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Chronology and Geospace Design in Virtual Reality for Archaeological Data Exhibition

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Abstract

The digital information that is collected during an archaeological investigation concerns all of its phases: the recording of the excavation process, the archaeological and the archaeometric analyses of the stratigraphic units and the findings, the interpretation of the results and their dissemination. All the digital materials can be displayed for a wide audience in a museum context as well as support further investigations by the researchers. This is especially applicable for 3D surveys of excavations (trenches and site surroundings) and the findings, which require some suitable applications for their display. Though there exist many digital archaeological projects and archaeological data abound in repositories, each display is a unique endeavor.

This paper describes the VR system developed for the BeArchaeo project. It specifically addresses the design metaphor, based on chronology and geospace, two major dimensions in archaeology. The novelty of the system is its ability to exploit such dimensions in order to support ongoing archaeological projects, providing access to both researchers and the general public. The goal of the digitally born BeArchaeo project is a thorough archaeological and archaeometric investigation of the Kofun period in Japan, also including materials related to adjacent chronological periods. The VR system described here, called BeA-ViR, is a virtual exhibition of the ongoing project findings, deployed for both a screen-gamepad installation as well as a CAVE platform, with abstract and physical structures that concur to provide access to heterogenous materials. It also includes the realization of a central informative infrastructure that relies on a semantic database for the metadata description.

Keywords: archaeology, virtual reality systems, design for humanities, museum installation

1 Introduction

Archaeological projects produce digital information in all their phases: data are collected, curated and recorded (see, e.g., [1]) for subsequent analysis and visualization (see, e.g., [2]) until the exhibition of the results to the general public (see, e.g., [3]).

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In recent years, data from imaging processes, in particular, are becoming widely acknowledged in the archaeological domain. On the one hand, not only do photogrammetry and laser scanning support the recording of archaeological sites before, during, and after the destructive processes of the excavation (see, e.g., [4],[5]), but they also allow the digitization of the artifacts thereby unearthed; such digital data of artifacts assists not only in morphological research, but also can be used for conservation and restoration purposes [6]. On the other hand, the 3D models can be customized for visualization in VR systems, for dissemination purposes (aided especially by the recent spread of VR headsets in the consumer market) and for research communication between archaeologists through some immersive visualization of the archaeological data [7].

The data from 3D survey can serve several purposes. Surveying a historical building or open-air archaeological site is the first step in the knowledge investigation for planning "a proper project of conservation, consolidation or reuse" [8, p. 329], thereby supporting "the coherent, coordinated and planned activity of study, prevention, maintenance and restoration" (2004 Code of Cultural Heritage and Landscape of Italy, Article 29 on the conservation of cultural heritage). However, the visualization of the survey depends on the system design for that purpose and the search for the most effective metaphors is a key ingredient of the system implementation. Also, archaeological projects can last for a long time, accumulating digital data and metadata, which will eventually receive some interpretation. In the meantime, while excavation activities and the laboratory analyses are ongoing, the database is updated and exhibitions are usefully organized to engage the human communities, who are the depository of the values that motivate the conservation of the archaeological site [9].

Archaeology investigates the past through the analysis of findings and their unearthed context. The goal is to position the findings within a specific time frame and define their geographic extent through their consistent appearance within a specific area. Although some researchers object that a formally defined time-space relation is lacking in archaeological studies [10], time and space are the basic dimensions of archaeology. Archaeology has long been used as a tool to date or simply form chronological schemes, rather than to purposefully reconstruct past society. In fact, apart from the simple dating of objects, time as a concept appeared relatively late in archaeology; space is the fundamental concept that supports research before the fieldwork starts [11, chapter 6]. The sampling of space into meaningful regions, by interpreting the geographic distribution of unearthed artifacts and the intimate bond with certain time periods, against the backdrop of various human activities, with all their repetition and continuity, forms the basis for the analyses of the major variables that affect change and stasis, conceptions of the identity of the concerned individuals and the determination of where power has concentrated in the past.

Therefore, time and space, the latter implemented in the geographic dimension provided by the GIS coordinates of 3D surveys, can be the major keys for the design of the VR system. However, for the VR system, a number of decisions about content and interface crucially depend on the actual exhibition device, ranging from portable Head-Mounted Displays (HMDs) to site-specific CAVEs. There are many dimensions, provided by cable-based or wireless systems, with output devices ranging from audio/visual to haptic devices, and input devices that include controllers, navigation and tracking technologies and body scanners [12]. The virtual reality environment, relying on the possibilities of augmenting the surveyed sites and findings with computer generated imagery (CGI), allows the visualization of abstractions and the realization of movements that would be impossible in a physical exhibition. These features are especially useful in the case of ongoing archaeological projects, where an updatable virtual environment can be connected in real-time to the database of the recorded information [13] to inform the communities and keep alive the digital materials, which are often endangered or inaccessible [14]. The virtual environment must merge the conventions for the exhibition of the archaeological site (reconstruction of known parts, hypotheses to be reported and artist inventions to be marked) with the conventions of the museums for the exhibition of artifacts, with information extracted from the database and exhibited together with items from related sites. Both conventions assume an interactive narrative approach for organizing materials and engage public in the exploration of archaeological matters.

'Beyond Archaeology' (BeArchaeo) is a methodological project that implements a digital approach, from the excavation plan through the interpretation of the findings and finally to the exhibition of the results[1]. In particular, the BeArchaeo database hosts all the information surrounding the excavation and analytical activities carried out at Tobiotsuka Kofun, a late 6th-century mounded tomb located in Soja City, Okayama Prefecture, Japan. Drawing upon data from this tomb and other mounded tombs (*kofun*), in addition to related archaeological material from the ancient Kibi and Izumo regions of Japan, researchers aim to develop a transdisciplinary vision for research into this archaeological site and other archaeological materials now stored in museums and laboratories. The photogrammetric surveys have produced a comprehensive 3D model of Tobiotsuka Kofun and of the findings unearthed there as well as from other related sites (see below).

Starting from the photogrammetric data, we have developed a virtual interactive model that can serve as a point of access to the database as well as inform the human community, consisting of the cultural-property team in Japan and the scientific methodological team in Italy. It has been deployed for a screen-gamepad museum, after a prototype installation for a CAVE system [15]. This paper illustrates the realization of the interactive virtual environment of the BeArchaeo project, based on a narrative metaphor and realized into a multi-platform system prototype, named BeA-ViR. The virtual environment introduces the archaeological sites addressed in the project, together with the most representative findings encountered during the excavation at Tobiotsuka and others stored in nearby museums, to represent the reference culture of the structure; finally, the progress in the excavation process and the trenches excavated by the different teams are displayed to compare the different disciplinary approaches to the archaeological investigation.

2 Related Work

The BeArchaeo project spans a number of tasks that are common to archaeological practice, which cross scientific communities for a transdisciplinary endeavor: archaeological reporting, 3D models in support of documentation, databases for archaeological data and metadata, and GIS mapping of archaeological entities. Here we address several of these areas, with a particular focus on the design of the systems that join scientific investigation and public exhibition.

2.1 Archaeological reporting

Modern archaeological reporting in the digital era is carried out through the web: in many projects, reports on the phases of excavation and subsequent publication of results are di-

[1]BeArchaeo website `https://www.bearchaeo.com/` (visited on 15 January 2024).

rectly inserted into a database (back end) and published (front end) through a website. Websites therefore become the major points of access for data collected on site and excavation data are then enriched with interpretations, increasing their visibility, and providing new opportunities for experimenting with new forms of publication (see, e.g., [16] on the interpretation of the necropolis of Saqqara).

With reference to 3D models, there have been some proposals for the integration of 3D content with solutions for their visualization into the overall archaeological reporting process. For example, the Interactive Reporting System (IRS) is a web-based tool that relies on 3D web information for the generation of digital interactive reports on excavations [17]. In particular, IRS proposes an interactive version of the archaeological report, connecting the textual paragraphs with the 3D spatial visualization of the site, which displays a narrative interpretation of the data. This dynamic, web-based solution supports dissemination and the active exchange of information between the diverse scientists who consult the report.

Particularly deserving of attention is the pioneering Çatalhöyük project of a Neolithic settlement in Turkey, carried out with the goal of maintaining the data as long as possible. The Çatalhöyük Database and the Çatalhöyük Image Collection Database[2] make the documentation of the Çatalhöyük excavation site available. Custom platforms allow for the searching of data uploaded during every excavation season, made available through the Çatalhöyük Living Archive, which conveys about two decades worth of excavations and analyses. The Last House of the Hill is another endeavor at the forefront of best practices, within the Berkeley Archaeologists at Çatalhöyük (BACH) project, for the management and online publication of archaeological content aimed at the harmonization and availability of the final report as a comprehensive digital resource [18].

On the more traditional 3D side is the pioneering Giza Archive Project[3], which publishes online both traditional archival documentation and immersive 3D environments. In fact, it has become the foremost reference repository for accessing archaeological data about Giza.

2.2 IT infrastructures of archaeological data

Archaeology is a discipline that has always been intrinsically linked to the data collected during the excavation activities and to their cataloging, management and interpretation [19]. This aspect is due to the nature of the archaeological excavation which is configured as a destructive experience [20] (therefore unrepeatable, making the collected data the only reference to the original status), distant (as the excavation activities tend to take place far from the research laboratories and information can only be managed at a later time) and limited (as only some members of the research team have access to the excavation area). This relationship of interdependence between data and archaeological research was significantly revolutionized around the turn of the millennium with the wide introduction of surface survey instruments (photogrammetry and laser scanning), underground survey (resistive georadars and dynamics), topographic mapping (kinetic and static GIS) and various types of archaeometric analyses. With the cyber-infrastructure of the past two decades, the dynamics are further enriched with the introduction of more user-friendly approaches. To date, many proposals have been made in terms of workflows and script optimization, software version control for data management and in general a push towards open and collaborative

[2] `http://www.catalhoyuk.com/research/database`, visited on 15 January 2024.

[3] `http://giza.fas.harvard.edu/about/`, visited on 15 January 2024

research in the field of archaeological research [21]. Today an urgency is felt for the definition of “quality” data, because the information collected is sent to computational pipelines that feed the pool of big data that represent the basis of future interpretation [22]. Furthermore, the new potentials of existing technologies allow the acquisition of information in real time [23], thus giving greater prominence to transparency phenomena [24]. More importantly, as the intermediate role of the human operator is reduced, one can avoid both error propagation and operational delays [25].

2.3 The use of GIS in archaeology

The official introduction of GIS (Geographical Information System) to scientific studies was during the 1980s, after a decade of experiments related to the application of statistical cartographic data in computer systems [26]. However, it was necessary to wait until the 1990s to witness a real explosion of this technology in Europe, especially in the field of Cultural Resource Management (CRM). Even more importantly, given the availability of portable computers and modern automated topographic instruments (total stations, GNSS receivers, laser scanners, etc.), an increase was observed in the capacity to acquire and georeference data from the excavation area [27]. While considering the natural thematic relationship between archaeology and GIS, one should not mistakenly think that this relationship has always been ideal. Even in 1996, with the increasing diffusion of this technique in the archaeological field, Barceló published a paper titled “A critique of GIS in archaeology. From visual seduction to spatial analysis” [28]. Although many of the criticisms made at the time may have been subsequently overcome by technological advancement (satellite acquisitions, interface, and data entry tools), some methodological issues are still to be kept in mind. Archaeological investigation can greatly benefit from the analysis of the relationships of positioning, contiguity and proximity between the various archaeological components. In fact, since the 1970s, well before the introduction of automated and digital tools, maps with the distribution of archaeological elements had become fundamental tools of archaeological research; it must not be forgotten, however, as expressed by Barcelo, that the human eye-brain system is not a very precise tool for evaluating the strengths of relationships, and that the study of a partial map (since it is the result of an interpretative projection too) can lead to partial or even erroneous analyses. Nowadays, GIS represents the basis of archaeological instrumentation and in some cases is central to archaeological research, to the extent that an exhaustive data collection and verification can be carried out from basic information and can represent a tool for driving new interpretations. This has proven to be true in those archaeological areas where the dynamics of displacement and interaction between different peoples over a long period of time represent the heart of the research: the analysis of the spatial relationship between ancient inhabited centers and the surrounding environment, the relationship between ancient cities and the natural environment by combining spatial information, the analysis of cultural distribution based on representative technological findings, etc., all by integrating information from satellite images, studies of on-site orogenesis and literary sources [29].

2.4 The use of VR systems

Virtual reality is not new to archaeology. Because of the concrete problem of the remoteness of the archaeological sites and the limited use of the findings, the work of archaeologists has always been focused on the collection of photographs and the creation of maps and detailed drawings to restore the archaeological experience even at a distance [13]. Virtual reality makes possible the digital acquisition of an artifact or structure, allowing the recreation of faithful copies that reconstruct the experience of being in their presence. This acquisition represents a fundamental branch of archaeology, and the entire lifecycle of acquisition, processing, data analysis, archiving, and dissemination has become integrated [30].

Christou et al. [3] have developed a large-scale virtual reality simulation suitable for the reconstruction of a Greek temple in Messene. Photographs and ground plans were used as the basis for an artistic reconstruction for the purpose of exhibition. The goal of the VR project carried out by Toubekis et al. has been the reconstruction of the destroyed 38m Eastern Buddha figure of the Giant Buddhas in Bamiyan, Afghanistan (destroyed in 2001), integrated into the model of the scanned niche [31]. The virtual model incorporates the results of several scientific explorations, including a photographic survey, featuring all seasons, of all cave structures around the vicinity of the Giant Buddhas, carried out by Japanese missions in the 1960s and 1970s, using the stereographic and photogrammetric techniques of the time. The documentation work and the virtual reconstruction have been embedded into the long term management plan. The approach in [7] is geared to help archaeologists and stakeholders in the exploration and analysis of the archaeological data in an immersive context. The VR reconstruction of the Pleito Cave, a fragile world-class rock- art site with limited accessibility, relies on the archaeological data captured via a number of techniques (mainly X-Ray Fluorescence – XRF), where multiple remote users can interact for collaborative interpretation and analysis. The system has also been employed in an exhibition aimed at Native American stakeholders.

Virtual reality has also been employed for archaeological investigation in Japan. Masuda et al. tested the hypothesis of archaeologists concerning whether torches were likely to have been used in Fugoppe cave, where numerous fascinating engravings can be seen from the prehistoric period [32]. They have designed and implemented a VR tool for the simulation of natural light on the interior walls in order to determine whether the ancient painters could have worked under natural illumination. The research proved that this was possible if the artists had chosen the optimum season and time for their artistic activities. Another recent Japanese project has implemented a 360^o video for the Taya cave, which was hand–carved by Buddhist monks between the 12th and 18th centuries[4].

Every VR project is characterized by a unique approach to the visualization and exploration of the digital data. In this paper, we advance on the current approaches by proposing a system, for ongoing projects, that joins the archaeological investigation and the exhibition to the public audience. The VR system must serve to both support the researchers in their development of interpretations, which are still partial, and inform the community in an engaging way, albeit through the use of yet partial information.

3 The BeA-ViR System

This section outlines the general design phase of the BeA-ViR system (see the workflow in Figure 1), with an analysis of the BeArchaeo project requirements, especially geared to produce a museum installation in the short term, the design of the layouts for the exhibition and the narrative structure of the VR application.

[4] https://www.ricoh.com/about/empowering-digital-workplaces/articles/explore-an-ancient-japanese-artificial-cavern-in-360, visited on 15 January 2024.

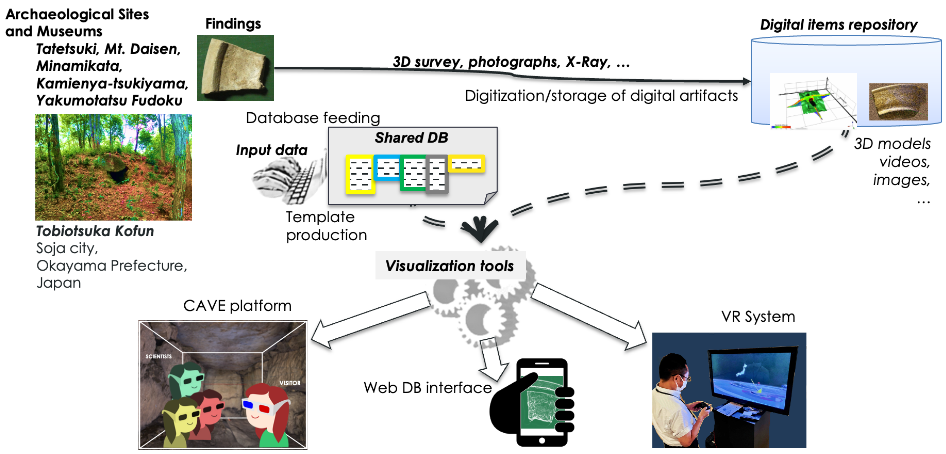


Figure 1: Overview of the BeArchaeo project software architecture.

3.1 The analysis of the installation requirements

The BeArchaeo project addresses the excavation activities at Tobiotsuka Kofun and archaeological/archaeometric analyses of the findings from Tobiotsuka Kofun as well as from other sites in the same area (Okayama Prefecture) and nearby prefectures (Shimane and Tottori) provided by museums.

Since one aim of the project was to establish artifact provenance through a comparison of features across several sites, the dimension of geospace was very relevant for the design of the VR application. Therefore, the geographical locations of the sites and findings should be evident from the exploration of the VR simulation.

Also, given the international character of the project and the fact that the installation will be displayed both in Japan and in Europe, the system must refer to both a general map of Japan and a local focus on the areas of Shimane and Okayama Prefectures. In our specific project, it has been necessary to represent the areas of Izumo and Kibi and the specific sites of Minamikata, Tobiotsuka, and Tatetsuki.

Each area should be provided with some introductory information, touching upon its historical importance. Then, representative elements of each area from each period should be selected. These elements can be photogrammetric surveys of entire areas or the progress of excavations, scanned findings (both human-made objects and animal/botanical remains), or 3D reconstructions of sites. In particular, from the general Izumo area, we display the following 3D models, reconstructed from photogrammetric surveys:

- the photogrametrically surveyed Kamienya-Tsukiyama Kofun;
- a *haniwa* (earthenware figure, Kofun period) displayed at the Yakumotatsu Fudoki Archaeological Museum; and
- a Jizō-Bosatsu carved from a single rock, encountered on Mount Daisen.

The Minamikata and Tatetsuki sites present a number of relevant findings. In particular, the Minamikata site, located today in the heart of the urban center of Okayama, is representative of the Yayoi culture in the Okayama area, and the various unearthed zooarchaeological findings demonstrate the creative use that local populations made of malacological and osteological resources. The exhibits shown are stored at the Okayama City Archaeological

Museum. The virtual reality system enables a highly effective exhibition of the artifacts, which would otherwise be stored in the museum warehouses.

Finally, for Tobiotsuka Kofun, we display the following 3D models:

- the current status of the tomb's earthen mound;
- the excavation trenches;

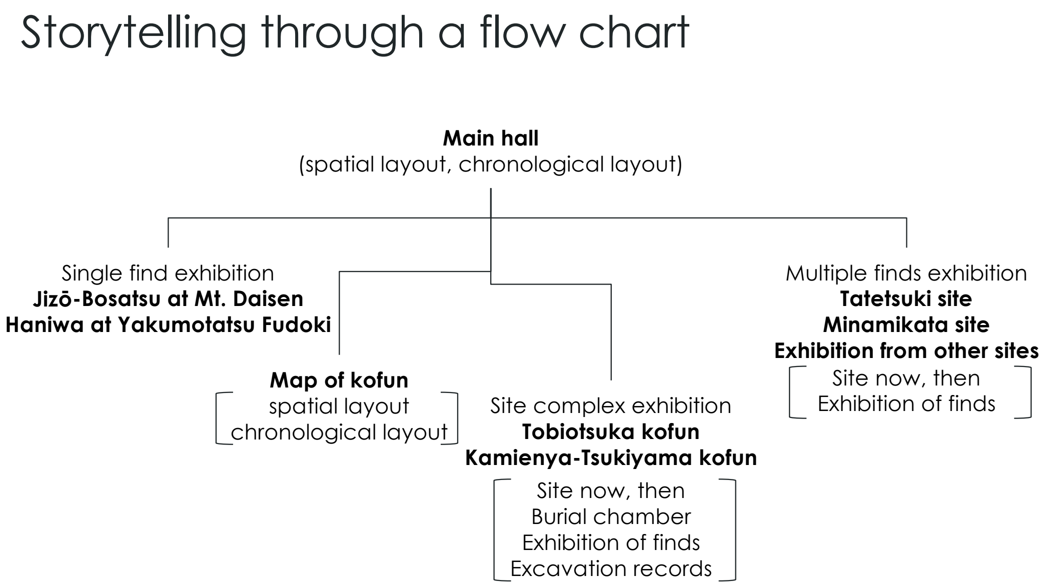


Figure 2: Flow chart of the BeA-ViR system. Accessible VR environments are in boldface.

Figure 2 displays the flowchart of the application, which follows the geographic distribution outlined by the requirements. Each node of the chart includes the features that the application implements. The main hall is the access to the global environment, which has to be arranged in a spatial and a chronological layout, respectively. The other nodes are classified according to the requirements above: there are virtual rooms for

- single-find exhibitions displaying outstanding pieces, namely the Jizō-Bosatsu from Mount Daisen and the *haniwa* from the Yakumotatsu Fudoki Archaeological Museum;
- multiple-find exhibitions assembled according to provenance, such as the Minamikata and the Tatetsuki findings, or some chronology, such as the miscellaneous collections named "other sites". In the case of the single-site collections, the site itself is displayed, with the current aspect (termed "now") and the archaeological structure ("then");
- site-complex exhibition with visualizations of the site ("now" and "then"), specific spaces (e.g., the burial chamber), an exhibition of the unearthed findings and the excavation records. In the BeArchaeo project, all these features are displayed for the newly explored Tobiotsuka Kofun, while the Kamienya-Tsukiyama Kofun only displays the burial chamber; and

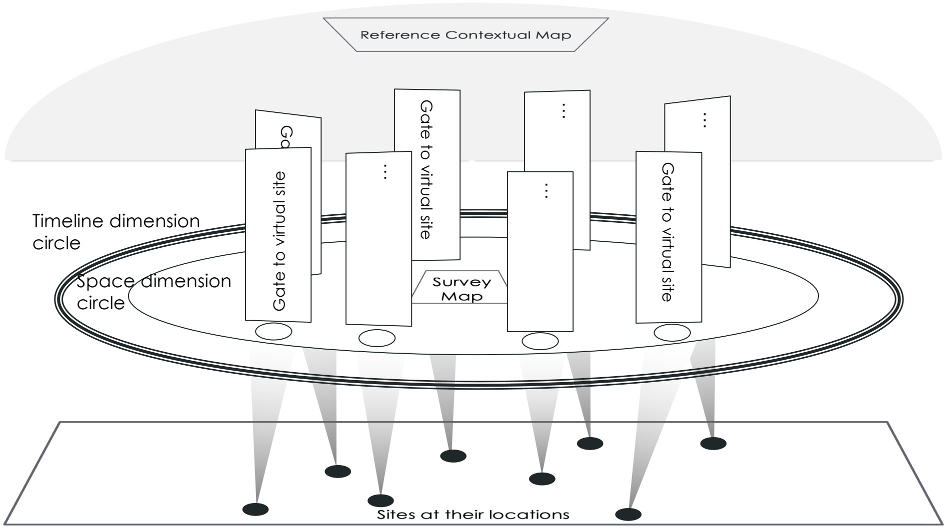


Figure 3: The design of the main virtual hall.

- the map of *kofun* is a display of the spatial layout of the surveyed *kofun* in the areas of Japan under consideration.

Given the arrangement of topics outlined in the flow chart, we need to design a suitable VR environment with an engaging narrative structure. The user must be encouraged to explore the environment and know more about the sites and the findings. Also, we must convey the values that characterize the cultural heritage items displayed here.

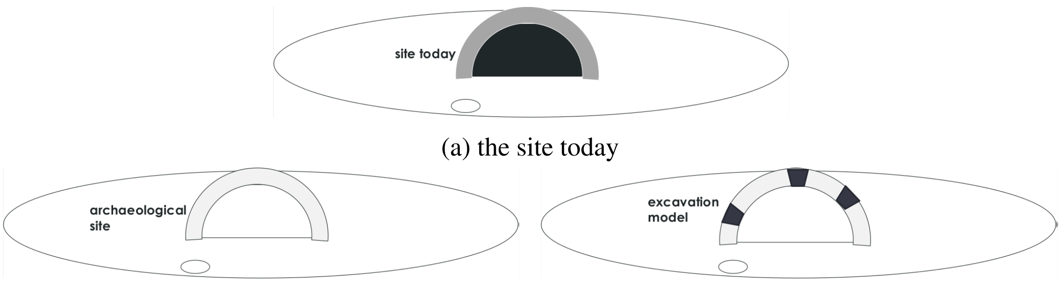
3.2 The design of the virtual space

The design of the virtual space, with the related narrative structure, is a challenging endeavor for a VR environment: on the one hand, the application must be engaging for the users, i.e., it must arouse some interest in the user to explore the environment; on the other hand, the application must limit the prevalence of the technological gadget on the informational content, i.e., it must communicate the relevant information as well as transfer the heritage values of the items displayed.

Figures 3-4 illustrate the layouts of the flow chart nodes. The layouts address the needs of the researchers to develop and share suitable interpretations about the site and of the general public to be informed about the ongoing archaeological investigation. As highlighted above, there are four types of nodes, if we exclude the map of *kofun*, which will be represented as an explorable cartography of the *kofun* locations in the considered areas of Japan. The layout templates, which are instantiated onto the unique items of the VR environment, are the main hall, the single-find exhibition, the multiple-find exhibition and the site-complex exhibition. While the site-complex exhibition is a tool for presenting the structure of the site, possibly with interventions that reveal the reconstructed structure in the past, the other three layouts resort to the metaphor of the virtual museum, which has existed since the early 1990s mostly to provide visitors with the presentation of 3D models of collection artifacts [33] [34].

The main hall layout template (Figure 3) is designed to introduce the whole environment in an engaging explorative interaction. The space is split into two settings. The first is an augmented reality setting, at the bottom and top, representing the land of Japan and the sky vault respectively. At the bottom, the land of Japan includes a highlighting of prefectures in which our sites are located; at the top, the sky vault includes some referential points, namely the sun and the moon, with a contextual map of Japan, which reproduces the bottom representation (i.e., with the concerned prefectures highlighted). This map is constrained to be in front of the user position; therefore, it is always visible. The goal of such a constraint is to provide a continuous context to the exploration. The intuitive message is: “You are exploring a part of Japan”, even if we are in a totally virtual setting. The virtual setting is a suspended plan, which contains all the virtual gates to the individual sites and exhibitions. The suspended plan is a platform consisting of two concentric circles. The inner circle implements the spatial dimension: all the gates, oriented frontally to the user, are projected from the real locations of the sites and lead to the related virtual environments. The small ovals on the platform are the footboards to jump upon to access the environment through the gate. This environment conveys general information to the user: about the VR project contents (sites, findings, chronological context, etc.) and directions for exploring the environment.

Then, we have three layout templates, corresponding to the single-find exhibition, the multiple-find exhibition and the site-complex exhibition, respectively. All of the layouts must provide some interactive element to return to the main hall (e.g., a home button).



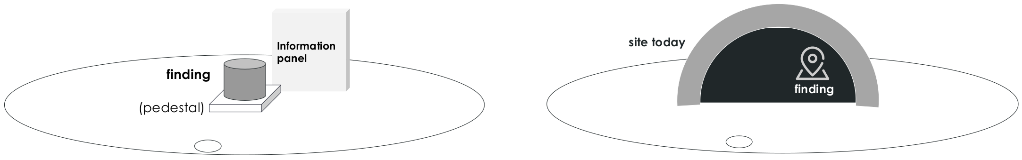
(a) the site today

(b) the archaelogical site

(c) the excavation model

Figure 4: The site design, consisting of a representation of the site today, the visual interpretation of the archaeological site and a model of the excavations at the site.

The site layout template (Figure 4) concerns the exhibition of a site. This layout is also exploited in the other layouts. The user can access three visual modes for a site: the site as it appears today, a visual interpretation of the archaeological site and a model of the excavation records. In particular, the second is an artistic visualization of the interpretations provided by the archaeologists about the structure of the site and its spaces, and the third is a visualization of the structures that have been revealed through the excavation process, e.g., the trenches, the burial chamber and other possible surveys or investigations carried out on the site.

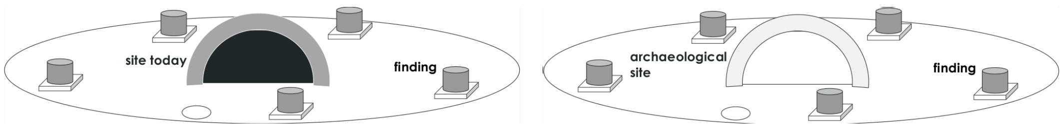


(a) single-find exhibition

(b) site where the find was encountered, with pin for position

Figure 5: Design of single-find exhibition alternated with site where it was encountered or unearthed.

The single-find exhibition layout template (Figure 5) concerns the exhibition of a single object. This layout alternates between the display of the finding and the display of the site where it was encountered/unearthed, with a pin in the known position where the object was found. The finding, depending on the size, is posited on a pedestal, and the visitor can rotate the object. An information panel is automatically displayed when the user is near the object. This interaction format is repeated throughout all the layouts. An active footboard allows the switch between the two alternating displays.



(a) A representation of the site today.

(b) A representation of the archaeological site.

Figure 6: Exhibition of multiple findings from a single site, with an alternating display of the site today and the archaeological site.

The multiple-find exhibition layout template (Figure 6) concerns the exhibition of a number of objects (two in our project, Minamikata and Tatetsuki). The objects are positioned all around a representation of the sites where the objects were encountered/unearthed. The interaction with each finding remains as above; the site representation can alternate, through operating a switch, between the aspect it has today with a visual interpretation of the archaeological site.

In all these layouts, the user is free to approach the findings or move away from findings on the horizontal plane, as well as jump to some higher position to view the suspended platform from above. Some visual cues on the sky vault help the user to orientate: a sun and moon in fixed positions in daylight representation, alternated with constellations that are known from the Japanese sky and Northern Hemisphere (such as Orion or Cassiopeia), for nighttime representation.

3.3 The narrative structure

Complementary to the design of the virtual spaces is the structure of the interactive narrative. The interactive narrative is a fundamental component in the creation of a virtual environment and should aim at guaranteeing an engaging and fluid interaction while accounting for the delivery of information to the user. The narrative structure cannot be disjointed from the graphic choices, which have a significant role in VR communication.

Following the time-space bi-dimensional design above, the opening environment (Figure 7) is structured as a double-encircled suspended platform on the land of Japan: in partic-

(a) top view (b) platform-level view

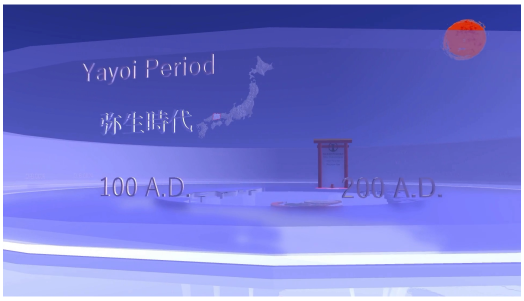
Figure 7: Main hall of the BeA-ViR system, with the double circled platform.

ular, the inner circle implements the spatial dimension, while the external circle represents the time dimension. The initial sequence for the player is a swooping flight towards the platform of the main hall (Figure 7a), landing in a random location on the platform (Figure 7b). The underlying visualization of Japan contains a focus on the area encompassing the prefectures of Shimane and Okayama and projects positions on the inner platform through light cones, as designed above, where a number of gates (each per node of the flow chart) are located. If the landing is in the inner circle, the user has access to all the sites through the gates. The gates have a stylized *torii* (Japanese traditional gate) shape in red (one of the colors of the BeArchaeo project, together with black and white), with the printed name of the site or finding displayed. A special gate leads to the map of *kofun*. Each gate, as per design, has a ground footboard with an arrow that invites the user to enter the gate to the site (see control below).

If the user lands on the external circle, the chronological dimension is triggered, and a transparent wall between the user and the gates arises (Figure 8). The wall reports the chronological succession of the periods of Japanese protohistory that are of interest for our material: the Yayoi (Figure 8a), Kofun (Figure 8c), combined Yayoi-Kofun (Figure 8b) and the historical periods all collapsed into one label (Figure 8d). The wall also reports the correspondence of the eras to western dating, mentioning some relevant years that mark Japanese historical events. The user can travel around the wall; gates appear and disappear depending on the chronological period displayed at the user's position: only the gates that lead to sites that were active in the current chronological period are visualized in the inner platform. For example, the Kofun period concerns the Tobiotsuka site as well as the *haniwa* at the Yakumotatsu Fudoki Archaeological Museum (Figure 8c).

The control operated by the user occurs through the buttons/footboards in the environment and the handles and buttons on the gamepad controller (Figure 9). The footboards (Figure 9a) allow access to individual environments: Enter and Map footboards take users from the main hall to the specific sites or the map of *kofun*, respectively; the Home footboard allows one to return to the main hall. The other two footboards activate specific environment settings. When exploring a site as it appears today the Archaeo footboard triggers the visualization of the archaeological structure (from there, the exploration of some areas automatically leads to the excavation model). The site today is also visualized with the findings exhibitions; also in these cases the Archaeo footboard leads to the archaeological site. The Findings footboard activates the findings exhibition related to a specific site.

The controls on the gamepad (Figure 9b) allow the player to move in the environment (Move Around handle) and to turn his/her sight (Look Around handle). Additionally, the X



(a) Yayoi period, sun as reference object in the sky vault

(b) combined Yayoi-Kofun period

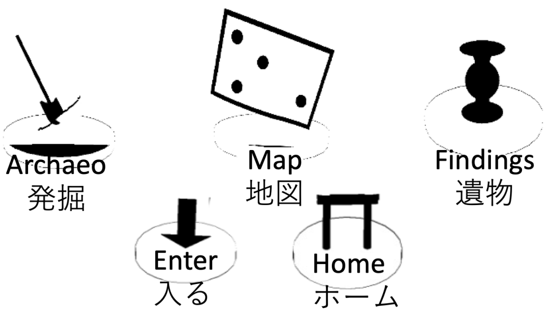
(c) Kofun period, moon as reference object in the sky vault

(d) Historical eras

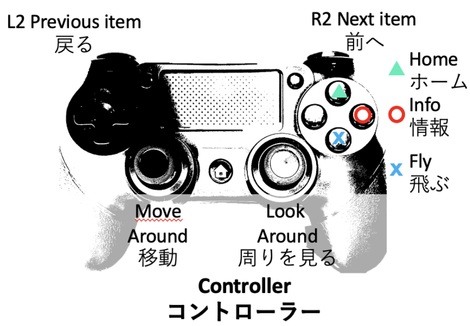
Figure 8: Chronological dimension from the external circle: only sites that were active in the displayed period are accessible.

button is for a specific motion, to fly or jump to a higher altitude before coming down with gravity (Fly button). The Info (circle) button is to visualize an overlay text with information about the currently displayed environment. The L2 and R2 buttons implement a simplified visit, to ease the interaction of users who are not familiar with the gamepad controls. It is a "guided tour" system that moves the user along established exploration tracks, reaching all the specific items of interest. Finally, the Home (triangle) button is a shortcut for going back to the main hall (analogous to the Home footboard in the environment).

The next paragraphs illustrate the rendering and narrations of the main layouts. While the main hall, as well as the site visualizations as they appear today, are represented in the

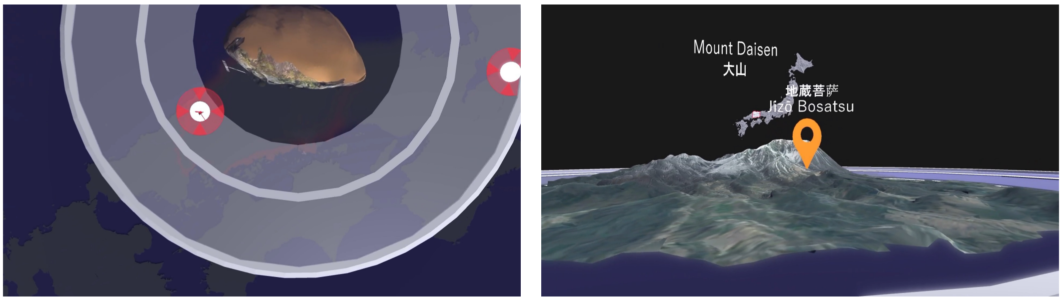


(a) roles of footboards



(b) controller

Figure 9: Buttons to be encountered and remote controls on the gamepad.



(a) Jizō-Bosatsu (b) Mount Daisen

Figure 10: Example of a single-find exhibition with related site.

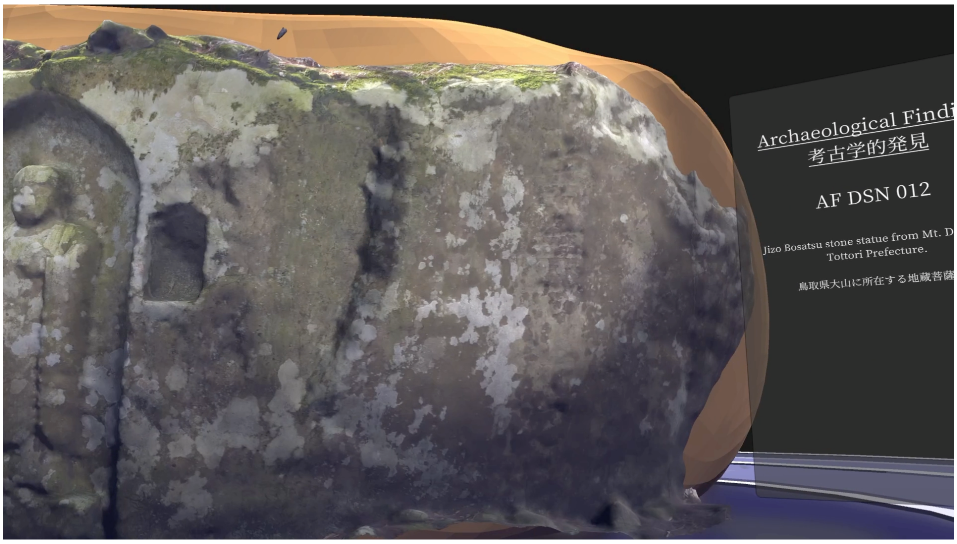
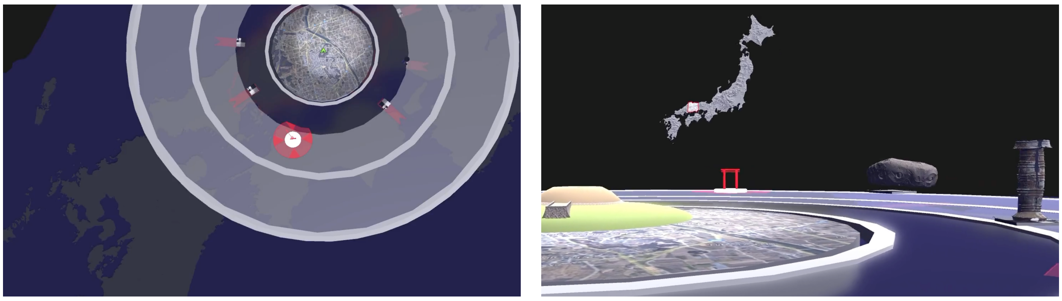


Figure 11: The single-object exhibition: close-up of Jizō-Bosatsu from Mt. Daisen.

daylight, with luminous color tones of the environment, the exhibitions of the findings are in a nocturnal mood. The reason for this is to allow more focus on the objects, with the archaeological structures in the background (center of the platform).

Single-find exhibition. For the illustration of the single finding exhibition, let us consider the Jizō-Bosatsu example; the other single-find exhibition in our project, namely the *haniwa* from the Yakumotatsu Fudoki Museum is structured in the same way. The environment in Figure 10a concerns the Jizō-Bosatsu, engraved in a rock near a path of the sanctuary of Mount Daisen (Figure 10b), chosen as representative of the "modern" period and indicative of the sacredness of the area. The object occupies the center of the platform and can be explored in detail by getting very close to the surface (Figure 11). The orange-brown area is an artist reconstruction of the non-surveyed parts of the rock (because of the lack of engravings). This orange-brown display marking the reconstruction of missing areas is kept consistent throughout all the environments of the application. The two red and white circles are footboards that activate the visualization of the site where the object was encountered/unearthed (Archaeo footboard) and returning to main hall (Home footboard), respectively. Figure 10b is the result of pressing the first: the visualization of Mount Daisen, where the Jizō-Bosatsu was encountered is augmented with a pin in the proper location.



(a) Top view (b) Platform level view

Figure 12: Tatetsuki site environment, with exhibition of multiple findings.

A ruler on its left side (slightly visible in Figure 10a) allows the appraisal of the actual size of the object. Users can also zoom in to see the finding in the greatest detail allowed by the 3D survey. An information panel, with a description of the object, is displayed on the right side of the object. It is worth noticing that such information is from the online BeArchaeo database, where archaeologists and archaeometers insert the metadata concerning the findings to support the scientific investigations. As we will see below, only the general description, which is of most interest to a general audience, is included here.

Multiple-find exhibition. The exhibition of multiple findings from a single site distributes all the findings along the border of the inner circle, while the circle-enclosed area is filled with the site as it appears today or simply a map of the site area. In Figure 12, there is one example of a multiple-find exhibition, namely the Tatetsuki site. The top view (Figure 12a) highlights the positions of the stalls (border of inner circle), a map of the area in the middle and the Archaeo footboard in the middle of the image. The environment in Fig 12b is reached by triggering the Archaeo footboard (notice the reconstructed burial mound on top of the map). In the same image we can also spot the Home footboard and two exhibition findings.

Figure 13: Pottery stand unearthed at the Tatetsuki site.

The finding on the far right is the pottery stand framed in Figure 13. The panel behind

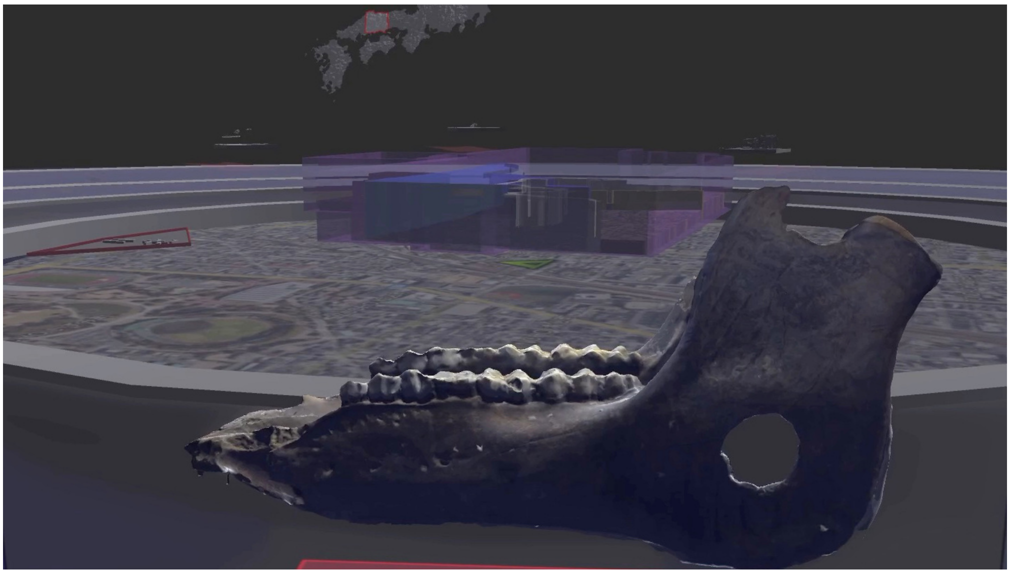


Figure 14: Wild boar jaw unearthed at the Minamikata site.

the object appears when the user is very close to the object. In the same image, also notice the constellations that act as reference points in the night sky vault. In fact, as seen above, the user can fly, or go upward until a certain height for some time, in order to get an overall view of the environment. Therefore, in the case of disorientation, the constellations provide a reference in high positions.

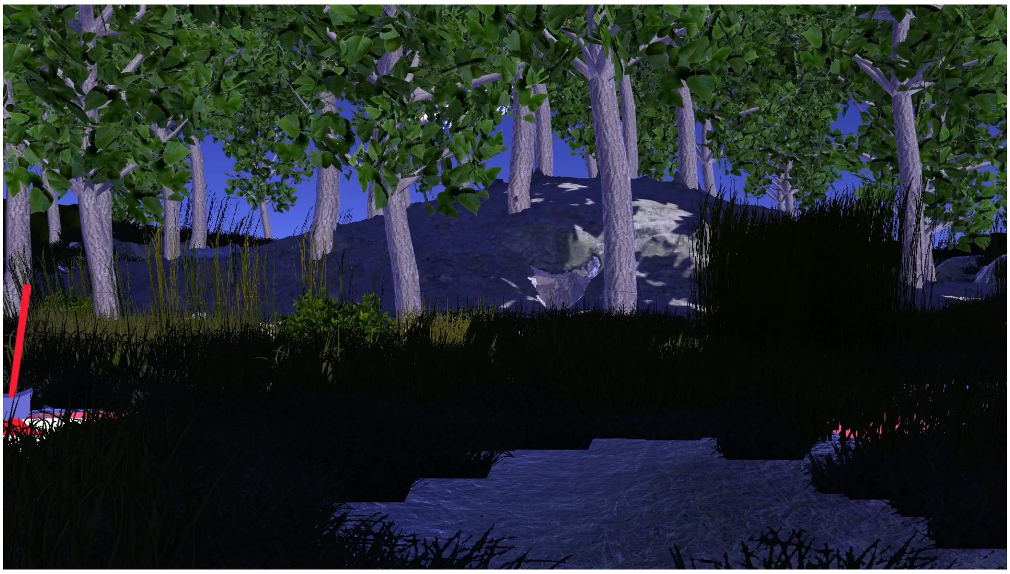
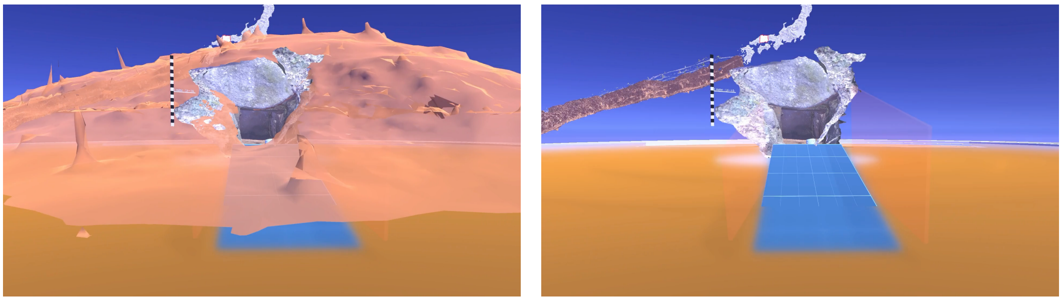


Figure 15: Tobiotsuka Kofun, today.

The Minamikata environment layout also follows the same structure. Here exhibits consist of zooarchaeological findings employed for the creation of artefacts in the Yaioi period. Of the various findings, Figure 14 displays a wild boar jaw. In the background is the archaeological site of Minamikata. The components of the site visualization, the site as it appears today and the archaeological site, behave as modules used in this layout; the site



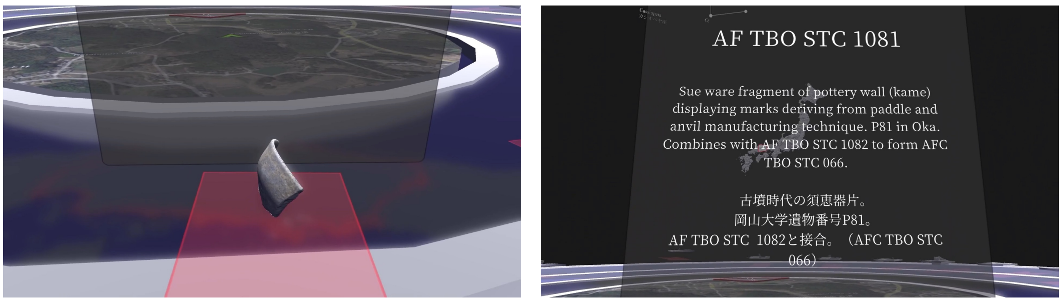
(a) Tobiotsuka, structure of the mound (b) Tobiotsuka, excavation elements

Figure 16: Tobiotsuka Kofun and its features.

today is also used in the single-find exhibition,

Site-complex exhibition. The site complex layout is the exhibition that makes use of almost all the layouts. Figure 15 contains the three visualizations of the Tobiotsuka site, the excavation site of the BeArchaeo project. The current state of the site is a tree-covered hill (Figure 16a), though the entrance of the tomb is clearly visible. The site can be explored thoroughly; however, to see the archaeological elements it is necessary to activate the Archaeo footboard (left of the Figure). This leads to the visualization in Figure 16b, where the mound structure is clearly visible. When one approaches the structure, the mound disappears and the excavation model is visible (Figure 16c). In this visualization, the user can access both the burial chamber and the trenches.

The Findings footboard leads to the exhibition of the findings unearthed at Tobiotsuka by the BeArchaeo project. These are mostly sherds of pottery and some fragments of metal objects. In Figure 17, the archaeological finding TBO STC 1081 is displayed, a fragment of Sue-ware pottery, shown over a floating pedestal (used for small objects) in Figure 17a, part of the larger fragment 066, when combined with 1082, as reported in its description (Figure 17b). Currently, the original positions of the unearthed findings are not displayed in the visualization, as they are in the single-find exhibition. This would have required an exact recording of their GPS positions during the excavations and this was not implemented in the BeArchaeo project. Nevertheless, some location indications are presented (e.g., the XY position from set points, the depth from the surface and unearthed stratigraphic unit) and some integrations to the model are possible in the future.



(a) Sue fragment AF TBO STC 1081 (b) its description in the BeArchaeo database

Figure 17: One archaeological finding from Tobiotsuka Kofun.

4 Implementation of the BeA-ViR System

The BeA-ViR system is implemented in Unity and deployed for several platforms. An initial prototype was developed for CAVE [15], while, recently, a web-based platform has been released too[5]. All the deployments share the 3D model base (with some specific adaptations to the platform). Here we present the implementation carried out with a screen-gamepad VR application. As we will see, the implementation follows in part the design above, since some materials were not available or the curator decided not to insert them in the exhibition.

4.1 The software architecture of the VR environments

Given the flow chart, we created a software architecture where several of the interactive environments are realized, modularizing on objects and behaviors. In particular, there are two mechanisms for triggering behaviors: the explicit footboards, which are explicit interactive objects, and the position of the user in the spatial environment, that is some active locations that are explicitly marked; the latter can be absolute locations (such as, for example, the case of the external circle for the activation of the chronological timeline) or proximity to some specific virtual object (such as, for example, the mechanism for displaying the information panel when the user position is near some finding).

All environments share the vertically suspended 3D model of the Japan map (see, e.g., Figure 14, top). This object moves horizontally on the skybox following the rotation of the player and is always oriented in favor of the camera. This 3D model is a simplified version of the model posited horizontally at the lower level of the main hall, which projects site locations to the suspended platform (Figure 3). Now let us go through the major architecture modules, which implement the design and narrative described above.

The main hall, namely environment module A, is equipped with footboards for implementing the active behavior of the *torii* portals, which allow access to the different environments listed in the flow c hart. The same mechanism, i.e., invisible footboards, allows the appearance/disappearance of the coeval *torii* depending on the time period that the navigation has reached at that point.

Single-find exhibitions are implemented as environment module B, with nocturnal settings that exploit the same 3D models of the main hall platform, a virtual exhibition open air room that positions the 3D model of the finding in the center, with an Archaeo footboard to allow for the switching of the finding with the model of the site today, including a pin for the location of where the artefact was found. However, there have been some adjustments during the implementation phase. While we only originally planned for two instances of such a module, specifically

- B1: the visualization of a *haniwa* from the Yakumotatsu Fudoki Museum and
- B2: the photo-relief and spatial location of the Jizō-Bosatsu from Mount Daisen,

we actually also have a B3, which is the visualization of a photogrammetric survey of the burial chamber of Kamienya-Tsukiyama Kofun. The latter, though being a site, has been implemented as a B environment because we have no representation of the site today and there are no findings that are on display in this exhibition. A burial chamber has thus been

[5] `https://vr.bearchaeo.unito.it/`, visited on 15 January 2024.

implemented as a single-find exhibition. Moreover, the B1 environment does not include any switch to the provenance site, which is not part of the exhibition.

Multiple-find exhibition layout and narrative have been implemented as environment modules C and E. Module C concerns the findings from the Minamikata site stored in the Okayama City Archaeological Museum: this environment also includes the central visualization of the site today and its archaeological counterpart in the excavation information found from this site, which has been absorbed once again into the urban fabric. Module E is a reduced version of C and concerns the findings from the Tatetsuki burial mound, as well as a reconstruction of the appearance of the mound in ancient times (archaeological site). The site as it looks today is presented only as a map (no survey was available). The latter difference accounts for the different module name, as listed at implementation time. Module F, a further reduction of E, accounts for the exhibition of significant findings from several sites of the Okayama area. Here, the reduction does not include any visualization of the site. These two modules will be merged for improving the system modularization.

In all these modules, the activation of the information panel concerning each object is yielded implicitly by getting close to the object; another effect of proximity is the zooming in on the findings for a better appraisal of the surface texture, especially effective due to the high quality of the photogrammetric surveys. Zooming out and panel disappearance are automatic as users step away from the objects.

Site-complex exhibition is implemented as module D. It is applied to Tobiotsuka Kofun and implements all the designed possibilities. It includes three 3D models: the current appearance of the site, called “Site Today”, the archaeological site, an artistic visualization of the archaeological interpretation, and the excavation model, activated by hiding the artistic visualization and only displaying the survey materials from the excavation period. Site Today is visitable through a walking simulation, also implemented in the archaeological and the excavation model. These two environments are actually implemented through the unique module D1. Module D2 is a reduced implementation of module C, very similar to module F, and realizes the exhibition of the Tobiotsuka findings, without the presence of the central site area, largely explored through module D1.

Switching between module D and D1/D2 is operated via explicit interactions with Archaeo and Findings footboards, respectively; the activation of the excavation model is yielded implicitly by getting close to the elements of interest for excavation.

Finally, module G, accessed with a specific footboard from module A (main hall), shows an interactive map of the positioning of the main *kofun* in the Okayama area. In this module, a variant of module A, there is an implicit interaction for the visualization of the chronological information and the consequent behavior of the appearance/disappearance of the *kofun* sites dependent on the traversal of the timeline.

All the environment modules implement explicit interaction with the “Home” footboard by triggering the return of the user to environment module A via a vertical translation and, through a coroutine, dropped into the arrival area (main hall environment, module A).

This implementation, which is to be improved on in its modularization, is compatible with other VR systems, such as headset and mobile, 3D Projector, and CAVE. However, each device is supported by different Unity modules and different templates that prevent the straightforward export/import of assets. To reduce the replication of activities and to be able to quickly produce different projects, all the models are inserted into a coherent reference system, curated within a large Blender project, from which the modules have been directly exported. This has brought the benefit that only the trigger system is rebuilt for each project.

4.2 The metadata coming from the BeArchaeo database

The information panels displayed when the user is near a finding are filled via a direct connection with the database. This issue is particularly relevant in the context of our project and for the advancements of the field, because, in an ongoing project, the database content is constantly updated to contain the latest findings. This also poses a challenge in the maintenance of the coherence in the narrative structure, and this requires a collaboration between the experts and the database managers.

The database is implemented in Omeka-S, a Content Management System (CMS) that allows a semantic representation of the cultural heritage knowledge applied to the archaeological and archaeometric domain in the BeArchaeo project [35] [36]. The database is connected to the BeA-ViR application through a Unity implementation of the Omeka-S API[6]. This tool made possible the retrieval of the metadata present in the database resource items. In particular, the library allows the user to retrieve the metadata for the items contained in a specific item set. The application retrieves a number of metadata for the accessed items: for each item, the set of Dublin Core metadata[7], namely ID, Title, and Description fields, which are used to address the general audiences, while, for some specific items, the details of the archaeometric analyses, which can be inspected by the researchers when getting physically closer to the exhibition artifact. The implementation currently allows the data to be read only, but it is expected that in the future the code will be expanded to also guarantee write options. This will open the possibility of full interaction with the database from the virtual environment.

The information obtained from the database is deserialized into easily usable C# objects on Unity. Through these objects, the ID, Title, and Description fields are taken and placed on a Unity canvas (a UI panel), which is shown to the user when close to an object. Within each canvas there are three TextMeshPro objects, useful for displaying the retrieved textual content. These textual fields are filled, for each canvas, overwriting the original content of the fields with the information received from the database. In case the information cannot be filled in due to connection problems, the text fields show a default text that signals the absence of a connection to the database.

As described above, the canvas is activated and shown to the user when he/she virtually approaches the exhibited 3D objects. However, the panels are filled with information that is retrieved at system startup and at any manual reset or at resumption from standby (when a screensaver animation is shown). Each canvas is named after the ID of the object in the database. In this way, once the metadata have been retrieved, it is possible to associate the panel with the correct finding. The main limitation of this implementation lies in the impossibility of maintaining a reference to the finds if their IDs are changed on the database. However, in the future we can plan some general retrieval depending on the name of the desired item set.

An interesting issue, bound to the multilingual aspects of the BeArchaeo project, was the display of different character sets, namely Western and Japanese. The search for a character font that contains as many *kanji* (Chinese characters) as possible and is compatible with the Unity canvas method resulted in the use of Noto Sans Japanese[8]. The correct

[6] `https://github.com/RenderHeads/UnityPlugin-OmekaAPI`, GPL-3.0 License, the same as system BeA-ViR.

[7] `https://www.dublincore.org/specifications/dublin-core/dcmi-terms/`, visited on 10 november 2022.

[8] `https://fonts.google.com/noto/specimen/Noto+Sans+JP`

display of characters on the canvas is due to the correct conversion of the Unicode data obtained by the API into *hiragana*, *katakana*, and *kanji*.

In addition to the completeness of the font, it was necessary to enable the Multi Atlas Texture feature from the editor via the TextMeshPro component. This option allowed the creation of new atlas textures from the font, since it is not possible to have them all in the main one.

4.3 The BeA-ViR system installation at the BeArchaeo exhibition

The BeA-ViR system was successfully installed at the BeArchaeo exhibition, held in October-December 2022 at the Shimane Museum of Ancient Izumo, in Izumo City, Shimane Prefecture, Japan, and in June-July 2023 at the Rectorate Building of the University of Turin in Turin, Italy (Figures 18). The application executable was installed on the appropriate hardware, specifically assembled for the exhibition: an HP ProDesk 400 G7 Microtower, with high performance specifications to achieve the most of the numerous aesthetic and light effects present in the virtual environments. The controller was a G-LAB K-Pad THORIUM Wireless, which has central controls, used interactively for navigation and visual exploration, aligned on the same axis. The choice of axis alignment was made after tests with sample users revealed that not all users were accustomed to gamepad controllers.

The installation was located in the center of the rooms (see figures), and since local technicians cannot interact with the machine using a mouse and keyboard, we opted for a Rii Mini i8 + Wireless system hidden to visitors and practically stored in the case. The local assistants were instructed on how to start and end the application and on how to avoid any problems when resuming the controller from standby or what to do in the accidental event of a system crash. The hardware has a dedicated Internet connection via LAN for the retrieval of the metadata from the database, to be updated in real time, at each resume operation.

Though the installation optimally requires a 49" Dual QHD Curved Odyssey Series G9 - G95T Gaming Monitor, the actual museum installation works with a television screen. This has required the adaptation of some specific display parameter settings (such as contrast and saturation). The user can be in a group (there are three raised chairs) or alone. The experience was designed for a short-medium stay at the station, with an average measured engagement during tests of about six minutes. However, careful observation of the users reveal many differences, from users who access all the information contained in the application through the information button on the controller to those who mostly exploit the

(a) exploring tthe Minamikata site

(b) exploring the Jizō-Bosatsu

Figure 18: Users at the installation at the Shimane Museum of Ancient Izumo.

visual features.

5 Discussion and Conclusions

This paper has presented the design and implementation of the BeA-ViR system, for the visualization of archaeological sites and related findings investigated in the BeArchaeo project. The application exploits a time-space bi-dimensional design and integrates the VR communication, with information transfer directly conveyed by the body of documentation developed from the archaeological and archaeometric investigations and stored in an online database. The application builds on a previous CAVE approach that featured constraints typical of that immersive device [15]. The current implementation was designed for installation at two exhibitions in Japan and Italy, in 2022 and 2023. The system is developed in Unity in a modular fashion and aims at being useful to archaeological investigation in the future, as for the previous CAVE prototype. We aim to carry out several tests and focus group analyses to understand the effectiveness of the application in quantitative terms and understand what aspects need redesign.

The BeA-ViR system addresses a novel feature of virtual reality applied to archaeological projects: the divergent needs to support researchers in their investigations, on the one hand, and to communicate with the local communities and the public in general, on the other, while the project is still ongoing. This is a delicate phase. Interpretation has not reached a stable condition yet, with multiple issues under debate, and the project needs to be communicated with its hypotheses and potential impacts, especially in its relationship with related sites. As the online database functions as a flexible content provider, updated by researchers, the multi-platform software architecture allows for the deployment of the VR system in several contexts.

At the public installations, we could also carry out some preliminary evaluations of the prototype through direct observation and questionnaires submitted to users, distributed over a wide range of ages and belonging to both the general public and the archaeological/archaeometric researchers [37]). The general public reacted positively to the application (3.6/5 average) and to the delivery of archaeological information. However, a large number of general users had difficulty with the gamepad controls (2.5 avg), and during the time between the different deploys we developed a "guided tour" functionality that overcomes the difficulty of user self-exploration of the environment. Researchers expressed a desire to have access to more archaeometric information, with a connection between the artifacts and the places encountered within the site, a feature not yet implemented in the database.

Users expressed appreciation of the novel feature of merging fine 3D representations with detailed archaeometric data, since these two features are usually kept distinct in projects. In general, unsurprisingly, experts looked for more information than general audiences, who were usually more focused on the reconstructed content. Finally, users could identify the different layouts (site complex exhibition, multiple finding exhibition, single finding exhibition), demonstrating the general clarity of the content organization.

There are a number of interesting technical features in the BeA-ViR system. First, it has been designed with a wide perspective in mind, by resorting to the dimensions of time and space, which are ubiquitous in archaeological research. Second, it has been implemented in a modular fashion, therefore easing portability between different devices and display techniques. Third, it has been at the center of a multinational and multilingual project, thus addressing differences in the archaeological practices as well as challenges in the design and textual displays.

In the future, we aim to develop two major aspects. The first concern is the improvement of the modularization of the VR environments in order to apply the system to other archaeological projects and exploit the competences and practices developed in BeArchaeo. The second is to improve the contribution to archaeological investigations from a scientific point of view. We know that virtual reality techniques are of particular importance for the reflexive methodologies applied to archaeology [38]. In fact, the journey of the archaeological investigations, which starts with the posing of research questions before the excavation starts and continues up to the exhibition of the results, is recorded by 3D items in the digital archives and these can be appropriately displayed through the VR systems. This documentation (video recordings, daily reports and data base entries) functions to support our published interpretations.

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