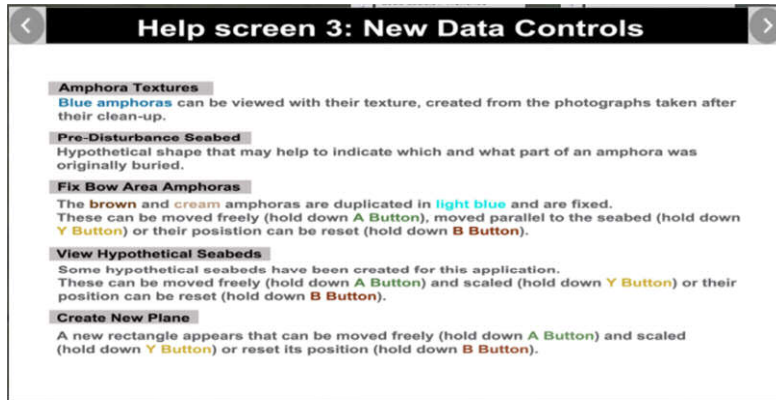


Figure 21: The third help screen with information regarding the New Data menu

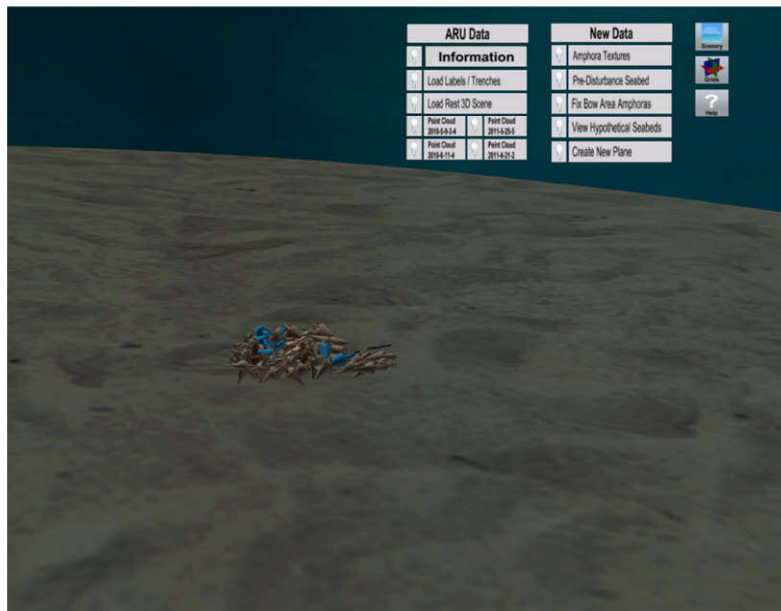


Figure 22: A screenshot of the application with the scenery loaded

Furthermore, the evaluators advised the revision of the description and instructions for Task-scenarios A and B, prior to the user evaluations, so that they are made more explicit and clear.

6.3 Formative evaluations of prototype 2 with users

Once the changes to the prototype were completed, the formative usability evaluations were able to begin. This evaluation method was chosen in order to collect both qualitative and quantitative data and to gain insight into the effectiveness and efficiency of the prototype.

The evaluation sessions took place in the controlled setting of the ICT Lab. The users were asked to carry out a set of predefined Tasks-scenarios. The methods used in the evaluation included a pre-test questionnaire, direct observation, a post-test questionnaire and semi-structured interviews, in order to achieve methodological triangulation (Rogers, Sharp, & Preece, 2011).

6.3.1 Participants

Nine users took part (out of the ten originally invited) in the evaluation study, during the period of 18-24 of November, each session lasting less than 2 hours to be completed.

All participants had been actively involved in the Mazotos project and research for longer than a year. Seven of them came from an archaeological educational background. With regard to their general professional experience, two of them had extensive experience of 14 and 20 years respectively, three had 4, 5 and 7 years respectively and two did not give information.

A total of nine participants (3 male, 6 female) took part in the user tests and three age groups were equally represented (21-30, 31-40 and 41-50). Various participant demographics were collected including computer skills and their experience with VR technology. The majority of the participants rated their computer skills as average, three as good and one as excellent. The majority, 5 participants had not used VR before.

It was also deemed important to have users with practical experience and particular interest in different stages of an archaeological research: research design, acquisition of archaeological data, analysis of data, interpretation of data and the dissemination of results.

6.3.2 Procedure

Each session started with the user completing a short pre-test questionnaire and signing the prepared consent form.

The user was then prepared for the VR CAVE, where the application was introduced and demonstrated briefly by the evaluator. This short introduction to the application aimed to familiarize the users with the new environment, the interface and the Xbox controls prior to the Task-scenarios.

Once this was over, the users were asked to complete certain Task-scenarios aimed to test how the application fared and met the purpose for which it was developed. Users performed

the Task-scenarios whilst being observed by the evaluator, and were encouraged to use the think-aloud protocol, to ask questions, to give information, and to expand upon comments and activities. Once the Task-scenarios were completed, each user was allowed to use the application further in any way and length of time they chose.



Figure 23: Photograph taken during an evaluation session, the user is examining hypothetical seabeds

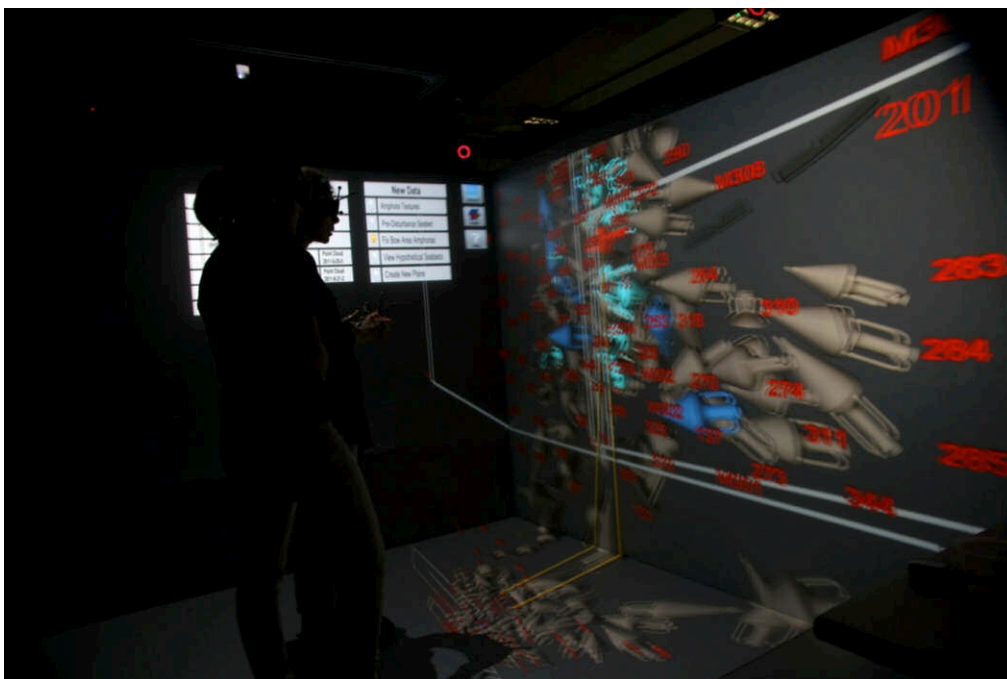


Figure 24: Photograph taken during an evaluation session, the user is moving a recreated amphora

The time spent using the application was audio recorded and the evaluator made observational notes for further analysis. Audio recording was chosen over video recording due to the difficulties of recording stereoscopic projection and the fact that the need for darkness would not permit the documentation of the other data such as the users' expressions etc.

The evaluation process ended with the users completing a post-test questionnaire and taking part in semi-structured interviews.

6.3.3 Documents and forms

For the usability evaluation, certain documents and forms were prepared, as suggested in the guideline by Salvatore and Koeffel (2007), which are presented below.

6.3.3.1 Invitation/information sheet

An overview of the intended evaluation process was sent to all the users, as part of their invitation to participate in the testing of the VR application. It contained information regarding the title of the project, names and contact information, brief synopsis of the project, duration times for each part of the study, tasks to be completed, how the sessions would be recorded, informing them that all information would be kept anonymous and that they had the option to withdraw from the study at any point.

6.3.3.2 Consent form

Signed consent forms were obtained from all participants before initiating any of the evaluation procedures. This form included all necessary information regarding the research project and its purpose, addressing issues such as confidentiality, risks and benefits of the research. All users agreed to be audio recorded and understood that they had the right to stop participating at any point during the process.

6.3.3.3 Pre-test questionnaire

This first questionnaire was administered to collect demographic information regarding the users. The pre-test questionnaire contained questions relating to the users' gender, age, occupation and years of practice and two questions were used to clarify their skills and experience regarding the use of computers and VR systems.

Further to the abovementioned general questions, three questions more specific to the

Mazotos project were included to establish how long, at what stage of the process and in what capacity each user was involved in the research of the site.

The questions contained in this questionnaire were designed to help in the analysis of the data obtained from the users, to determine what factors may influence their answers, interests and opinions during the evaluation and to enable the comparison of the results, to see whether and how responses vary between subgroups.

The final question asked for each participant to elaborate on personal research questions that may have formed while working on the Mazotos project and was included as a way to examine whether the prototype could be useful in their further exploration and assessment.

6.3.3.4 Task-scenarios

A set of task-scenarios was extracted to determine whether the application is usable by the intended users to carry out the visualisation and assessment of the two Hypotheses/research questions, for which it was designed. This method gives insight into how each user will tackle these task-scenarios whilst in the VR CAVE, how they will respond, their actions, cognitive status, always in conjunction to how the application performs. Moreover, through this method, required functionalities that are missing in the prototype could be pointed out.

Task-scenario A aimed to examine whether the VR environment incorporated all the necessary information and data that users would need whilst using the application for analysis and interpretation purposes. The participants were asked to inspect how well the amphora UV texture maps were placed and subsequently how well the hypothetical planes (hypothetical seabeds) were placed on the amphorae. They were also asked to interact with these hypothetical planes, moving them and extending them.

Task-scenario B required participants to use the pre-disturbance seabed to visualize buried and visible parts of amphorae. The second part of this scenario tested how the application performed when the user manipulated amphorae, moving and rotating them with the intent of placing them in a specific location.

6.3.3.5 Observation form

Observational notes made by the evaluator, whilst users were in the VR CAVE, significantly enhanced the data audio-recorded. Through this method, additional data was documented such as evaluator comments, mistakes that the user hadn't realized he/she made, user

expressions and what was visible on the screens during every user reaction and comment recorded through audio.

6.3.3.6 Post-test questionnaire

The questions contained in this form, were derived from the VRUSE questionnaire designed by Kalawsky (1999) and were utilized to measure the users' attitude and perception during the evaluation of the VR application.

This questionnaire served to ascertain what the users thought of their interaction, their overall impressions and to get their feedback on the more technical aspects of the specific VR application. For this reason the post-test questionnaire was also divided into 7 sections in terms of: Interface, User Input, System Output, User Guideline and Help, Consistency, Immersion/Presence and Overall Impressions. The participants were asked to rate the difficulty (using a 1 to 5 Likert scale) of the aforementioned aspects and their level of satisfaction with the interaction.

The quantitative data yielded from this method will be of great importance in the future development of the prototype.

6.3.3.7 Interview questions

Semi-structured interviews were conducted to gather qualitative data from the representative users, to reveal more information regarding three key issues of interest: the perceived effectiveness of the application, the application's perceived suitability in assessing ARU research questions and finally the perceived suitability of the VR CAVE as a tool for the Mazotos project and research.

Five of the users were interviewed individually and the remaining four, were interviewed as a group.

6.3.4 1st user evaluation session

The Mazotos research team was consulted only prior to the development of Prototype 1 and after the heuristic evaluation the author thought it necessary to get an expert –context wise-opinion from this first user, once his/her evaluation session was over.

Important concerns were discussed, such as whether all users would be able to perform the intended tasks and be in a position to answer the interview questions, by learning more about

their background, experience and research focus. This session also provided an estimate on the expected duration of each evaluation session and was used to check the audio recording equipment.

No alterations were needed or made either to the evaluation process, the documents or the application after this discussion.

7 Results and discussion

7.1 Pre-test questionnaire

With regards to their participation in the Mazotos shipwreck project, two have been involved for 6 years (since the beginning), three have been involved for 4 years, three others for 3 years and one is involved for 2 years. With regard to their role and research areas, as members of the Mazotos team, the information is as follows:

- 6 answered that they are involved in the design of the research. This unfortunately is not correct – to the authors' knowledge, only three of the participants are actually involved in this process with one more participant consulted regarding important decisions the team makes regarding methodology, equipment, technology.
- 8 out of 9 are involved in the acquisition of archaeological data
- 4 out of 9 are involved in the analysis of archaeological data
- Only 3 are involved in the interpretation of archaeological data
- 4 out of 9 deal with the dissemination of results
- 1 is involved in the 3D modelling aspect of the research

In the section of the pre-test questionnaire, requesting participants to state their research questions, there were the following entries:

- The construction of the ship's hull
- Ship's dimensions
- The cargo – what was traded
- The route and the final destination of the ship
- Everyday life on the ship
- The method of the stowage of the cargo
- Amphora sizes
- Likely causes of the shipwreck

- Stages of ship disintegration
- The cultural and physical site formation process
- The stages of decomposition of the hull and the breakage and scattering of the amphorae
- The speed of the sediment building around the site (i.e. the reversal of the gradual burial of the finds)
- Phenomenological perspectives (i) the embodiment of an underwater site by the diver (ii) synesthetic experience of archaeological sites (iii) interaction with place and spatiality: the hybridity of the underwater environment and the interweaving of tangible and phantasmic places.
- Separation of excavation layers

It is evident that these research questions cover a very wide spectrum of issues and points of interest.

7.2 Post-test questionnaire

The post-test questionnaire comprised of 43 questions evaluating 6 different aspects of the VR application, plus the general impressions of the participants.

7.2.1 Interface functionality - control

It is clear from the answers that everybody found the functionality of the application easily accessible and furthermore, seven users found it appropriate for the task. One participant definitely did not use all the functions provided, but five participants did, with the remaining users either undecided or did not respond.

Overall, there were 75% positive reactions for this category.

When asked how successful they were in performing the two Task-scenarios, eight participants responded positively and the remaining user did not answer.

7.2.2 User input – interacting with and controlling the virtual environment

In this section we have the biggest density of undecided and disagreeing scores, compared to other categories of the questionnaire.

Seven participants found the Xbox controller easy to use, but the remaining two were undecided. Four users felt they made no mistakes and had the right level of control, in contrast to three users who were undecided and two who responded negatively. When asked how easy they found it to select and move objects, four responded favourably, four negatively and one was undecided. Five out of nine participants found it easy to position themselves in the VR environment, two were undecided and two did not find it easy.

When asked whether they would prefer an alternative input device, three users were undecided and one disagreed, but five agreed.

Overall the evaluation of interaction was about 53% positive.

When asked how well the users could move and manipulate elements within the virtual environment, six responded with “well”, one with “somewhat” and two with “very little”.

7.2.3 System output – information displayed to the user

The majority of users found the display device -the use of the VR Cave- appropriate for the tasks, with only one user still undecided. Seven users did not feel nauseous and five felt that their eyes were fine after using the application. The objects contained in the application were found to be realistic by seven of the users and eight users considered the displayed information to be simple.

Overall, 77% of the answers regarding this category were positive.

When asked how well they could examine elements within the virtual environment, seven users responded “well” and two with “somewhat”.

7.2.4 User guidance and help

Eight users felt the application was easy to learn, but one disagreed. The same answers were given when asked whether they found the application easy to use. Six out of nine users felt the need for further help when using the application, two did not and one was undecided.

Overall, there were 81% positive reactions for this category.

When asked whether they had felt confused or disoriented when using the application, eight participants responded that they hadn't and only one gave the answer “somewhat”.

7.2.5 Consistency – operation of VR application

In this section the concentration in positive (“agree” and “strongly agree”) options is the greatest. All users found the application responding as they expected and all thought that their actions matched their understanding of the task. Only one participant did not find the information and the use of icons/menus/toolbars, displayed by the application, consistent.

Overall the reactions for this category were 94% positive.

When asked if they found the application clear and simple to use, eight users agreed.

7.2.6 Immersion / presence – feeling like you are a part of the virtual environment

This section also has strong concentration of positive “agree” and “strongly agree” answers.

The same result was recorded for the two statements asking the participants to indicate how immersed they felt in the virtual environment and whether they felt as if they were at the Mazotos site; with six responding positively, 1 negatively and two were undecided. The majority of users found that the quality of the image (7 users) and the field of view (8 users) enhanced their sense of presence, while eight users found it easy to move around in the VR CAVE. Finally five users responded that the application and the VR CAVE gave a good sense of scale, with two users disagreeing and the rest undecided.

Overall 74% answers were positive.

When asked how natural their interaction with the environment seemed, four users found it natural, four users found it somewhat natural and one not very natural.

7.2.7 Overall impressions

All participants felt they can work easily in 3D and all of them enjoyed using the application. Seven participants felt they had a clear idea how to perform a particular function but the other 2 users disagreed. The majority of users (8 positive answers and 1 undecided for each of these questions), were impressed with the interaction felt they achieved what they wanted from the application and found the VR environment simple. When asked whether they would feel comfortable using the application/VR CAVE for long periods of time, six users responded positively and the remaining did not know.

Overall this section scores strong positive answers, 87%.

Finally, as to the system's usability, five users rated it "very satisfactory", another three as "satisfactory" and only one rated it as "unsatisfactory". All nine users think that the application will help the Mazotos research, two of them think "much" and the remaining seven "very much".

7.2.8 Additional comments

The following additional, constructive comments were made:

There was a request to add the function of rotating each amphora separately from the rest of the scene, in order to examine it more closely. Another user felt the big screens were particularly suitable for the study of the site in detail and that a screen above the users would help. The same user mentioned the difficulty in manipulating objects using the Xbox controller and made the suggestion of having the input device fixed somewhere. The labels for the artefacts would be better placed on top of each object.

The comments made by the users in this section, suggest an enthusiasm with regards to their experience and its potential: "Immersing into such an environment could help research, education and presentation (interpretation) of shipwreck archaeology, could bring to the surface more research questions and provide the environment for answering them and can make this physically and "conceptually" non-accessible environment, accessible." The VR environment gives the "feeling of the shipwreck, of the artefacts, the location, the excavation procedure and the finds position in the field".

One participant, a key member of the Mazotos team, came to the conclusion that the VR CAVE is the perfect tool/environment for the dissemination of information to the general public, especially after the excavation. Another participant wrote: "The texture of the objects makes a big difference with respect to the embodiment of the underwater environment. If all amphorae appear in the same colours and with the same texture as this of the photos (not the Rhino file) then the interaction with the site will be more natural and realistic. Most importantly, what you wish to achieve is the synesthetic experience of the site. Do not place unequal emphasis on vision. Add sounds of the sea. Regulate the temperature so that it feels chilly. If possible increase the humidity."

7.3 Observation findings

The general response was very encouraging and enthusiastic with users having no trouble seeing the potential of visualizing the documentation data in a VR CAVE.

They felt this first session provided them with a general overview of its capabilities, but felt they needed time to process their thoughts and experience, to brainstorm and think of how to best to utilize it, and for which research areas it would be more appropriate for.

Initial ideas on how this environment could be used to help the Mazotos project and research were also discussed. Users commented that the application could be used as a first introduction to the Mazotos site, for new divers, new researchers, colleagues and other experts who were not divers. The VR CAVE would also be ideal for presenting the Mazotos site in a museum. It could also be used to help plan a new dive-excavation, so that what needs to be done underwater is better explained and understood. University students could also benefit from its use, to understand how marine archaeologists work, how to perform certain procedures, how to check and use data, as well as for training purposes prior to participating in the excavation of the site. These were their initial assessments; with time and more experience at using the system, it is highly probable that a more in depth understanding of the full potential of the system will become apparent and developed.

The participants commented that the type of investigation provided in the VR CAVE environment, is the closest method to the original underwater experience they have tried so far. It gave them a better sense of scale and spatial relationships and brought the data and the site alive, without the limitation of how much time they could spend investigating it, as it happens underwater. Without this limitation, researchers can also cover more ground, exploring all the site at once or sections of it at a time. However, users expressed the concern that working in the VR CAVE for longer periods of time might be tiring.

One user, interested in checking point clouds said that he/she could use the application now, as it made the process easier, clearer and more time effective seeing the point clouds in such a scale. Also of interest was seeing the 3D site in conjunction to the point clouds and was particularly enthused by being at eye-level with the amphorae.

Another viewpoint that was interesting to certain users was the view from under the assemblage, but artefacts could not be examined easily as there is no ceiling-screen. It was

also noticed that when artefacts were between two screens, there was some distortion to the image, but this could be easily rectified by navigating the scene away from the corners.

7.3.1 Functionality issues

During the formative evaluation sessions, certain functionality issues were noted concerning the interface and environment, the Xbox controller and the hypothetical new data.

The artefact labels caused confusion, as they did not always indicate the correct artefact. Users suggested placing these labels onto each artefact, as is done underwater.

Many users continued to mistake the light-bulb icons (used as part of the menu buttons) for buttons. When the user moved behind the assemblage, the 3D objects appeared darker, as did certain text in the information panel (photograph numbering).

When objects could be manipulated, the system experienced delay/lag in its response, which made interaction difficult. Due to this, one user expressed the need for the position of the input device to be fixed – so that the functions would be performed more easily. In general, users expressed their desire to try out other input devices further to the Xbox controller.

The hypothetical plane for amphora 001 did not highlight when the laser beam hovered over it. When examining hypothetical seabeds the use of transparencies was found problematical. This attribute hindered users from understanding which amphorae were intersected by a hypothetical plane. It was also pointed out that it would be more accurate to mark points on 2 amphorae and then somehow connect them with a projected surface, instead of using ready-made shapes whose form cannot be altered.

The most significant drawback of the application in its current form, is the fact that it is not an accurate tool for researchers. Participants felt that any moving and scaling of 3D elements, within the VR environment, was done by approximation and this way of working will not yield reliable information for them to use or work from.

7.3.2 Ideas for additional functions

The application could be further developed taking into account certain comments users made during their interaction.

Inconsistencies found in photographs made some users feel the need to look at the excavation logs, information that is currently missing from the application.

Users expected all the elements to have the function of being manipulated, even the information panels, so that photographs could be made bigger and could be rotated.

Participants also made interesting suggestions with regards to the already developed functions concerning the two Task-scenarios. The process of examining an artefact more closely would be simplified by having the option of isolating it from the rest of the scene. Some users also felt that mapping the amphorae with just the cleaned-up texture was enough; they would be interested in seeing different texture maps per amphora from different excavation stages (i.e. when undisturbed underwater, lifted with debris still attached, cleaned-up at the museum).

When performing the tasks, many users wanted to know which specific data were used as references for the texture maps and the pre-disturbance seabed, an interesting question which leads to the need for the application to have a way of informing the user of how these visualizations were created.

Other functions mentioned in the evaluation that could be developed in further iterations of the application are: the ability to leave annotations in the environment, to leave marks on amphorae and other artefacts and finding a way to indicate distances in relation to stable point.

Using this application for serious research work also demands the function of saving versions of the environment (original environment altered or added to by the user) for later work and reflection. A way to create a screen capture of an interesting aspect would also be helpful for interpretation and presentation purposes. By creating a screen capture, a researcher can have something in hand to compare against the physical evidence available at the museum or at the site. It can also help in terms of providing visuals for publication purposes.

Three users expressed the need for the application to be connected to a database, allowing users to perform queries and to find artefacts in the VR environment more efficiently.

7.3.3 Issues with documentation data

It is interesting to mention that during their brief interaction with the application, users identified 3 issues concerning the ARU reconstructed scene and documentation data.

During task B, several users (users 3, 8, 1, 6) noticed an inconsistency with the selected photographs relating to amphora 137. The seabed seems to have changed (even though the photographs date to before the excavation and lifting of the artefact), showing one of the amphora's handles more in certain photographs and less in others.

One user commented that the 3D model of amphora 001 was not as accurate as it could be, noticing differences in the way its missing part was positioned. Another user commented that the 3D model for amphora 137 needed to be slightly turned in the 3D scene.

It is unknown to the author whether these observations are indeed new or valid; they will need to be presented to the experts in order for them to be assessed.

7.3.4 New lines of investigation

Whilst still immersed in the VR CAVE, many ideas for possible new lines of investigation were expressed, of which the most thought provocative suggestions are outlined next. One user stated that the marks left on the inside of amphorae (remains of retsina) would be interesting to visualise and further investigate in this environment. Another interesting idea, derived by one user noticing that fixed amphora 377 intersected the unbroken one 259, would be to recreate all amphorae fragments found so far, in order to check whether this happened elsewhere, since this gives the information to the researcher that amphora 377 must have broken prior to landing in the position it was found, or it would have broken 259 too.

The user interested in checking point clouds, also expressed the idea of creating a physics-based simulation with which to visualize sea currents, for instance, or how artefacts fall when underwater.

The idea of creating a timeline of how sand was removed also came up during a session, with the user describing that through such a visualisation the artefacts and site could be slowly revealed in chronological layers.

7.4 Interview findings

7.4.1 Individual interviews findings

Having used the application the 5 participants, that were interviewed individually, found it not just useful but very impressive and creative, even though it took them a little time to get acquainted with the Cave and the Xbox controller. They managed to move around easily, found the application helpful and easy to use and the tasks manageable. Some users weren't as interested in the assessment of the two Hypotheses/research questions, but they could see their relevance for other colleagues of theirs, who dealt with the morphological aspects of the site.

When comparing the VR Cave with other methods, all users made a guess-estimate that alternative methods would be more time consuming. Alternative methods would entail, retrieving photographs from databases, opening them, loading the 3D scene and the point clouds. They concluded that it would definitely take them longer, and they wouldn't be able to see all the data together in one environment, as achieved by the application.

Moreover, investigating the virtual site in the VR Cave is much closer to the feeling of examining the actual site underwater than any other method used presently. It opens new ways of investigation and it helps research.

The application could help them to understand the spatial relationship of the artefacts, and find any mistakes in the documented data, easily. The fact that you can see and experience everything together and on land, facilitates the interpretation and assessing of hypotheses.

All the users felt that there is huge scope for the application to facilitate that part of the Mazotos research, which concerns the presentation and dissemination of information. It was considered far superior to videos and digital presentations and no other method gave them the feeling of being immersed in the research site. The immersion advantage is first and foremost important for the archaeologists who now can have a full reconstruction of the site at various stages of excavation. As one user said: "Excavations are destructive by their nature. The archeologist's work, as it unfolds can only be recorded in a way that remains on bookshelves and in drawers, and hardly anyone will seek it to revisit it no matter how perfect and inspired it had been. The VR CAVE can make it easy and quick for any user to observe/experience every stage of the excavation process, in a short period of time".

The VR CAVE was considered to be a great dissemination tool for the public. Data collected from years of excavation, thousands of dives and enormous work, can now be presented effectively. People visit archaeological sites and obscure artefacts in museums, but they don't realize what they are about, because they see them out of context. Now they can relate to them and engage actively. It is accessible and alive, and thought an ideal method for presentation, particularly useful for museums and education.

The users highlighted the usefulness of this method for training and orientation of new researchers and other associates, who do not dive, or before they dive. They found it a great way to prepare, to have an overview and to understand the site and how to tackle it, and more

importantly to understand what the archaeologist wants to achieve and the objective of each dive.

It was also thought ideal in the case of archeology students and trainees, who have short research assignments of 2 weeks, and are not familiar with underwater research. The VR Cave and the application can help them to understand the shipwreck, the excavation process, and various relevant aspects of the work, and it supports the educational aspects of the research process.

Because researchers are away from the site when they perform the analysis and interpretation, and try to answer questions regarding the site formation process, the five users quickly saw the advantage of using the VR Cave. They agreed that the feeling of immersion creates a frame of mind, writing the thought process of all the research involved; it transmits the research process to the team and to the public at large. They felt that immersion really helps on all levels and that the application in the VR Cave should be developed further.

The users considered this application suitable for visualizing and testing their hypotheses. They also had suggestions for improvements to be incorporated in the application in order to improve the current version of the prototype.

These 5 participants expressed their wish to see further data incorporated in the application such as the environmental information available regarding currents, the sedimentation, the hardness of the seabed, the various layers and levels of excavation and many other elements. They believe that interacting with these newly proposed elements will fuel more questions and hypotheses and that there is a great potential to make the most of all available data and information.

Furthermore, if additional information is incorporated, which is not currently in the possession of the ARU, such as data from biologists, oceanographers and other disciplines, this would lead to new insights regarding the site formation process. Each additional piece of relevant information will increase the interaction, will shed more light and will facilitate the process of data analysis and interpretation. There is data collected by means of coring (depth samples of seabed extracted in vertical tubular form) which might also prove very revealing.

The users considered the application, a useful research tool for the archaeologists and all the other professionals working on the Mazotos project. It was the first introduction and

experience using a VR CAVE, for most of them, and they realized that the more they use it the more they would get out of it, which they would gladly do.

The investigator can do things that cannot be done underwater and cannot be accomplished by looking at the artifacts in museums. Also because of the harsh conditions and short time available during diving, this application could help the investigator recall what they observed, remember the context and the relationships of the site.

On the other hand there are doubts whether clear, accurate answers can be obtained from using the application alone. One concern was that they believe they can only trust physical evidence. They wouldn't base any conclusion exclusively on the system. They would always use the application in correlation with the shipwreck and physical evidence, as a way to ensure better results. The users expressed the concern that using the VR CAVE for long time periods would be tiring but having to travel to Limassol to use the VR CAVE was not really considered an issue.

7.4.2 Group interview findings

The 4 key members of the Mazotos team, took part in this group interview which developed into a very honest discussion that helped to clarify each participant's opinion and understanding of their experience of using the application and the VR CAVE.

They were unanimous in their belief that the developed application is very useful in the process of interpretation and formulation of research questions and that they were able to successfully complete the two tasks-scenarios proving exactly this point.

The loading of amphorae textures was found extremely useful in visualizing and assessing hypotheses regarding the site formation process.

As an educational tool for archaeology students, it can be used even now, in its current form, to acquaint them with the technology used in the project, the documented data, the excavation process and the methodology used.

The VR CAVE was considered a wonderful educational tool and an excellent means of dissemination and outreach. It could be very effective in communicating information to the general public. In terms of research the great advantage that was agreed upon was the scale, as it enabled users to view and examine complex and visually rich data (point clouds) with ease and from new vantage points, even alongside the other documentation deliverables.

It was considered an ideal tool for dissemination; to communicate to people and to transmit the reality of the shipwreck; people who will never dive, people who will dive after the excavation, the archaeologists who are faced with an inaccessible site and one which changes with every excavation period and vanishes irretrievably. With the completion of the excavation and the display of the artifacts in a museum, it will be impossible for anyone to re-live that experience. But if alongside the original amphorae you have this application offering you the possibility to be there, to move around, see the inside of an artifact, it is an ideal showcase for educational purposes, workshops and for the public at large.

One of the four users, expressed the opinion that the use of the VR CAVE opens up a horizon of research questions focusing on the marine archaeologists. The user found it a very interesting tool with which to investigate the interaction between the archeologist and the shipwreck. A psychological test could be developed for the archaeologists: considering their interaction with the 3D model, then with the application, simulating how they would interact on site, record their research questions, what they consider issues of priority and urgency and how they would tackle them. “It is a whole new world of meta-archaeology; investigating not the shipwreck but how the archaeologist observes the shipwreck”. Secondly it is an interesting tool and environment that aids the underwater archaeologist in understanding and interacting with place and spatiality, and can facilitate in the interweaving of tangible and phantasmic plans.

The VR CAVE was also found promising for training purposes. It can constitute a training course for students, team members who have yet to dive, for the divers who will excavate, for new archaeologists. They can be shown things and be instructed and trained in a way that cannot be done to the same extent and depth as using another method.

One of the users explained that by moving the amphorae around in countless experiments, ideas regarding their stowage will in turn give birth to fresh archaeological questions – what about the ropes, how many, where were they fastened, etc. The process of visualizing and investigating a research question quickly and efficiently, generates further questions just as quickly. “There is better understanding and more effectiveness because it is a holistic interactive knowledge”. The notion that the VR CAVE is an environment in which the user can continuously visualize research questions and possible interpretations is shared by another user, stating that: “this method creates ideas continuously, the more you play with it the more creative the process becomes. This is its quality.”

The VR CAVE was considered, a good environment for productive collaboration with other experts from different disciplines as the assessment of research questions requires the insight and knowledge of shipbuilding experts, engineers, and others.

One participant believes that the VR Cave can help in putting together, pieces of evidence which are very fragmented, or very small and which are left unexplored at present. For instance only a small fraction of the hull has been found so far - 40 to 50 cm from each side. With further excavation more pieces of wood may be found and hypothetical scenarios (regarding how they were fastened together, in which direction, etc) could be assessed in a newer version of the application.

As the VR Cave is not available at the ARU offices or closer to the Mazotos site, it cannot be used continuously by the researchers, but probably before and after excavation periods. The researcher would need to come to the VR CAVE prepared, with more recorded evidence from the museum or other information that he/she would want to assess using this technology and application. This limitation,, makes it imperative for this technology to be used in conjunction to the other software used by the ARU researchers.

They agreed that having to go to any other location outside the office can be cumbersome but if they feel the need to use the VR CAVE because it offers them an easy, appropriate and effective way to assess their hypotheses, then the trip would be considered worthwhile.

The users understand that they need to become more familiar with the application, to feel comfortable working in the VR environment, using the input devices and moving around in the VR CAVE. The more they use it the more their skills will increase in geometric progression.

The users agreed that the limited time spent immersed in the VR environment, was not enough for them to draw conclusions from, describing a natural inertia to the new, preferring the methods they are used to. They also felt that the two Hypotheses/research questions used as a basis for the application, could also be investigated through any 3D modeling software on a desktop computer. As users are not well acquainted with this technology they felt it was impossible to know all its potential. Only after using it for the purposes of the evaluation, did users begin to discuss in what way the VR Cave is better and unique and could be beneficial to their research. They agree that they should be insisting on using it and developing it and

training in it, as a way to realize the VR CAVE's potential, in assisting their work and research.

Conclusion and further work

7.5 Conclusion

The work described in this thesis has been concerned with the development of an interactive, immersive application using the VR CAVE, as the method to study whether and how this technology could be useful in visualizing and assessing hypotheses, for marine archaeology. The application's environment was created almost exclusively from the archaeological site's documentation data, in order to ascertain whether this data can be further utilized and in what way by the ARU. Finally, the last research objective was to examine whether the application and the visualization of hypotheses would lead to new lines of investigation for the Mazotos research team.

In order to evaluate this application and gather the necessary information to answer the third research question, Mazotos researchers and marine archaeologists were asked to use the final prototype to perform different types of investigations based on two present hypotheses/research questions regarding the site's formation process. It was observed that during the formative evaluation sessions, the ARU researchers interacted easily with the documented data that made up the virtual environment and were successful in completing the 2 pre-defined task-scenarios. Even though apprehensive at first, all users quickly realized certain unique attributes the VR CAVE has to offer, that could assist in their work, especially in the analysis, interpretation and dissemination areas of their research.

Members of the Mazotos research team have also expressed their wish to continue with the work and application created for the purpose of this thesis and to develop further functionality to aid in the visualisation and assessment of their research questions.

7.6 Future Work

This thesis concludes by providing examples and ideas for further research.

Several very interesting research questions and new lines of investigation regarding the Mazotos archaeological site, were mentioned during the evaluation process; the placing of the retsina marks inside the amphorae, the recreation of artefacts from fragments found, the creation of physics based simulations, to name but a few.

Even though users were very complementary of the application developed for the purpose of this research, the feedback gathered during the formative evaluation sessions, calls for further improvement and new, useful functionality to be added.

The application's credibility depends on the accuracy of its content. It needs to become capable of accurate measurements within explicit margin of error and to allow the correct manipulation of its elements.

Further iterations of the application will need to handle larger amounts of data and the author believes that the possibility of connecting the VR CAVE application to a database needs to be investigated.

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APPENDICES

7.1 Heuristic evaluation report

This report summarizes the feedback from the Heuristic Evaluation conducted at the ICT Lab on the 11th of November 2013, by two HCI experts.

Description of expertise and experience:

Experts in usability, human computer interaction and user experience design

Evaluation Process:

Tasks were performed by the author, while heuristic users identified issues and problems.

The virtual environment was explored thoroughly and task details were inspected in order to identify problems.

Duration of evaluation: 3 hours

1. Technology audit:

Operation of the user's presence:

An imaginary laser beam (triggered by the Xbox controller) is used to represent the user's presence and controls.

Lack of haptic feedback:

The user can go through objects and elements of the virtual environment.

Haptic feedback when selecting an object is indicated by colour change when the beam intersects the object.

Interactive techniques:

Interactivity offered for certain objects (scale and position and orientation using the laser beam).

Realistic graphics:

User can toggle between photorealistic and non-photorealistic visualizations of certain elements in the virtual environment.

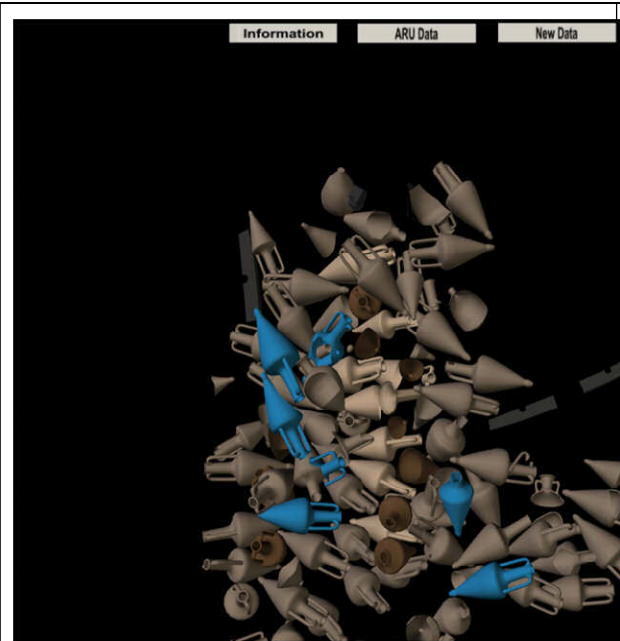
Certain tasks require high fidelity graphics in order for user to inspect details.

2. User test feedback analysis (issues highlighted in yellow indicate which were deemed imperative to be addressed prior to user evaluations)

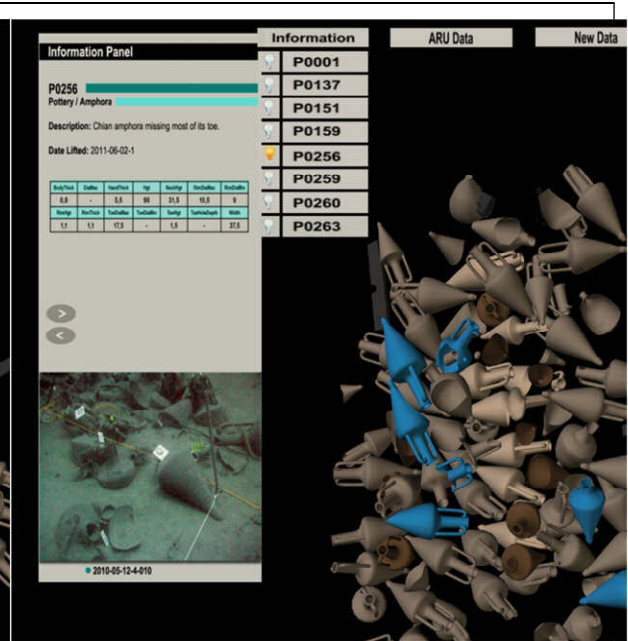
#	Prototype Screen	Name of Heuristic	Reason for negative feedback / breakdown	Scope	Severity (High/Medium/Low)	Way(s) to rectify / Trade-offs
1	See Picture 1	Sense of presence Navigation / orientation support Natural Engagement	No surrounding area depicted (sand and sea). Black background prevents user from understanding in which direction he/she is moving. 3D scene appears to be floating most of the time.	Throughout application	M	Dome and surface (transparent or not) that would indicate floor-seabed. Add more context by adding surrounding area somehow.
2	See Picture 1	Navigation / orientation support Perceptual difficulties	Issue of not knowing where you are or how to get back to another section of the 3d scene easily. Difficult for user to get his/her bearings, orientation, which way he/she is moving	Throughout application	H	Depicting surrounding area might be a solution- would give user landmarks to guide him/her. or Mini map- the 3d scene in miniature somewhere visible all the time tracking users' movement. or the use of a grid

3	See Picture 2	Compatibility with the user's task and domain	User doesn't know how many photos are available in each information panel and which photo he/she is currently viewing.	Information panel	M	Add additional information to information panels: i.e.: 10/24
4	See Picture 3	Compatibility with the user's task and domain	Amphora labels (red and white) Confusing, too much information all at once.	When loading labels	L	Remove white labels if not valuable in this version of the application. Can be added at a later stage, using a new button to activate so that user is not overwhelmed with information.
5	See Picture 4	Perceptual difficulties	A way to indicate different levels of amphorae. Easier for user to understand which are closer to him/her. Depth perception.	Throughout application	L	Perhaps through the use of colour degradation
6	See Picture 5	Support for learning	Some amphorae are coloured (blue, dark brown and cream). No information given to user as to why these are coloured differently to the other amphorae that populate the 3D scene.	Throughout application	L	An introductory screen or key would explain this to user
7	See Picture 6	Support for learning	Some functions require the user to know what he is looking for and where to look for it: i.e. Menu buttons "information" and "load amphora textures". Difficulty for first time user.	Information Amphora textures	H	Selecting an amphora first to activate options for it would have been a more intuitive way to perform this function.

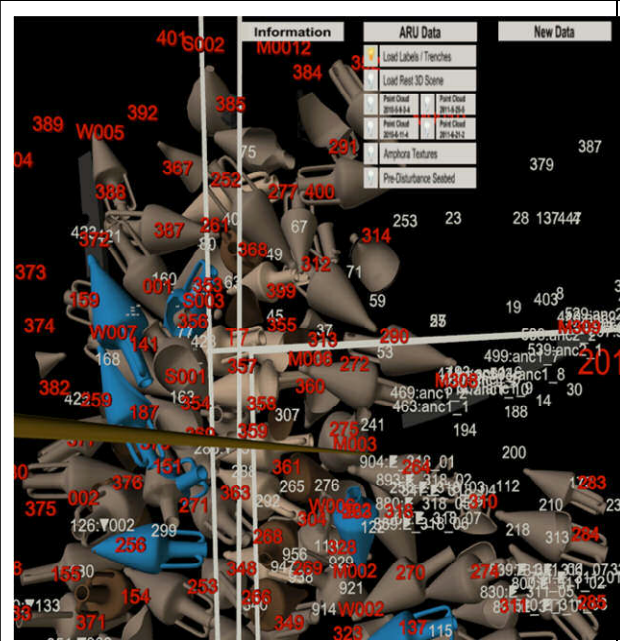
8	See Picture 7	Graphics	Numbers on light blue amphorae (fixed amphorae) were not legible.	Load fixed amphorae	M	Need to be smaller, placed differently
9	See Picture 8	Support for learning	Unclear why some 3d models were transparent and blue. Confusion as to which objects could be moved.	Load hypothetical seabeds load fixed amphorae	M	Using a key to explain certain things.
10		Visibility of system status System feedback	Insufficient system feedback. Help documentation needed. Introducing controls to users.	Throughout application	M	A way for the system to inform the user of his/her actions: moving up, moving down, etc.
11		Realistic feedback	Lag experienced occasionally when moving fixed amphorae	Load fixed amphorae	H	Hardware or script issue.



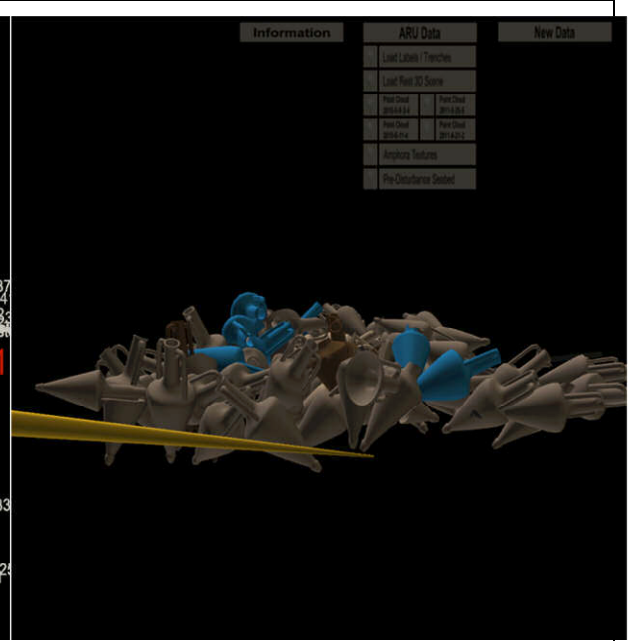
Picture 1



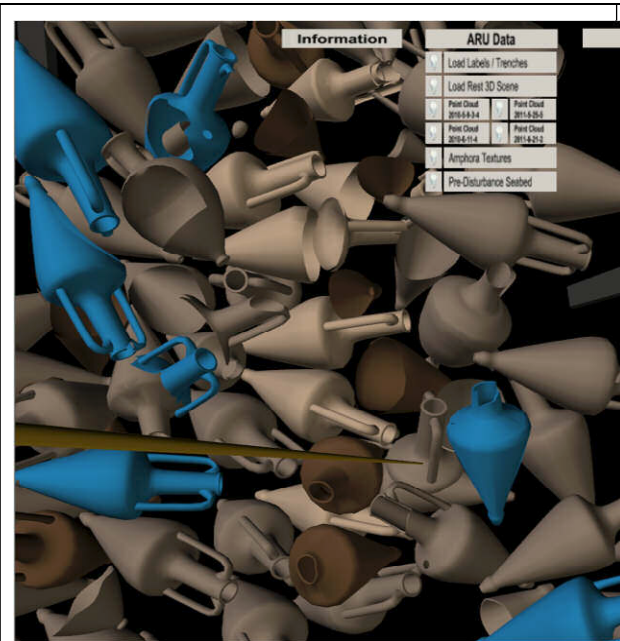
Picture 2



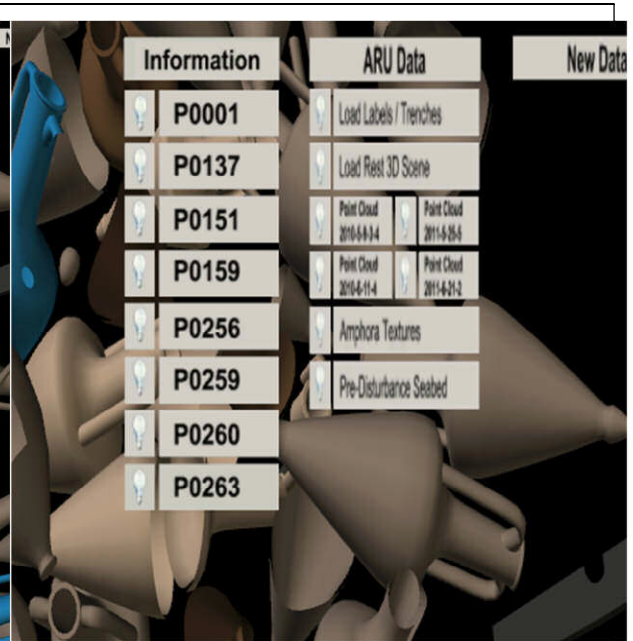
Picture 3



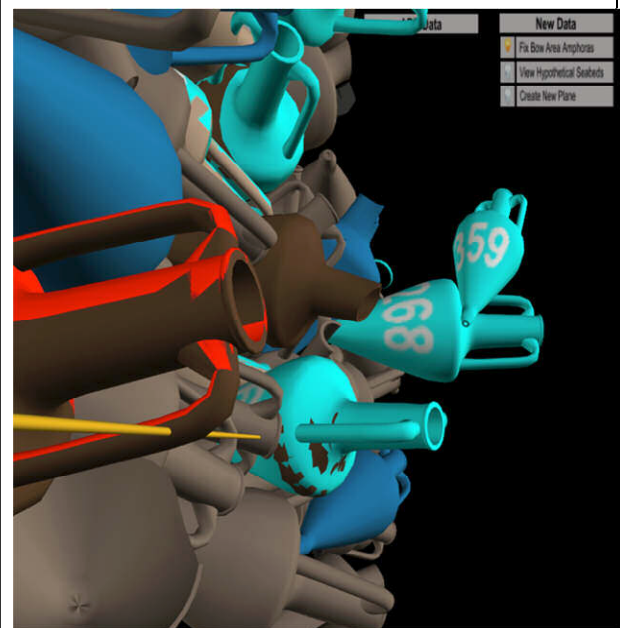
Picture 4



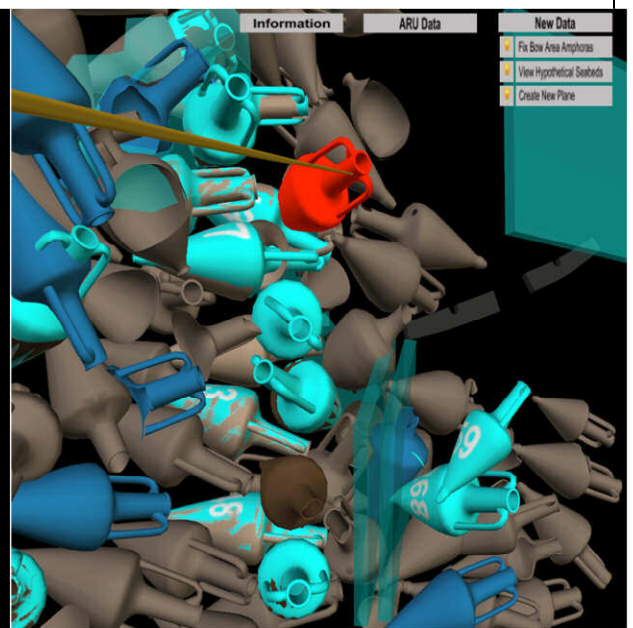
Picture 5



Picture 6



Picture 7



Picture 8

3. General remarks

Could not perform/complete specific tasks intended for actual users.

Unfamiliar with data, terminology and/or their purpose.

How point clouds can be used as part of the tasks for the evaluations, is unclear

Evaluation Tasks need to be made more explicit and clear.

Non-intended user has difficulty to understand how these can be beneficial, how they may be used or compared.

7.2 Consent form

Project Title	Visualizing and Assessing Hypotheses for marine Archaeology in a VR Cave Environment
Why is this research being done?	<p>This is a research project conducted by Irene Katsouri as part of her MA Thesis at the Cyprus University of Technology. The goal of this research is to evaluate the performance, usefulness, suitability and potential of a newly developed VR application. Identifying issues and ways to improve its functionality and efficiency. We are inviting you to participate in this research project because you are familiar with the Mazotos shipwreck and archaeological research and your profile matches that of the applications' intended target user.</p>
What will I be asked to do?	<p>The participants will be directly observed whilst taking on specific tasks. In order to accurately record your interaction we would like to use audio recording.</p> <p>Several topics will be addressed including:</p> <ul style="list-style-type: none"> • How the participants interact with the specific application. • How well the application fares when participants are asked to perform certain tasks. • To investigate ways of utilizing archaeological documentation data. • To investigate the potential of the VR CAVE to assist archaeological research. <p>After the interaction with the prototype, you will be asked to participate in a short interview.</p> <p>The total time for your participation will be around 90 minutes.</p>
What about confidentiality?	<p>All information will be provided anonymously and will be treated in the strictest confidence.</p>

	<p>This research project involves making audio recordings of the participants' interaction with the application, in order to accurately document all information. Audio recordings and information gathered from the interviews will only be used for the purposes of this research.</p> <p>Please check one of the following:</p> <p>_____ I agree to be recorded, during my participation in this study.</p> <p>_____ I do not agree to be recorded, during my participation in this study.</p> <p>By signing this consent form, you acknowledge that we can record and analyse your interaction and use information gathered from it, in publications after they have been made anonymous.</p>
<p>What are the risks of this research?</p>	<p>There are no known risks associated with participating in this research project.</p>
<p>What are the benefits of this research?</p>	<p>This research is not designed to help you personally, but the results may help the investigator evaluate and improve a specific application.</p>
<p>Do I have to be in this research?</p> <p>May I stop participating at any time?</p>	<p>Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, your information will not be used and will be destroyed.</p>
<p>What if I have questions?</p>	<p>This research is being conducted by Irene Katsouri, MA student at the Cyprus University of Technology. If you have any questions about the study itself, please contact me, at: 4 Eratosthenous Street,</p>

	<p>Agios Andreas, 1101 Nicosia, tel. 99223392 or at katsouriirene@gmail.com. If you have any questions about your rights as a research subject or wish to report a research-related injury, please contact: Cyprus University of Technology, tel. 25 002500.</p> <p>This research has been reviewed according to the Cyprus University of Technology review procedures for research involving human subjects.</p>	
Statement of Age of Subject and Consent	<p>Your signature indicates that: you are at least 18 years of age; the research has been explained to you, your questions have been fully answered; and you freely and voluntarily choose to participate in this research project.</p>	
Signature and Date	Signature of Researcher:	Date:
	Signature of Participant:	

7.3 Pre-test Questionnaire

Questionnaire

User number:

Please the boxes or use the lines provided to answer the following questions:

1. Gender:

Male

Female

2. Age:

20 and under

31-40

51-60

21-30

41-50

61 and over

3. Occupation: _____

4. Years of Experience: _____

5. How would you rate your computer skills?

Poor

Weak

Average

Good

Excellent

6. Have you ever used virtual reality before?

No

Yes

6. b. If yes, what type of VR system was it?

7. How long have you been involved in the Mazotos project?

8. Please **the areas of the Mazotos research that you have been and will be involved**
in:

Research design

Acquisition of archaeological data

Analysis of archaeological data

Interpretation of archaeological Data

Dissemination of results

Other: _____

9. Please mention some of the research questions you have had, concerning the Mazotos site, that are difficult to be checked at the moment:

Thank you for completing this questionnaire!

7.4 Post-test questionnaire

Questionnaire after evaluation

User number:

Please circle your response to the following statements and questions:

Question	Response				
	Strongly disagree	Disagree	Not decided	Agree	Strongly agree
Interface functionality (control)					
The level of functionality (control) provided by the system was appropriate for the tasks	1	2	3	4	5
I found it easy to access all the functionality (control) of the system	1	2	3	4	5
I did not need to use all the functions provided	1	2	3	4	5
User input: interacting with and controlling the virtual environment:					
I found the XBox controller easy to use	1	2	3	4	5
I would have preferred an alternative input device	1	2	3	4	5
I kept making mistakes while interacting with the system	1	2	3	4	5
I had the right level of control over what I wanted to do	1	2	3	4	5
It was easy to select and move objects in the virtual environment	1	2	3	4	5
I found it easy to move or reposition myself in the virtual environment	1	2	3	4	5

System output/Information displayed to the user:					
I found the display device (VR CAVE) appropriate for the tasks	1	2	3	4	5
My eyes felt uncomfortable after using the system	1	2	3	4	5
Objects in the virtual environment were very realistic	1	2	3	4	5
Displayed information was too complicated	1	2	3	4	5
I felt nauseous when using the system	1	2	3	4	5
User guidance and help					
I did not need any further help	1	2	3	4	5
I found it difficult to learn how to use the system	1	2	3	4	5
I found the system difficult to use	1	2	3	4	5
Consistency: Operation of VR system according to the user's understanding:					
The VR system behaved in a manner that I expected	1	2	3	4	5
The information presented by the system was consistent	1	2	3	4	5
The sequence of inputs to perform a specific action matched my understanding of the task	1	2	3	4	5
The use of icons, menus and toolbars was consistent	1	2	3	4	5
Immersion/presence: Feeling like you are a part of the virtual environment:					
I felt a sense of being immersed in the virtual environment	1	2	3	4	5
I got a sense of presence (i.e. being at the Mazotos site)	1	2	3	4	5

The quality of the image enhanced my feeling of presence	1	2	3	4	5
I thought that the field of view enhanced my sense of presence	1	2	3	4	5
I had a good sense of scale in the virtual environment	1	2	3	4	5
I found it easy to move around in the VR CAVE	1	2	3	4	5
Overall impressions:					
I could not achieve what I wanted in the VR system	1	2	3	4	5
I was impressed with the way I could interact with the application	1	2	3	4	5
The virtual environment was too complicated	1	2	3	4	5
I would be comfortable using this system for long periods of time	1	2	3	4	5
I did not have a clear idea of how to perform a particular function	1	2	3	4	5
I found it difficult to work in 3D	1	2	3	4	5
I enjoyed using it	1	2	3	4	5
	Not at all	Very little	Some-what	Much	Very much
How successful were you in performing Task A?	1	2	3	4	5
How successful were you in performing Task B?	1	2	3	4	5
Was the application clear and simple to use?	1	2	3	4	5
Did you feel confused or disoriented during your experience with the system?	1	2	3	4	5

Do you think that this system can help the Mazotos research?	1	2	3	4	5
How natural did your interactions with the environment seem?	1	2	3	4	5
How well could you examine elements within the virtual environment?	1	2	3	4	5
How well could you move or manipulate elements within the virtual environment?	1	2	3	4	5
	Very unsatisfactory	Unsatisfactory	Neutral	Satisfactory	Very satisfactory
Overall I would rate the application as:	1	2	3	4	5

Please write any additional comments you may have, regarding your experience in the VR CAVE and using the application, in the space provided below:

Thank you for completing this questionnaire!

7.5 Instructions for formative evaluation

Introduction

Explore the scene; familiarize yourself with the menu buttons and the Xbox controller, until you feel ready to begin the tasks.

Use the HELP icon to learn the Xbox controls and to find out information about the menus and buttons.

Find amphora 002 in the scene and point at it with the Xbox controller beam.

Find 001's height and say it out loud.

TASK-SCENARIO A

Look at the museum photos for 159.

Load amphora textures.

Was the 3D model of 159 textured correctly when compared to the museum photos?

Find 001.

Load hypothetical seabeds.

Check if hypothetical plane was placed correctly, from photos.

Scale up 001's hypothetical plane.

TASK-SCENARIO B

Look at the early photos for 137 and by loading the pre-disturbance seabed decide whether it was placed correctly: i.e. correctly shows which part of 137 was originally buried.

Load fixed amphorae.

Select and move 353 into the white box in the grid.

Change 353's orientation so that it becomes upright.

You may use the application in any way and for as long as you wish.

7.6 Observation form

ΕΝΤΥΠΟ ΠΑΡΑΤΗΡΗΣΗΣ

Ημερομηνία:

Διάρκεια παρατήρησης:

Αριθμός Χρήστη:

ΕΡΓΑΣΙΕΣ	ΔΡΑΣΕΙΣ	ΑΝΤΙΔΡΑΣΕΙΣ	ΠΡΟΒΛΗΜΑΤΑ
ΕΙΣΑΓΩΓΗ	Explore the scene; familiarize yourself with the menu buttons and the Xbox controller, until you feel ready to begin the tasks.		
	Use the HELP icon to learn the Xbox controls and to find out information about the menus and buttons		
	Find amphora P0002 in the scene and point at it with the Xbox controller beam.		
	Find P0001's height and say it out loud.		

ΕΡΓΑΣΙΑ Α	Look at the museum photos for P0159.		
	Load amphora textures		
	Was the 3d model of P0159 textured correctly when compared to the museum photos?		
	Find p0001		
	Load hypothetical seabeds		
	Check if hypothetical plane was placed correctly, from photos		
	Scale up p0001's hypothetical plane and		

ΕΡΓΑΣΙΑ Β	Look at the early photos for P0137 and by loading the pre-disturbance seabed, decide whether it was placed correctly: i.e.: correctly shows which part of p0137 was originally buried.		
	Load fixed amphorae.		
	Select and move p0353 into the yellow box in the grid.		
	Change p0353's orientation so that it becomes upright.		
ΕΛΕΥΘΕΡΗ ΠΕΡΙΗΓΗΣΗ	You may use the application in any way and for as long as you wish.		
ΑΛΛΑ ΣΧΟΛΙΑ			

7.7 Interview Questions

Application Effectiveness Questions

1. Were you able to successfully test a hypothesis, through the use of the application?
 - Thoughts on Task A
 - Thoughts on Task B
- 2.1 How much time, approximately, would it have taken you to perform the equivalent tasks, using other methods?
- 2.2 Can you describe the process of performing the equivalent tasks, using other methods.
3. Was the ARU data used effectively to form a virtual environment that could help in the research/interpretation process?

Application Suitability for ARU Questions

1. Would such an application be useful to your research?
 - Would the process of analysis of archaeological data be facilitated by using the prototype in its current form? How?
 - Would the process of interpretation/forming of hypotheses be facilitated by using the prototype in its current form? How?
 - Would other areas of the Mazotos research be facilitated by using the prototype in its current form? How?
 - Do you think the application would be a suitable tool with which to visualize and assess the hypotheses/interpretations you described in the pre-test?
- 2.2 If yes – what needs to be incorporated / what is the prototype lacking in its current version?
 - If no – why not?
3. Do you think this prototype would be more useful if used alongside other software or other methods? Example? Why?

VR CAVE Suitability for ARU Questions

1. Do you think the VR CAVE could be a useful research tool for the Mazotos project?
2. Do you think this technology can provide users with new perspectives and viewpoints which can lead to novel ways of investigation?
3. What would you say are the benefits and drawbacks of using this technology, with regards to the Mazotos research?

General Closing Question

1. Do you have any other opinions, suggestions, critiques, appraisals that you wish to share?

7.8 Post-test questionnaire results

DATA:

A crude overall rating has been attempted as a percentage per section. It represents the ratio of positive scores to the total number of possible participant answers in the section, i.e. for section 1, 16 agree + 5 strongly agree = 21, 9 participant x 3 questions = 27, $21 / 27 = 75\%$.

Questions:	How users responded					
	Strongly disagree	Disagree	Not decided	Agree	Strongly agree	No answer
Interface functionality (control) 21/27=75%						
1. The level of functionality(control) provided by the system was appropriate for the tasks			1	5	2	1
2. I found it easy to access all the functionality (control) of the system				8	1	
3. I needed to use all the functions provided	1		2	3	2	1
User input: interacting with and controlling the virtual environment: 29/54=53%						
4. I found the Xbox controller easy to use			2	6	1	
5. I would have preferred an alternative input device		1	3	5		
6. I didn't make mistakes while interacting with the system	1	1	3	4		
7. I had the right level of control over what I wanted to do		2	3	4		
8. It was easy to select and move objects in the virtual environment		4	1	3	1	

9. I found it easy to move or reposition myself in the virtual environment		2	2	4	1	
System output/Information displayed to the user: 35/45=77%						
10. I found the display device (VR CAVE) appropriate for the tasks			1	5	3	
11. My eyes felt fine after using the system (reversed)	2	1	1	3	2	
12. Objects in the virtual environment were very realistic			2	5	2	
13. Displayed information was simple (reversed)		1		4	4	
14. I didn't feel nauseous when using the system (reversed)			2	1	6	
User guidance and help 22/27=81%						
15. I needed further help (reversed)		2	1	5	1	
16. I found it easy to learn how to use the system (reversed)		1		6	2	
17. I found the system easy to use (reversed)		1		5	3	
Consistency: Operation of VR system according to the user's understanding: 34/36=94%						
18. The VR system behaved in a manner that I expected				5	4	
19. The information presented by the system was consistent		1		6	2	
20. The sequence of inputs to perform a specific action matched my understanding of the task				9		
21. The use of icons, menus and toolbars was consistent	1			6	2	
Immersion/presence: Feeling like you are a part of the virtual environment: 40/54=74%						

22. I felt a sense of being immersed in the virtual environment		1	2	4	2	
23. I got a sense of presence (i.e. being at the Mazotos site)	1		2	5	1	
24. The quality of the image enhanced my feeling of presence		1	1	6	1	
25. I thought that the field of view enhanced my sense of presence			1	7	1	
26. I had a good sense of scale in the virtual environment	1	1	2	4	1	
27. I found it easy to move around in the VR CAVE			1	6	2	
Overall impressions: 55/63=87%						
28. I achieved what I wanted in the VR system (reversed)			1	6	2	
29. I was impressed with the way I could interact with the application			1	5	3	
30. The virtual environment was simple (reversed)			1	7	1	
31. I would be comfortable using this system for long periods of time			3	3	3	
32. I had a clear idea of how to perform a particular function (reversed)	2			6	1	
33. I found it easy to work in 3D (reversed)				6	3	
34. I enjoyed using it				1	8	
	Not at all	Very little	Some- what	Much	Very much	No answer
35. How successful were you in performing Task A?				5	3	1
36. How successful were you in performing Task B?				5	3	1

37. Was the application clear and simple to use?			1	2	6	
38. Did you feel confused or disoriented during your experience with the system?]	4	4	1			
39. Do you think that this system can help the Mazotos research?				2	7	
40. How natural did your interactions with the environment seem?		1	4	3	1	
41. How well could you examine elements within the virtual environment?			2	7		
42. How well could you move or manipulate elements within the virtual environment?		2	1	6		
	Very unsatisfactory	Unsatisfactory	Neutral	Satisfactory	Very satisfactory	No Answer
43. Overall I would rate the system usability as:		1		3	5	

Please write any additional comments you may have, regarding your experience in the VR CAVE and using the application, in the space provided below:

2: delay in manipulation of 3d elements

3: I would like to be able to rotate each amphora without rotating the whole scene

4: a. the Xbox would operate better if it was fixed somewhere, b. a screen above the users would help, c. the numbers should somehow be integrated in the amphora models, d. the big screens give a particular purpose for studying the site in detail, e. this is the perfect tool/environment for the dissemination of information to the general public, especially after the excavation.

6: the texture of the objects makes a big difference with respect to the embodiment of the underwater environment. If all amphorae appear in the same colours and with the same texture as this of the photos (not the rhino file) then the interaction with the site will be more natural and realistic. Most importantly, what you wish to achieve is the synesthetic experience of the site. Do not place unequal emphasis on vision. Add sounds of the sea. Regulate the temperature so that it feels chilly. If possible increase the humidity.

7: my experience in the VR cave was better than expected. Immersing into such an environment could help research, education and presentation (interpretation) of shipwreck archaeology, could bring to the surface more research questions and provide the environment for answering them and can make this physically and “conceptually” non-accessible environment, accessible. Great work!

8: it was very interesting experience. You could the ‘feeling’ of the shipwreck, the amphorae, their location, the excavation procedure, the finds, their position of the field, etc.