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Integration of an archaeological database in a virtual reality environment: Venta Micena, Orce (Granada, Spain) archaeological site

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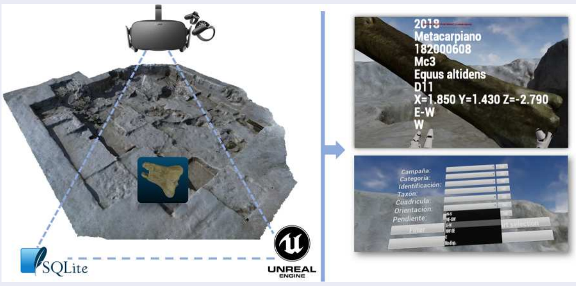
ABSTRACT

Virtual reality and databases are two technological domains employed in many scientific fields. In archeology, several works are being developed along these lines. This paper presents the workflow for the creation of an executable virtual reality: it integrates a virtualization of the archaeological site of Venta Micena (Granada, Spain) and a database of some of the most relevant archaeological remains from that site. The strength and novelty of this project are that it allows any user or researcher to walk through the archaeological site, pick up and put down any of the remains found there, access the database of the archaeological remains from any place and time, and visualize them in stereoscopic mode, which could unveil new information and conclusions. This document moreover discusses the contributions and possible limitations of this type of technology, as well as key concepts and the significance of archaeological excavation.



KEYWORDS
Virtual reality; SQLite; database; Orce

1. Introduction

Virtual reality (VR) is the ability to create immersive, imaginative and interactive simulations for the user through visual and auditory output (Larin 2021). In recent years, VR has accelerated its development and is being applied in archeology and many other scientific science. In medicine, it is used to visualize in detail certain parts of the body previously scanned (Goo, Park, and Yoo 2020; Hu et al. 2019) or as a tool for the treatment of neuronal lesions, simulating goals that the patient aims to achieve in real life (Cheung et al. 2014; Maggio et al. 2019). In psychology it may be used to treat anxiety and depression (Parsons et al. 2017; Parsons and Rizzo 2008); and in education, as a new resource to improve the teaching and learning process (Radianti et al. 2020; Szcześniak et al. 2021). In architecture and engineering, VR serves to anticipate the desired result before building execution (Bashabsheh, Alzoubi, and Ali 2019; Zaker and Coloma 2018), and as support for the conservation and maintenance of existing buildings (León-Robles, Reinoso-Gordo, and González-Quiñones 2019; Reinoso-Gordo et al. 2018; Rodríguez-Moreno et al. 2018).

Specifically in the field of archeology, 3D content and VR are no new achievements, having been described in the book by Barceló in 2000. In 2010, Forte introduced the concept of cyberarchaeology, exploring how digital technologies can transform traditional archaeology and site study. Virtual reality is also used to disseminate research by generating virtual visits to museums (Arias et al. 2022; Barbieri, Bruno, and Muzzupappa 2018; Cassidy et al. 2019; Conti et al. 2020; Liu et al., s. f.; Schofield et al. 2018), to document excavations or archaeological campaigns (Aiello et al. 2019; Balsi et al. 2021; Reinoso-Gordo et al. 2020), to improve the conservation

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of an archaeological site (Cantatore, Lasorella, and Fatiguso 2020; Fanani et al. 2021; Monterroso-checa et al. 2020; Threesiana, Suwardhi, and Riyanto 2013) and to search for patterns by applying machine learning techniques to digitized archaeological remains (Bassier, Vergauwen, and Van Genechten 2017; Fu et al. 2022; Mesanza-Moraza, García-Gómez, and Azkarate 2020; Monna et al. 2020; Sanders 2018). In archaeology, much 3D content starts from a structured point cloud, which is a three-dimensional geometric representation based on the most primitive form (points), from which it is possible to represent the shape, size, position and orientation of objects in space (Aldoma et al. 2012; Rusu et al. 2008). Furthermore, this spatial information could be augmented with additional data obtained through electromagnetic sensors in different bands of the spectrum (visible, IR, reduced spectrum bands, etc.), thus deriving a point cloud that is spatially located, with local attributes (Grilli, Menna, and Remondino 2017).

To date, a point cloud of a real object can be generated by means of three different techniques: i) Automatic photogrammetry, ii) Laser scanning, and iii) structured light. Photogrammetry is defined as the technique that studies and provides a precise definition of the shape, dimensions and position in space of any object, taking measurements from photographs, with overlapping images offering multiple angles to generate 3D point camera locations (Bonneval 1972; Hartley and Zisserman 2000; Lowe 2004). Laser scanning is a technique that emits a laser light that is reflected by a solid body, which returns it to the system, generating a point cloud of all objects touched by the light rays emitted. Structured light denotes the process of projecting a pattern in a known wavelength and capturing the deformed pattern with a sensor sensitive to the wavelength; the object´s shape is recreated through the study of pattern deformation. Using the 3D data acquired from these three techniques, it is possible to compose a virtual environment where a person can feel immersed and interact. Furthermore, the virtual environment can be produced anytime and anywhere.

The technology that allows all of the above is known as virtual reality, and to create VR environments it relies on two graphics engines that are widely used and relatively cost-effective: Unity and Unreal Engine. In a comparative study, Morse (2021) highlights that Unity is free for small companies and costs between $400 and $2400 per year for big companies, it works on the most widely used operating systems, and its code works in C# but does not allow natively working with Visual Scripting except with the plugin called Bold. In turn, Unreal Engine is likewise free but for commercial use, it works with a percentage of royalties, it also works on most operating systems, its code works in C++ and it does allow you to work natively through Visual Scripting called Blueprint. For this reason, it was the engine of choice for our research.

This research introduces an application of immersive virtual reality for archeology allowing any researcher around the world to explore, form hypotheses, or make interpretations about the Venta Micena archaeological site (Orce, Granada, Spain) without needing to visit the site in person. In addition, because the application integrates the database of 30 archaeological remains found at the site, it allows researchers to interact with them and make prescribed queries. The present contribution also discusses the potential impact on archaeology of this development, from more theoretical issues such as the concept of archaeological excavation to more applied aspects such as heritage dissemination.

Venta Micena (VM) is an important palaeontological complex from the Early Pleistocene that contains various palaeontological sites explored since the 1980s. They are located on the northeastern limit of the Basin of Guadix-Baza. The exact coordinates of the site are 552459, 417635 ETRS86/UTM ZONE 30 N (Figure 1). At present the excavation area amounts to some 37 square meters. This sector of the Orce region underwent the dynamics of transgression and regression of a large saline paleolake that dominated this sector of the basin. The wealth and good conservation of fossil accumulations – including species of canids, felids, hyenas, elephants, horses, deer and bovids, of African, Asian and European origin – make VM a key place to study the palaeoecologyy of the Early Pleistocene in southwestern Europe (Ochando et al. 2022; Saarinen et al. 2021).

Studies of geochronology and biochronology place it at 1.6-1.5 Ma (Agustí et al. 2010; Duval et al. 2012). Several sectors have been discovered in VM, the most noteworthy one being VM3, interpreted as a hyena den (Arribas and Palmqvist 1998; Palmqvist et al. 2022). Another sector, VM4, has been excavated more recently (2005, 2013-2015, 2017-2019) and offers a more complex history; it is interpreted as an open-air site on the margins of bodies of fresh water, an ideal setting for hunting carnivores (Luzón et al. 2021; Yravedra Sainz de los Terreros et al. 2023).

Excavation at VM4 (Figure 2) poses a great challenge because the abundance of material causes overlapping and interlocking of fossil elements. Additionally, the environmental climate conditions are very different (warmer and drier) from those of the sediment containing the fossils. This can cause small fissures to expand into cracks, compromising the integrity of the fossils. To prevent or mitigate this situation, many fossils (especially bones) are extracted with a bed (base) of sediment that protects the bottom (topographically speaking) of the element.

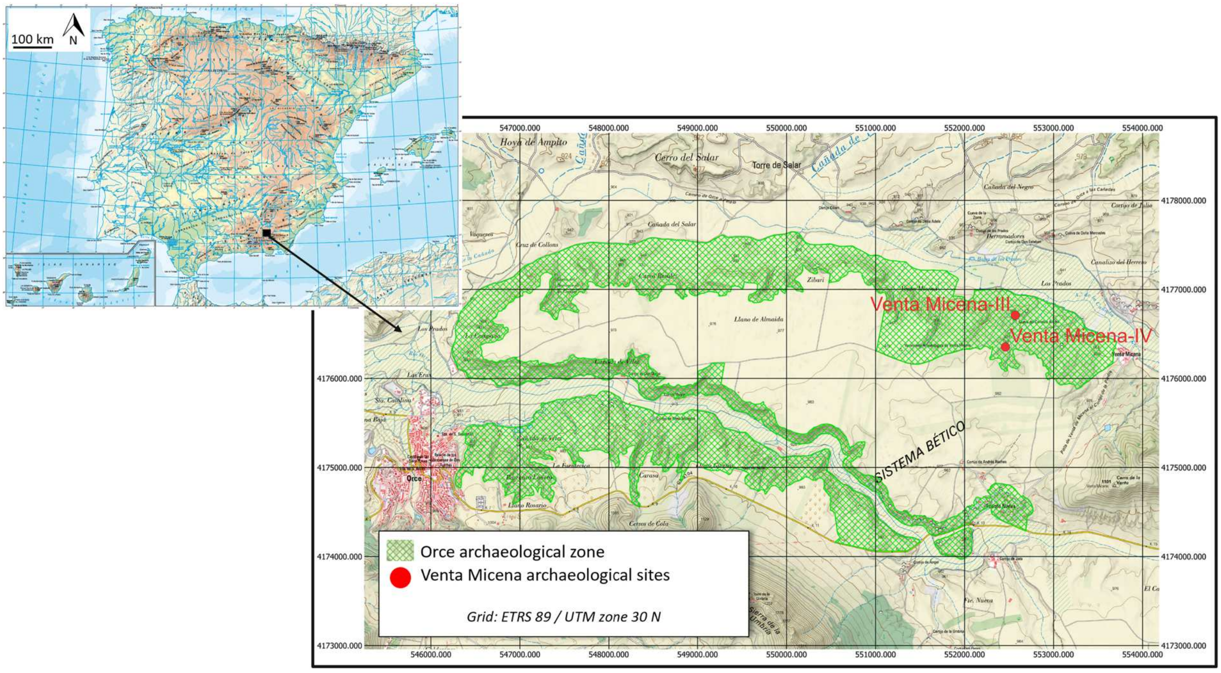

Figure 1. Location.

Subsequently, the excavation is completed in the laboratory under more controlled conditions.

2. Materials and methods

The research is presented in two phases. Phase 1 (P1) involves data acquisition to create 3D meshes of the archaeological remains and of the site itself. Phase 2 (P2) involves integrating the 3D content from P1 (archeological remains and the archeological site) with a database of the recognizable taxonomical and anatomical archaeological remains so that anyone can interact and consult pertinent information through an executable application based on virtual reality.

The equipment and software involved in each phase are presented in Figure 3. A Leica TS02 total station with an angular accuracy of 3″ and a ranging accuracy of 1.5 mm ± 2 ppm was used, along with a Sony A5100 camera equipped with a 23.5 x Exmor APS-CMOS sensor 15.6 mm^2 and 20 Megapixels. In addition, a portable structured light scanner MHT Artec with 15 frames per second provided a spatial accuracy of 0.5 mm, while Artec Studio 10 Professional and the software Agisoft Metashape (photogrammetry algorithms) were used to generate 3D models (meshes) from the acquired digital photographs. The material used for P2 included Unreal Engine, a video game engine with the external plugin USQLite Database, and the plugins native Oculus Audio, Oculus VR and Oculus Online Subsystem to build the VR environment, while Oculus Rift VR glasses were used with their corresponding gamepad for user immersion.

Figure 2. Venta Micena archaeological site.

2.1. Acquiring 3D content

The P1 procedure for acquiring data and generating the meshes of archaeological remains and site can be described in two parallel flows (Figure 4): P1.i. to acquire the archaeological remain meshes, and P1.ii. to acquire the archaeological site mesh.

2.1.2. Archaeological remains

In P1.i., the aim is to generate a 3D textured mesh of each of the most relevant archaeological remains found at the Venta Micena site during the excavation campaigns of 2018 and 2019. To obtain the texturized mesh of each of the archaeological remains, the MHT Artec, a structured light portable scanner served to collect 3d points and Artec Studio 10 Professional was employed to edit, optimize and texture the mesh.

Each archaeological remains is scanned from different points of view to obtain a set of points (point cloud) of the object. Every scan file contains point

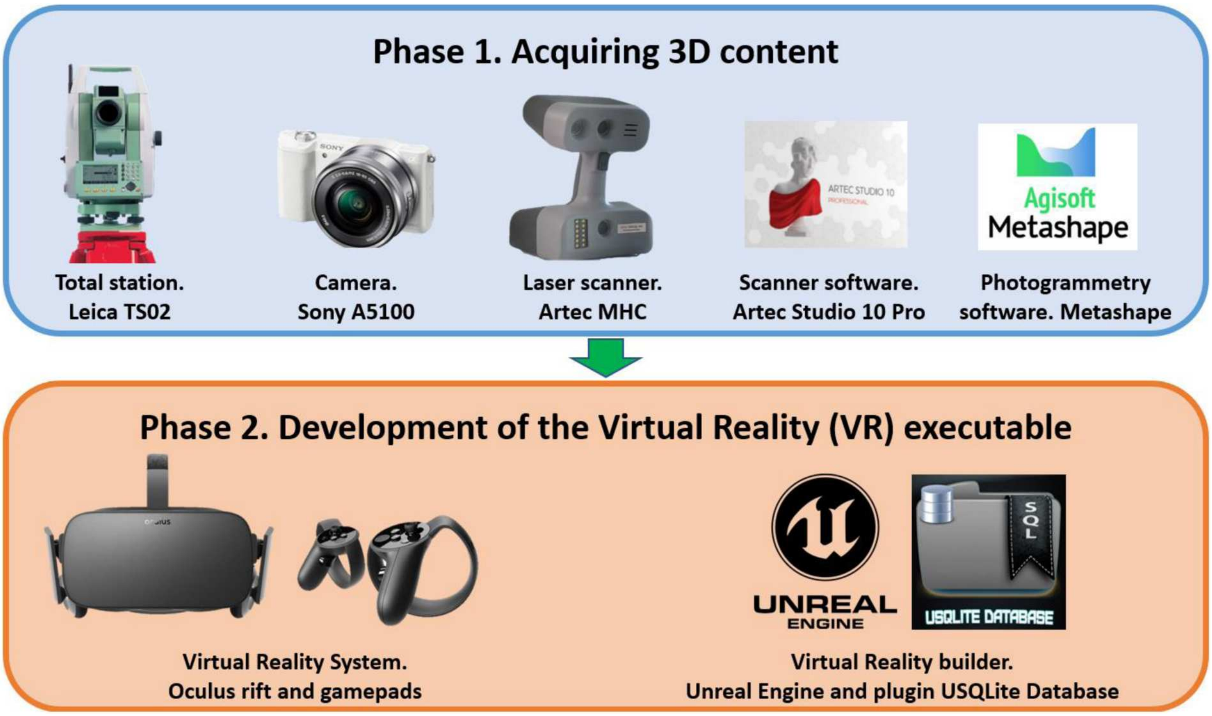

Figure 3. Equipment and software.

clouds that further include the information regarding the space surrounding the object, which implies that any "noise" must be removed.

Every scan of a given object is aligned according to tie points to compose a single structured point cloud of the object in a single coordinate system. The algorithm for global optimization of frame positions selects a group of unique geometric points in each frame, then optimizes the position of all the frames, correcting errors and alignment anomalies.

The scans are integrated into a geometric model via a geometric algorithm – fusion – that interpolates multiple views and generates a solid mesh based on triangles. Then, the mesh can be checked for small defects: outliers, filling small holes and surface smoothing. Finally, we can texturize the solid mesh. In this work, we used the "generate textures atlas" method, which cuts the surface into pieces, unfolds and nests them on a flat plane, and fits them into an image of a specified size. The textures were generated with 8192×8192 pixels. Some parameters can be edited (brightness, contrast, saturation, gamma correction, hue), and in some cases, the texture healing tool was employed to fill texture gaps in selected areas. The 3D models were exported in OBJ format, providing 30 3D textured meshes pertaining to the

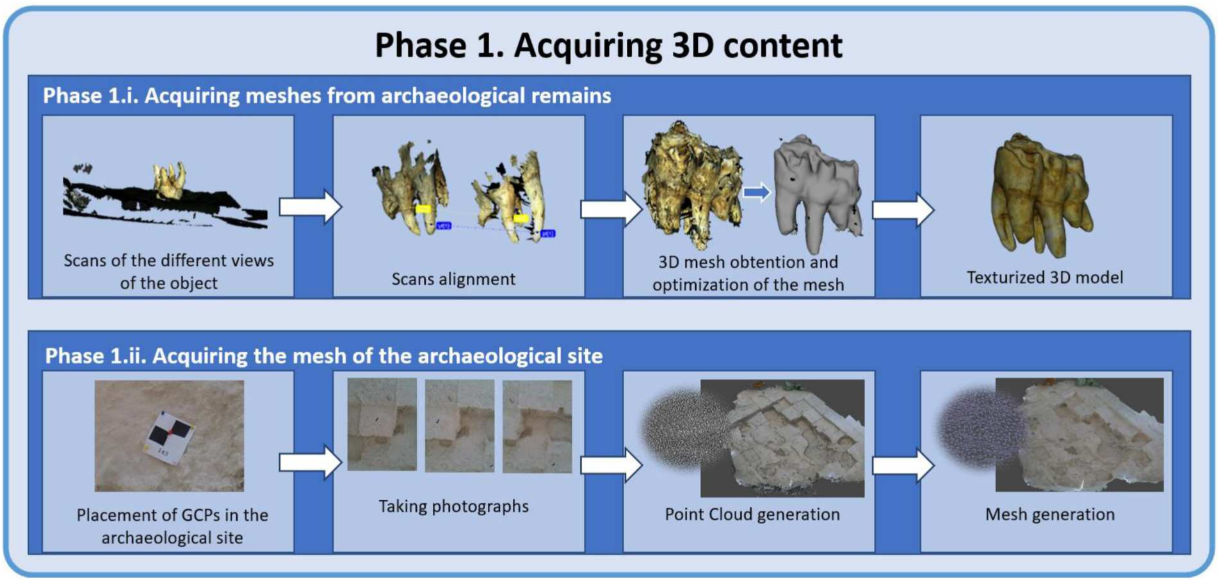

Figure 4. Phase 1. Acquiring and generating all the 3D content of the archaeological site.

most relevant archaeological remains from the excavation campaigns.

2.1.2. Archaeological site

Regarding P1.ii., the objective was to generate a 3D textured mesh of the Venta Micena site at the end of the 2019 excavation campaign. This mesh was obtained using photogrammetry techniques. The techniques entailed a first part of field work, and a second part of lab work.

Regarding field work, seven ground control points were set on the site floor. They were placed along the perimeter and within the archaeological site, when possible at different heights, as recommended by Martínez-Carricondo et al. (2018) and Nagendran, Tung, and Mohamad Ismail (2018). Afterwards, the coordinates of each target were taken with reference to the total station, as previously established through a local reference system.

Once the above was done, and at a time of day that offered optimal lighting conditions, 176 photographs were taken, guaranteeing both longitudinal and transversal overlap greater than 80% as indicated in González-Quiñones et al. (2018).

Regarding the lab work involving Agisoft Metashape software, the first step was aligning the photographs to obtain a sparse cloud. Then, the photo coordinates of all ground control points in each photograph were identified, and the coordinates of each control point obtained with the station are imported. Subsequently, the dense cloud is built along the same local coordinates as the ground control points.

After that, a mesh is constructed from the point cloud, and this mesh is textured. The 3D textured mesh is obtained in local coordinates of the Venta Micena archaeological site.

2.2. Development of the VR executable

In the P2, the aim is to integrate a database belonging to the scanned archaeological remains with the 3D content obtained in P1, in a single VR scenario, using an executable format. This executable will allow any user, anywhere and at any time, to interact with the Venta Micena archaeological site using the Oculus Rift VR glasses and the database of each of the scanned archaeological remains. Specifically, the user is able to handle the scanned objects, and at that moment the values of each of the variables in the database pertaining to that object appear next to the object in hand, as seen in Figure 5. In addition, the user can invoke a filtering and search menu based on the values of the database variables using the B button on the gamepad, shown in Figure 6. The database integrated into the executable contains the following variables: campaign, record number, category, identification, taxon, grid, number, position, orientation and slope. To carry out the above, we followed the workflow shown in Figure 7 (broken down in the following paragraphs).

2.2.1. Unreal engine and Oculus Rift integration

Firstly, an Unreal Engine project was configured so that Oculus Rift could interact with the virtual environment to be created. As UE recommends on its website, it is best to proceed by creating a virtual reality type project with Starter Content and perform an initial configuration of the engine settings. Then, the plugins that UE installs by default during installation – Oculus Audio, Oculus VR and Oculus Online Subsystem – must be activated. Additionally, one must choose MSAA as the Anti-Aliasing Method and enable the following parameters: Start in VR, Forward Shading, Instance Stereo, Supports Dash and Composites

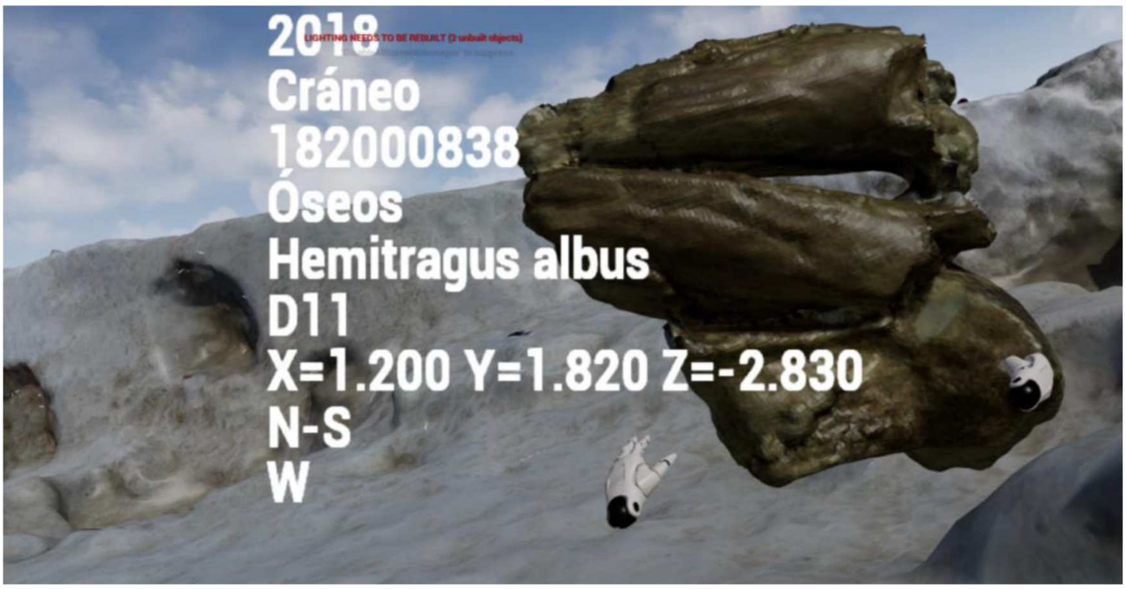

Figure 5. Screenshot of the appearance of the values of the variables when picking up archaeological remains.

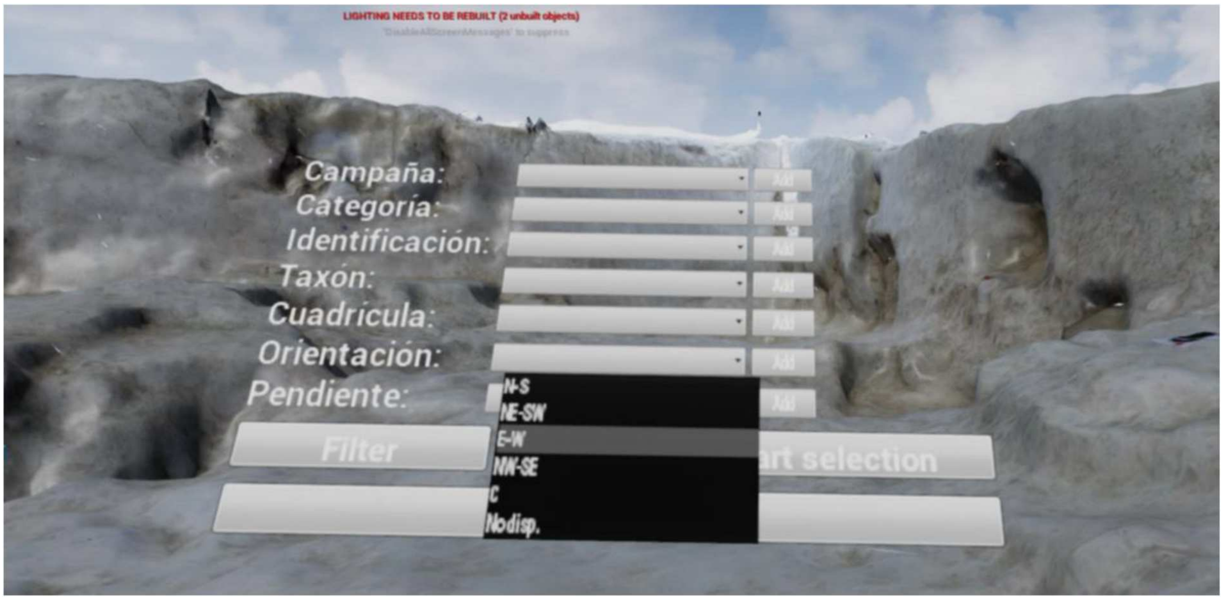

Figure 6. Filter menu screenshot.

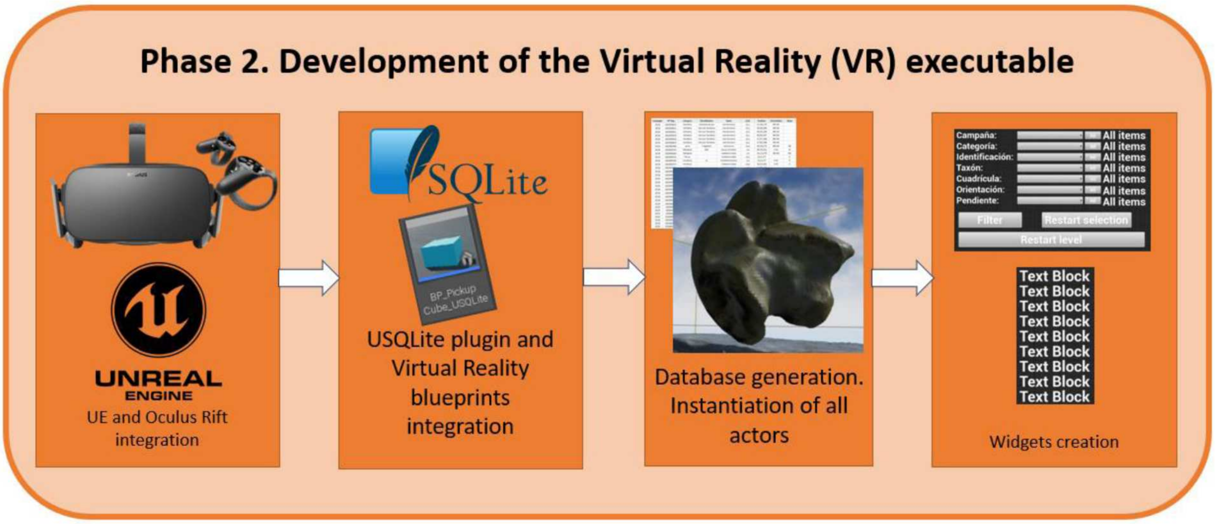

Figure 7. Phase 2. Virtual reality executable generation.

Depth. Once the above is done, it is possible to start creating content in the project under Oculus Rift – like with any interactive device, receiving and sending data in real time. The device receives image and sound data from the virtual environment where it is running, and sends position and orientation data of the subject's head. In addition, through the gamepads, it can send data on the position and orientation of the subject's hands, activation commands, kind of grasp, and buttons to activate predefined actions.

2.2.2. USQLite plugin and virtual reality blueprints integration

At this point, the USQLite plugin was integrated with the virtual reality blueprints to ensure connectivity between them. It is important to stress that so far (section 2.2.2.) the database is not filled, but rather the blueprints are configured so that the database can be filled in the next section (2.2.3.) when instantiating each actor (Figure 8).

To do this, as mentioned earlier, we worked with the USQLite Database plugin developed by Bruno (2024). First of all, we must bear in mind that the meshes of the archaeological remains containing data from the database will be instantiated objects, actors, able to be pick up and rotate the fossil or remnant of interest via virtual hands and the gamepad. Our starting point was the UE Virtual Reality Start Content asset called BP_PickupCube, which allows this pick-and-drop action. In short, any given actor in that asset can be handled and released. This asset was duplicated and edited as follows: it was labelled BP_PickupCube_USQLite, as many variables were added to the database contents, the interface called SQLiteData belonging to the plugin

Figure 8. USQLite plugin and virtual reality blueprints integration.

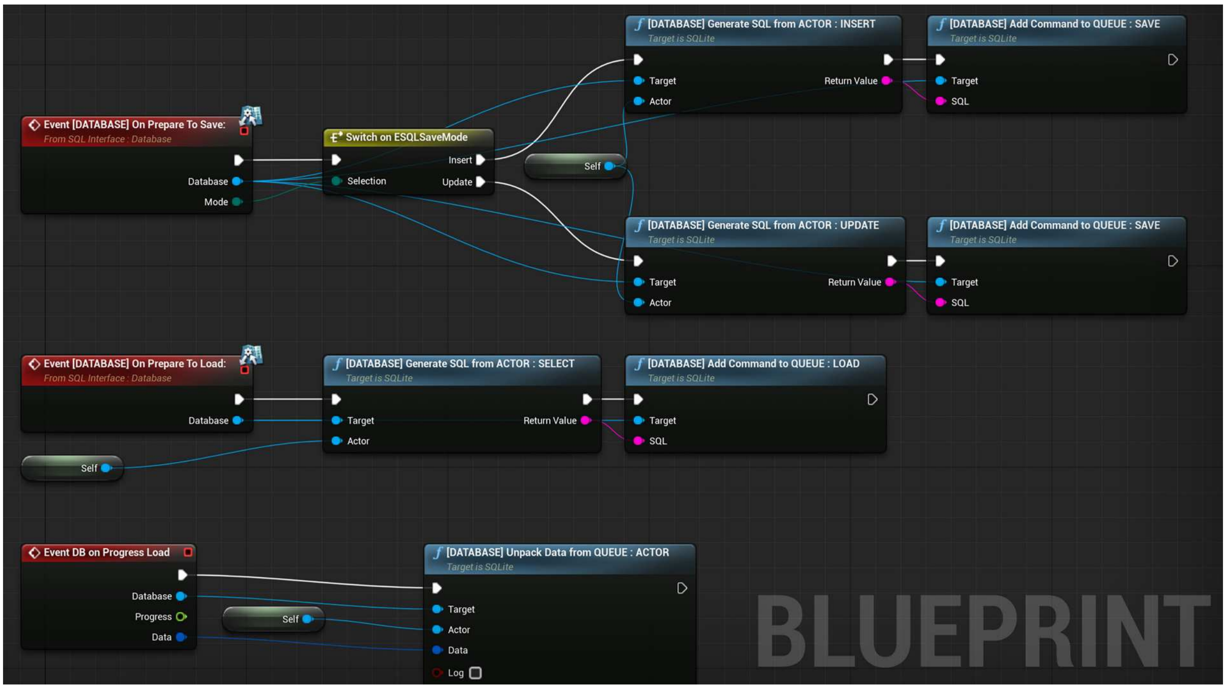

Figure 9. Visual Scripting on BP_PickupCube_USQLite so that this class could interact with the database.

was likewise added, and the Blueprint structure shown in Figure 9 was added. Next, an asset of SQL Database class named DataBase was created. In this asset, as many columns as there are variables in the database could be added, labelled with the same name as the variables of the BP_PickupCube_USQLite asset.

In addition to the two previous assets, a further Game Mode Base class asset called GameMode_USQLite was created, and configured as follows: the SQLiteDriver interface was added, a variable of type SQLite was created, and the Blueprint structure shown in Figure 10 was added.

Having completed the process described above, it is now possible to instantiate actors of the BP_PickupCube_USQLite class, to add the desired value to the variables created in that class, and to transfer the value of the relevant variables into a row of the Database.

2.2.3. Database generation. Instantiation of all actors

Now it is time to add to the UE level, the meshes corresponding to each archaeological remains developed in P1.i. and the mesh of the archaeological site generated in P1.ii.. Specifically, 30 actors of the BP_PickupCube_USQLite class were instantiated with their corresponding Static Mesh Component containing the mesh of each archaeological remains, and one actor type is instantiated, containing a Static Mesh Component with the mesh of the Venta Micena archaeological site. Furthermore, the corresponding value is added to the created variables (campaign, registration number, category, identification, taxon, grid, number, position, orientation and slope) of each actor (30 actors) instantiated from the BP_PickupCube_USQLite class, as shown in Table 1.

The first column of variables in Table 1 corresponds to the excavation campaign in which the archaeological remains were found; the second corresponds to the registration number within the record of everything found at the site; the third shows the category; the fourth an identification within its categorization; the fifth column defines the taxon of the archaeological remains; the sixth column indicates the grid in which it was found (Figure 11); the seventh

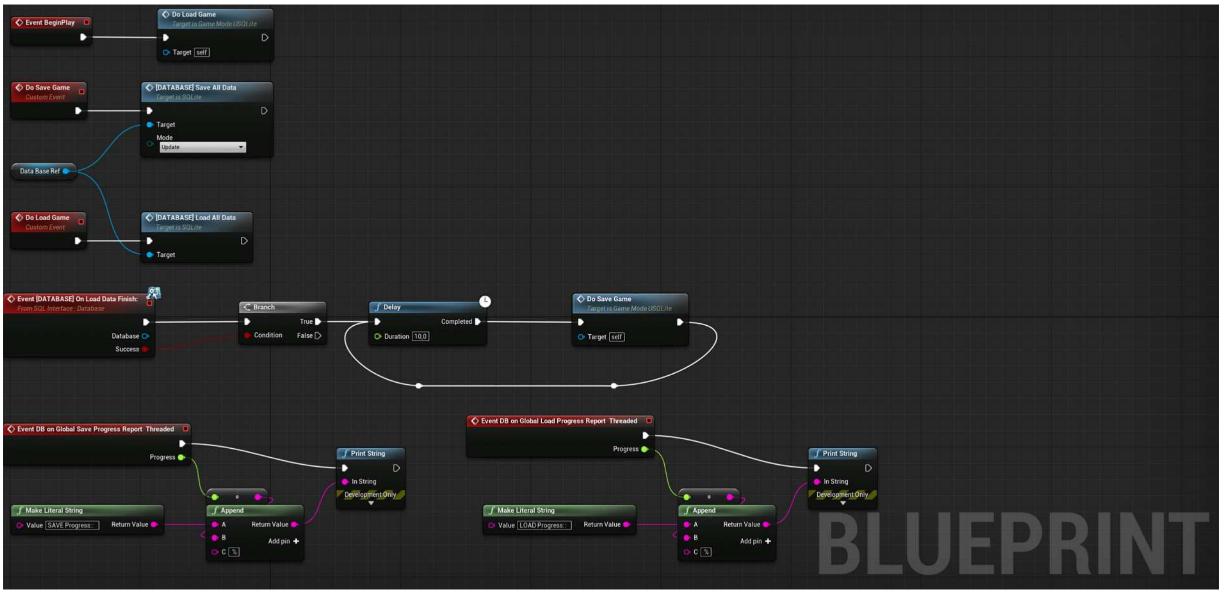

Figure 10. Visual Scripting on GameMode_USQLite to load the values from the database when starting the level.

shows the coordinate with respect to the south-west corner, the origin of the grid in meters. The fifth column also expresses the orientation of the longest side of the archaeological remains, while the sixth shows the slope under which it was unearthed.

2.2.4. Widget creation

At this point of P2, it is necessary to explain how the data will be displayed and how to interact with them using filtering techniques. To create display menus, there are widget-type classes in UE. For our work, two widgets were developed in parallel, denominated W1 (Figure 6 and Figure 12) and W2 (Figure 7 and Figure 13).

2.2.4.1. Widget to display the data of the picked-up object. The first, W1, will be invoked when the user picks up any archaeological remnant and is hidden when the user puts it down. It contains nine Text Blocks, each linked to one column of Table 1 so that when archaeological remains are picked up, the widget will automatically show each value associated with

Table 1. Database.

Campaign	N° Reg.	Category	Identification	Taxón	Grid	Position	Orientation	Slope
2018	182000823	Vertebra	Vertebra dorsal	Mammuthus meridionalis	D11	31,46,270	NE-SW	
2018	182000822	Vertebra	Cervical Vertebra	Mammuthus meridionalis	D11	29,46,269	NE-SW	
2018	182000821	Vertebra	Cervical Vertebra	Mammuthus meridionalis	D11	33,55,269	NE-SW	
2018	182000819	Vertebra	Cervical Vertebra	Mammuthus meridionalis	D11	36,56,267	NE-SW	
2018	182000818	Vertebra	Cervical Vertebra	Mammuthus meridionalis	D11	41,57,268	NE-SW	
2018	182000815	Vertebra	Cervical Vertebra	Mammuthus meridionalis	D11	37,63,268	NE-SW	
2018	182000496	pole	Fragment	Praemegaceros verticornis	H14	63,28,275	NE-SW	NE
2018	182000744	Metapod	Mt3	Equus altidens	I14	58,78,251	E-W	W
2018	182000629	Metapod	–	Indeterminado	I14	23,14,279	NE-SW	SW
2018	182000515	Pelvis	–	Indeterminado	H11	22,0,277		E
2018	182000530	Humerus	Cc	Stephanorhinus hundsheimensis	I14	5,41,277	E-W	P
2018	182000373	Humerus	–	Indeterminado	H14	76,25,281	E-W	E
2018	182000283	Hueso largo indet.	–	Indeterminado	I15	12,85,245		
2018	182000070	Rib	–	Mammuthus meridionalis	G14	61,84,268	E-W	P
2018	182000838	Skull	Bone nuclei	Hemitragus albus	D11	20,82,283	N-S	W
2018	182000787	Pelvis	–	Equus altidens	D10	75,14,283	E-W	P
2018	182000655	Tibia	Fragment	Equus altidens	H14	97,8,282	N-S	N
2018	182000640	Astragalus	C	Equus altidens	J14	15,22,231	NE-SW	
2018	182000608	Metacarpal	Mc3	Equus altidens	D11	85,43,279	E-W	W
2018	182000441	Vertebra	Vertebra indet.	Indeterminado	H12	30,13,279	N-S	P
2018	182000187	Maxillary	–	Equus altidens	I14	22,10,277	N-S	S
2018	182000580	Patella	–	Mammuthus meridionalis	I14	35,55,274	N-S	S
2018	182000675	Femur	2–4	Mammuthus meridionalis	D10	47,18,283	E-W	W
2019	192000186	Astragalus	Left	Stephanorhinus etruscus	D14	65,45,243	C	P
2019	192000166	Metapod			G11	43,90,271	NE-SW	SW
2019	192000164	Frag. Tibia			H14	77,41,269	NE-SW	NE
2019	192000053	Calcaneus			H14	70,64,265	NW-SE	S
2019	192000173	Phalanx			I14	64,38,275	E-W	W
2019	192000128	Frag. Tibia			I14	17,75,249	NE-SW	SW
2019	192000194	Frag. Humerus			I14	62,40,264	NE-SW	NE

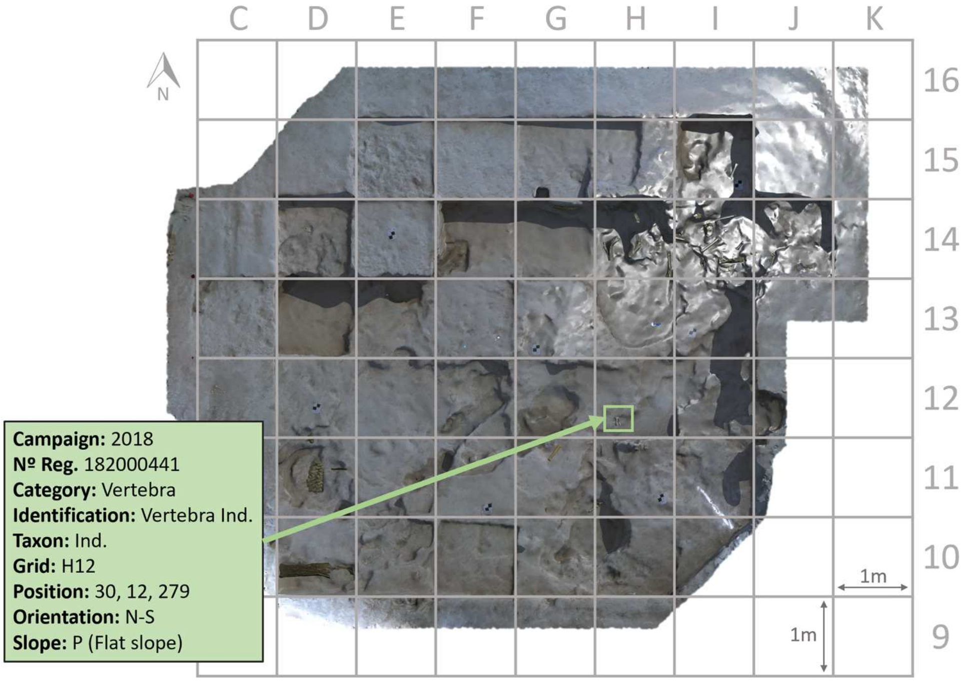

Figure 11. Archaeological site and remains of Venta Micena 4, including grid and an example of the data in Table 1. The origin of each square (0,0) is the southwesternmost corner. Most of the remains are located in squares H14 and I14.

that object in its corresponding Text Block. To develop this logic, a widget called WhilePickup was created, containing the visual script seen in Figure 14 as well as the graphic menu shown in Figure 12. In addition, two events were added to the BP_PickupCube_USQLite class with their corresponding logic, see Figure 15, to create the above-described effect. The on-screen ultimate outcome when picking up an object is shown in Figure 6.

2.2.4.2. Widget to data filter. The second widget, W2, can be invoked or hidden by pressing the B button on the Oculus Rift gamepad. When pressed, a floating menu appears, with the same position and orientation relative to the user's view. In other words, the menu follows all movements that users make with their head. This feature is based on logic developed and shared by Just2devs (2024). A piece of this logic is shown in Figure 16.

The logic behind W2 is quite complex and will therefore be broken down for complete description in the next four subsections. The first part, which we will call W2.a., contains seven drop-down menus corresponding to the seven columns of Table 1. The name of each drop-down menu matches name heading of each column: campaign, category, identification, taxon, grid, orientation and slope. Each drop-down menu is a combobox-type graphic object that contains all the different values that each previous variables can adopt. The logic that builds each drop-down menu is displayed in Figure 17.

The next part, designated W2.b, contains the filtering logic: the drop-down menus created in W2.a., the seven buttons with the text "Add", seven lines of text made up of graphic objects of textblock type, and a button with the text "Filter". This functionality allows

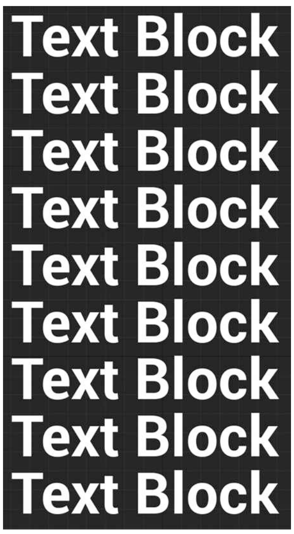

Figure 12. Unreal Engine Widget for the appearance of database variable values when collecting archaeological remains.

Figure 13. Unreal engine widget filter menu.

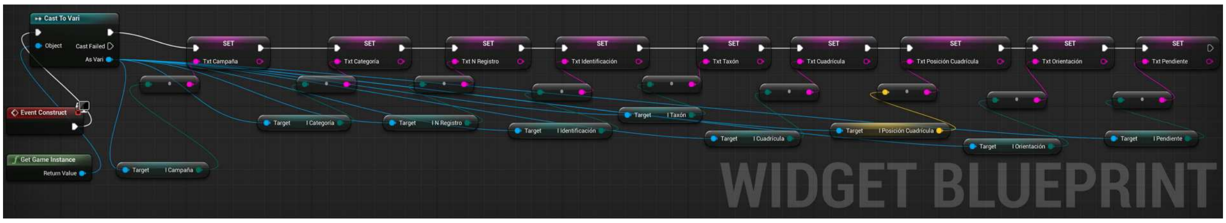

Figure 14. WhilePickup visual scripting.

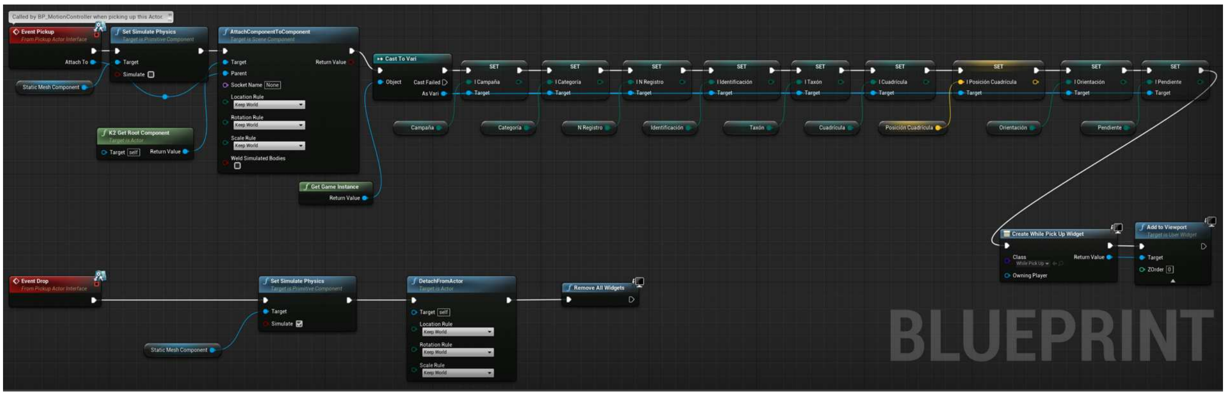

Figure 15. BP_PickupCube_USQLite Visual Scripting to show and hide the widget when picking up the archaeological remains or dropping it, respectively.

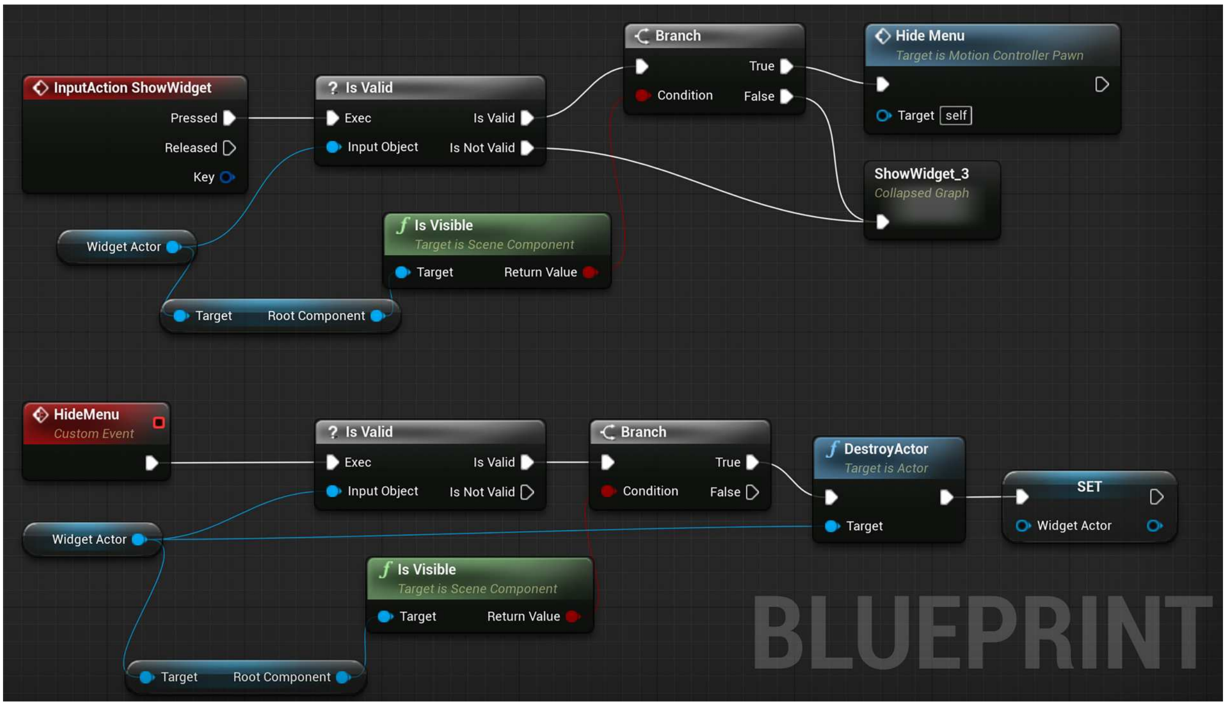

Figure 16. Part of the logic developed by Just2devs to show and hide a floating menu with a constant position and orientation relative to the user's view, invoked or hidden with the A button of the Oculus Rift gamepad.

the user to select one or more values for every variable from each drop-down menu, then incorporate them using the Add button to the text line corresponding to the added variable. The ensuing logic is presented in Figure 18. Once the values of the desired variables have been added, the user can press the filter button to leave inside the executable only those objects containing at least one of the selected values. The logic that performs the filtering is presented in Figure 19.

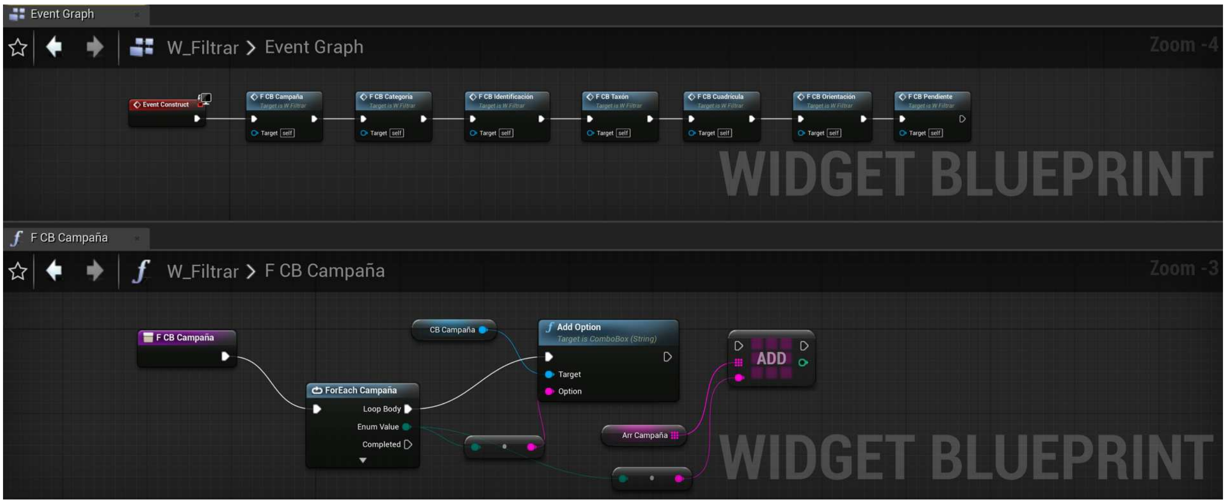

Figure 17. W2.a. Construction of each dropdown menu.

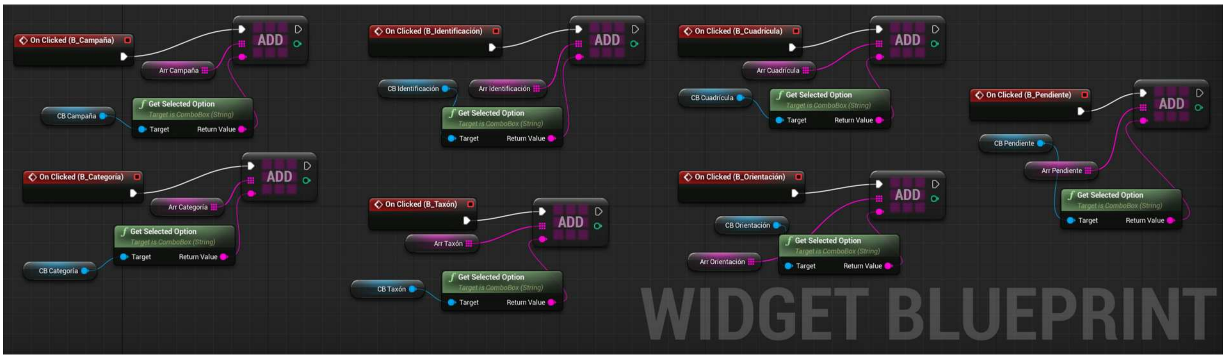

Figure 18. W2.b. Visual scripting to add text to the textblock.

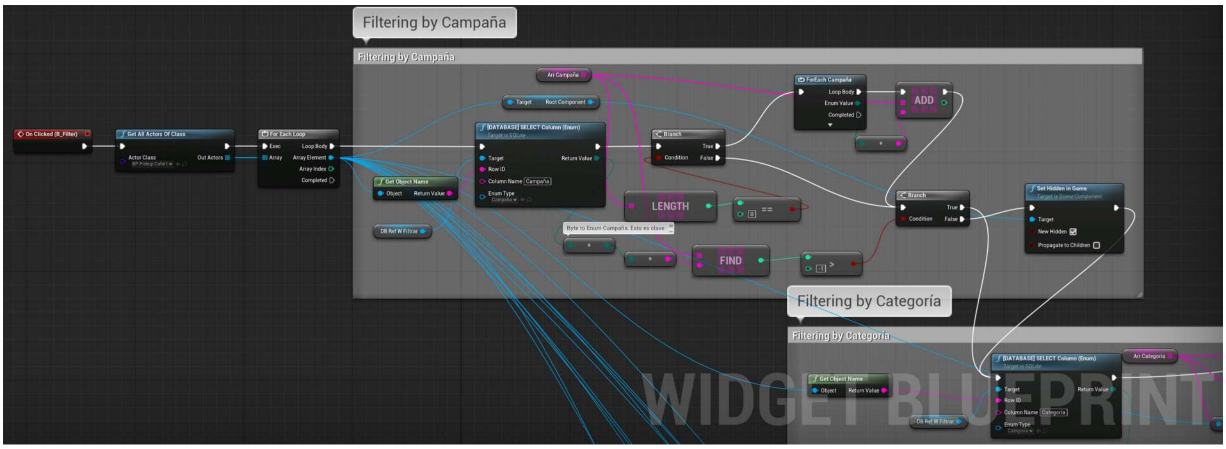

Figure 19. W2.b. Filtering logic.

The next part, W2.c., allows the user to reset the selection of the values added from the drop-down menus by pressing the Restart button. The logic that performs this reset is presented in Figure 20.

The last part of W2, called W2.d., allows the user to perform whatever filtering they wish to, without needing to undress the Oculus Rift system. One simply restarts the level using the Restart level button. The corresponding logic is seen in Figure 21. The on-screen ultimate outcome when filtering is shown in Figure 7.

By following the complete process described above, it is possible to develop an executable that integrates the virtualization of an archaeological site with the database of specific archaeological remains. The contribution of this research to science in general and to

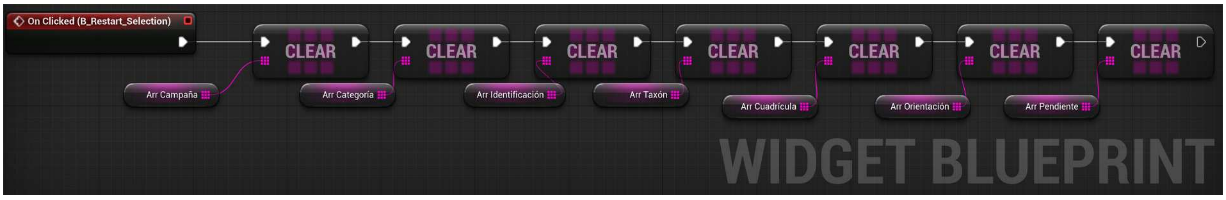

Figure 20. W2.c. to reset the selected and added values of each dropdown menu.

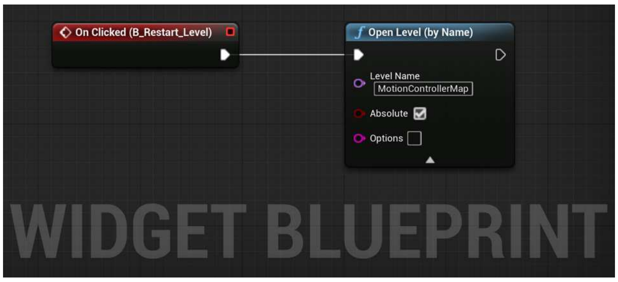

Figure 21. W2.d., to restart the level.

archaeology in particular will be discussed in the following section.

3. Results and discussion

The main result of this work is an executable stereoscopic viewer compatible with virtual reality glasses, developed in the context of the Venta Micena archaeological site (Orce, Granada, Spain), that allows any user to interact with the remains of the site and access the database to obtain information about each of the virtualized archaeological pieces, in this case, the 30 most relevant ones encountered at Venta Micena. The variables presented in the USQLite database are: campaign when found, record number, category, identification, taxon, grid, position, orientation and slope. Archaeological excavation faces a paradox: in order to generate scientific knowledge, it is necessary to dramatically disturb the preservation environs of fossils. This disruption affects many aspects of how the extracted elements were deposited and housed from the time they were buried until their recovery by specialists.

This paradox has led to many a reflection about the "nature" of excavation as a largely destructive activity. Sir Mortimer Wheeler, one of the fathers of modern Field Archeology, stated: "At best, excavation is destruction; and the destruction unmitigated by all the resources of contemporary knowledge and accumulated experience cannot be challenged too rigorously" (Wheeler 1954). Yet not all archaeologists agree with this viewpoint. Barker (1982) highlighted the character of "unrepeatable experiment". Venta Micena is located within Andalusia (Spain), an autonomous community whose government has powers in legislating matters of heritage, with the broad understanding that researchers excavate to preserve.

The underlying debate must weigh the importance of the archaeological objects themselves (fetishism), of the discoveries (Shanks and Tilley 1989), and the relevance of their meaning. Authors such as (Lucas 2001) focus on the hermeneutical nature of archaeological excavation. And over the years, documentation has become the quintessential form of information gathering in archaeology. The traditional means of collecting, ordering, and storing information in analogical archives have been greatly enriched by digital technologies developed in the past three decades, with the widespread use of personal computers and database software (Huvila, Sköld, and Börjesson 2021).

The tool presented in this work combines aspects of more traditional archeology with very recent developments. Thus, a virtual environment can be created to transfer the extracted fossils to study realms using the following information and elements:

- Georeference of the midpoint of the element in question (longitude, latitude, altitude);
- Orientation of the object in its greatest dimension;
- Slope (understood as the point towards which the fossil dives);
- Dimensions (to scale the elements once they are scanned);
- Photogrammetry of the site (with image taking as frequent as possible);
- Scanning of fossils.

The main advantage over virtual topographic surveys when fossils are *in situ* is that the material can be returned in all its volumetric complexity. For example, in VM4 it is common to extract the material with a "sediment bed" to prevent sudden changes, hence potential damage, in the conditions under which the fossils lie in the sedimentary matrix. They are transferred to the laboratory where, in more controlled conditions, they can be explored and restored if necessary.

Another advantage of this realistic and immersive executable stereoscopic tool is that it overcomes the "unrepeatable experiment" (sensu Barker 1982) character of archaeological excavations. That is, discovery cannot be repeated, although it can be less "unrepeatable". Such approaches allow interested members of the scientific community to have visual information closer to the reality of materials forming part of an archaeological site. The tool described here is not intended to replace the reservoir, since certain aspects of the physical sedimentary matrix cannot (yet) be recreated. But the position of the materials is transmitted with great precision, and their texture is reflected as well as currently possible. Altogether, the methodology described here represents an important research advance in terms of spatial distribution, particularly when the elements are highly interlocked or overlapping.

What this type of tool does not impose, in our opinion, is a paradigm shift. Author Kuhn (2012) held that paradigm shifts do not affect the social sciences. Later, Handa (1986) introduced the idea of "social paradigm shift" to refer to the social circumstances that might precipitate changes in our bodies of knowledge. Regarding the case at hand, no such change has emerged from the existence of so-called new technologies per se, but rather from the lowering of costs involved and simplification in the use of these technologies (Del Pozo et al. 2020).

What these tools do imply is the incorporation of new formats that abbreviate the physical distance that tends to isolate the focal point of research studies, and, from the point of view of dissemination, facilitate the incorporation of new audiences.

The capability to recreate an archaeological site, providing a maximum of information about it (database of the remains) becomes an invitation to anyone, anywhere, at any time, to travel virtually to the archaeological site to contemplate it and theorize with new ideas about the findings. Until now, a researcher who was not physically at the site could hardly make sound interpretations about it (Heilen and Manney 2023); nowadays, executable elements of the type proposed in this research reduce the gap.

Traditionally, working at an archaeological site may imply some wear-and-tear, erosion or compression due to the footsteps of the archaeologists themselves. It is very common for archaeologists to navigate the site with very firm steps and bare feet. Because the executable proposed in this research converts the site into a digital element, it can be revisited as often as needed without the site suffering damage. The same can be said of archaeological remains that are digitized and placed in the executable. It is possible to observe and even handle the objects without any damage whatsoever.

The manipulation of the archaeological remains presented in the stereoscopic viewer allows them to be extracted from the site with virtual hands, and viewed from all angles, just as if the archaeological remains were physically held. Additionally, when one starts the viewer, the objects are located at the same precise point, orientation and slope at which they were first discovered or extracted. Likewise, once the virtual archaeological remains have been isolated for observation, one can restart the viewer so that all the remains are placed in their initial extraction position. When picking up the object with virtual hands, the value of the variables integrated in the SQLite database appear on the viewer screen, giving the campaign in which it was found, registration number, category, identification, taxon, grid, position, orientation and slope. Likewise, the viewer allows filtering for each of the previous variables, interacting with the SQLIite database, thus helping the researcher focus on the aspects they consider most relevant. In short, a researcher can now tele-theorize about what was found at a given site.

The procedure put forth here may also streamline and facilitate the documentation and legal processes that research leaders must carry out before or during a campaign. The developed executable allows access to the archaeological site and the archaeological remains with just a few clicks.

Regarding the dissemination and spread of the executable, some legal questions arise that are not fully resolved and are proposed for future research. For instance it might not be best for society to have access to all data – both on the archaeological site and the remains located there – with a high level of resolution, unless they have previously identified and declared the use to be made of such key information (Luo et al. 2018). Therefore, we proposed that future endeavours be aimed to establish a Level of Detail for the dissemination of information on archaeological sites. A low Level of Detail could be posted on a website for any user, whereas the high Level of Detail would be reserved for persons who clearly identifies themselves and declare their interests with respect to the site data. More precisely, it could be said that a low Level of Detail is one compiled with a low resolution of meshes and their texture, lending minimal data on each archaeological remnant. In turn, the high Level of Detail could provide evens

In accordance with the human resources required to carry out this kind of works, it is necessary to count on technicians or a work team with knowledge of topography, having experience working with both hardware and software for the generation of 3D content, and adept at object-oriented programming in the arena of Virtual Reality. Knowledge of topography, 3D contents and virtual reality would be the bare minimum. Taking into account virtual reality research at archaeological sites to date (see Introduction), the most noteworthy contribution of our research proposal is the access achieved to the database of the archaeological remains to be studied found. In sum, this approach integrates a database from the excavation works with the virtualization of the archaeological site.

4. Conclusions

It is possible to virtually visit the Venta Micena archaeological site in Orce (Granada, Spain) and access the 3D model of the archaeological remains extracted from it, as well as the most relevant data. In this way, any researcher, anywhere and at any time, will be able to arrive at new conclusions based on the information extracted from the site. Following the workflow scheme outlined here, a given archaeological site, together with the database of the archaeological remains extracted from it, can be digitized for consultation.

For proper conservation of an archaeological site, its documentation is essential. Moreover, conservation is not just about preserving the integrity of fossils or knapped stone structures. Preserving also implies knowledge, as detailed as possible, of the context. The work described here enriches the documentation behind an archeological site, helping us to better understand its former and current contexts, therefore contributing to its conservation.

A main advantages of this type of tool, compared to the traditional methods (record sheets, photographs, etc.), is that the three-dimensional information of each element can be visualized in relation to the rest of the elements. This does not happen with photographs or drawings of traditional excavation plans and sections, which typically record the arrangement of excavated materials year by year. To obtain a comprehensive image, a new composite image with the previous plans and sections would have to be created. With the tool presented in this paper, a unique platform is created in which materials are integrated as they are excavated, recorded, and scanned. Another advantage is that elements appear in plan photographs without showing their full vertical dimension (topographically speaking). The scanning and virtual return to their original position resolves this limitation. Finally, we can adopt different angles for visualization and preliminary spatial exploration, not just fixed views (top-down and/or lateral).

Future work along these research lines might attempt to create a classified global repository of digitized archaeological sites that could be consulted by the scientific community. Furthermore, as hardware and software development continue to thrive, it will soon be possible to simulate the mass of objects, improve the detail in obtaining meshes and textures of archaeological remains, and recreate more complex environments.

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