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Reconstructive Archaeology: In Situ Visualisation of Previously Excavated Finds and Features through an Ongoing Mixed Reality Process

Miguel Angel Dilena [1,*] and Marie Soressi [2]

[1] Via del Carmine 4, 10122 Torino, Italy
[2] Faculty of Archaeology, Leiden University, 2300 RA Leiden, The Netherlands; m.a.soressi@arch.leidenuniv.nl
* Correspondence: dilena69@yahoo.it; Tel.: +39-338-5723-019

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Featured Application: This automatic 3D reconstructive process currently underway supplies archaeologists with a mixed reality (MR) technique that allows them to interactively visualise 3D models representing formerly extracted finds, and to position such models over the features still present at the archaeological site.

Abstract: Archaeological excavation is a demolishing process. Rather few elements outlast extractive operations. Therefore, it is hard to visualise the precise location of unearthed finds at a previously excavated research area. Here, we present a mixed reality environment that displays in situ 3D models of features that were formerly extracted and recorded with 3D coordinates during unearthing operations. We created a tablet application that allows the user to view the position, orientation and dimensions of every recorded find while freely moving around the archaeological site with the device. To anchor the model, we used physical landmarks left at the excavation. A series of customised forms were created to show (onscreen) the different types of features by superimposing them over the terrain as perceived by the tablet camera. The application permits zooming-in, zooming-out, querying for specific artefacts and reading metadata associated with the archaeological elements. When at the office, our environment enables accurate visualisations of the 3D geometry concerning previously unearthed features and their spatial relationships. The application operates using the Swift programming language, Python scripts and ARKit technology. We present here an example of its use at Les Cottés, France, a palaeolithic site where thousands of artefacts are excavated out of six superimposed layers with a complex conformation.

Keywords: mixed reality; 3D virtual site reconstruction; Les Cottés; in situ analysis; 3D virtual tour; automatic process; interactive simulation; 3D tablet application

1. Introduction

Techniques that incorporate digital content into the physical world are now numerous. In 1994, Paul Milgram and Fumio Kishino introduced the notion of a *virtuality continuum* among these methodologies, offering access to a virtual reality, a completely simulated virtual scenario digitally created, and actual reality, the physical world in which we live. Mixed reality (MR) procedures are typically positioned in the middle of such a continuum, merging both virtual and real contexts. In mixed reality approaches, physical and 3D digital objects coexist and interact in real-time [1]. Mixed reality superimposes and aligns virtual and real settings, rendering graphical information onto tangible items. It also anchors virtual objects onto the physical context, giving the user the possibility to acquire a high degree of interaction and collaboration with such a hybrid environment [2].

Advancements in input systems, display technologies, digital vision and graphical-processing enhancement have fostered the development of mixed reality in cultural heritage and archaeology. Indoor and outdoor mixed reality, augmented reality (AR) and virtual reality (VR) applications [3] have been created for educational [4,5] and exhibition purposes [6,7], virtual museums [6,8], reconstructing lost or intact archaeological sites [9] and manipulating, displaying and exploring in situ features [10] (see Figure 1).

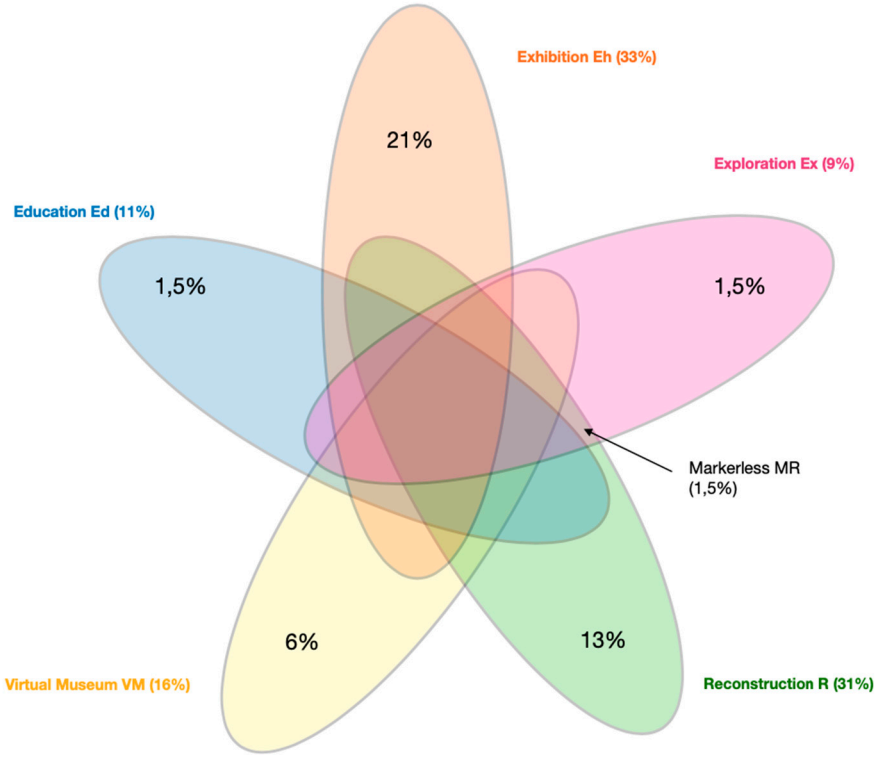

Figure 1. Venn diagram showing the percentage of implementations for distinct purposes used in cultural heritage and archaeology, based on the use of a single shared technology (e.g., markerless mixed reality, representing 1.5% of the total applications. Part of it overlaps both exploration and reconstruction purpose areas), after [3].

The markerless mixed reality approach refers to applications that depend on the natural features of a surrounding rather than the fiducial identifying images, which are markers containing visual hallmarks, to overlay virtual 3D objects into a real setting [11]. Currently, markerless mixed reality explorative/reconstructive applications account for less than 1.5% of the total *virtuality continuum* software programmes used in cultural heritage and archaeology [3]. The vast majority of this 1.5% consists of cultural heritage projects, and only a small portion are archaeological applications [12,13]. Furthermore, from this fraction, a limited number of projects deal directly with the field of excavation. There are some pioneering examples among them [14–16], as well as some more recent approaches [17–21]. These works often offer tridimensional reconstructions of a site (e.g., structures, buildings, walls, gardens, etc.) by using mixed reality. Very few projects propose MR approaches that enable the archaeologist to see the finds as they were discovered and in correspondence with the features still present at the excavation.

Here, we aim at facilitating access to an innovative application for reconstructing and exploring previously excavated sites by providing archaeologists with a device that directly interacts in situ with both virtual (formerly extracted) and real finds. From this perspective, the current approach contributes to what is called v*irtual heritage*, i.e., the utilisation of computer-based interactive technologies to register, preserve or recreate artefacts and sites of cultural value [22].

When visiting a formerly unearthed archaeological area, it is hard to mentally conceive or reconstruct the precise location of every discovered find. Few elements physically persist after the extractive operations. A previously excavated site often maintains only the bedrock, natural terrain and maybe some sections. Likewise, when returning to a formerly unearthed area for taking samples of a preserved section, it frequently necessitates a long series of measurements with a total station to identify where features close to that section were before the extraction. Even then, researchers cannot directly experience or envision previously excavated finds in a 3D space. Mixed reality reveals opportunities that until quite recently were limited to our imagination [23]. We present here a mixed reality application employed in archaeology that enables the visualisation of formerly unearthed finds.

2. Materials and Methods

Mixed reality techniques enable archaeologists to perceive a final composite scenario constituted by two settings. On the one hand, video cameras installed in mobile devices capture the real environment. On the other hand, 3D software modeller scripts automatically produce digital 3D models displaying the previously unearthed finds, excavation landmarks, sediment samples and geological layers.

To showcase the applicability of our mixed reality application, we chose the site of Les Cottés, located in west-central France [24]. Les Cottés consists of an artificial indoor underground excavation: $10 \times 12 \times 4$ m. Such compact dimensions facilitate the implementation of a mixed reality approach [25]. The Les Cottés cave preserves occupations dated to circa 50 to 35,000 years ago [26], divided into nine stratigraphic units spread over a sequence measuring up to 4 m in depth (see Figure 2).

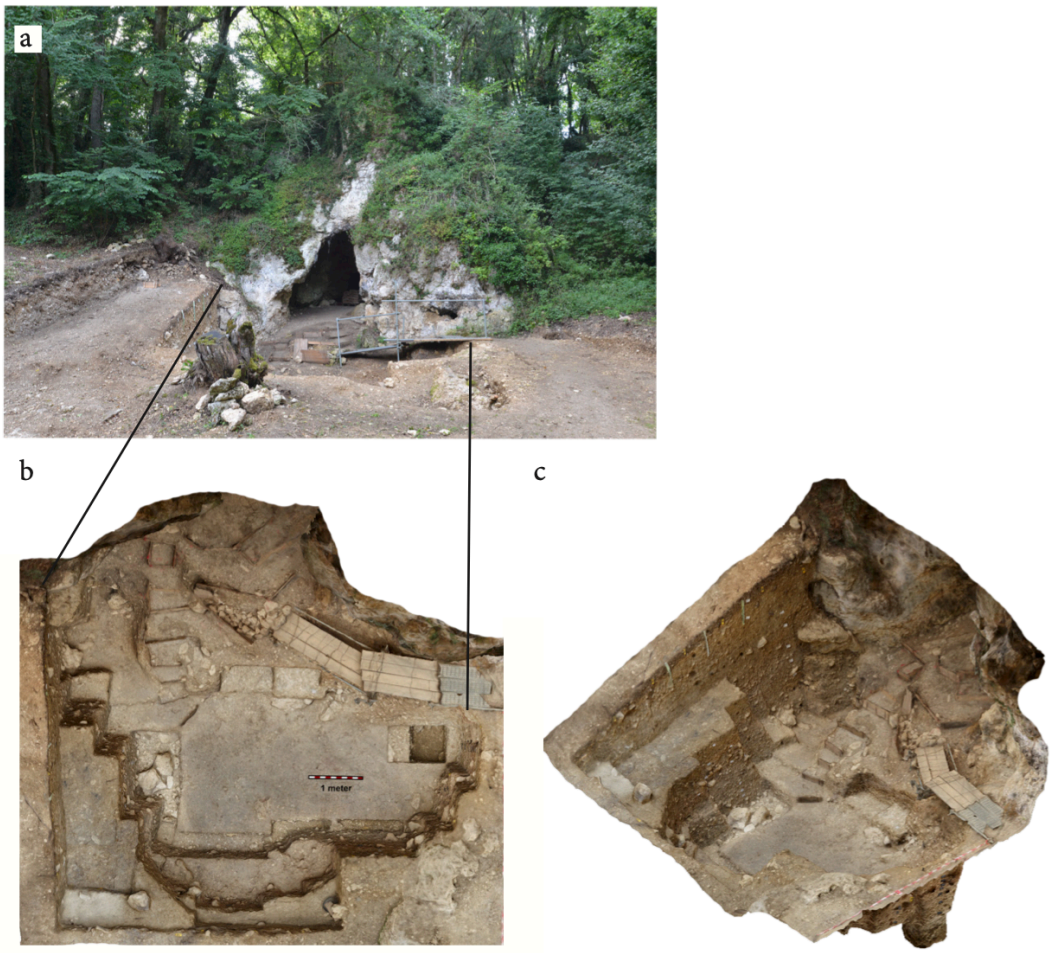

Figure 2. View of the Les Cottés cave (**a**). Plan view (**b**) and oblique view (**c**) of the excavation at the foot of the cave (a 3D model of the excavation area is available in [27]).

To create a mixed environment that will enable the operator to move freely and interact therewith, we included two computational platforms into the architecture of the Les Cottés mixed reality system. The hardware platform comprises an Apple™ iPad 6th generation tablet. The software platform consists of four components with their respective processes (see Figure 3):

- A *database software component* that extracts the relevant information from the excavation database (DB) to standardise it and produce external data compatible with the platforms.
- A *mesh-creator software component* that automatically creates 3D models (meshes) by relying on the above-mentioned normalised data that reflects the positional characteristics of artefacts, landmarks, sediment samples and geological layers encountered during archaeological work.
- A *locator software component* that receives such virtual models and combines them with real-world features to position them while respecting the volumetric profile of the physical context.
- A *visualiser software component* that interactively shows the combined environment in real-time and provides display and analytical facilities to interact with it.

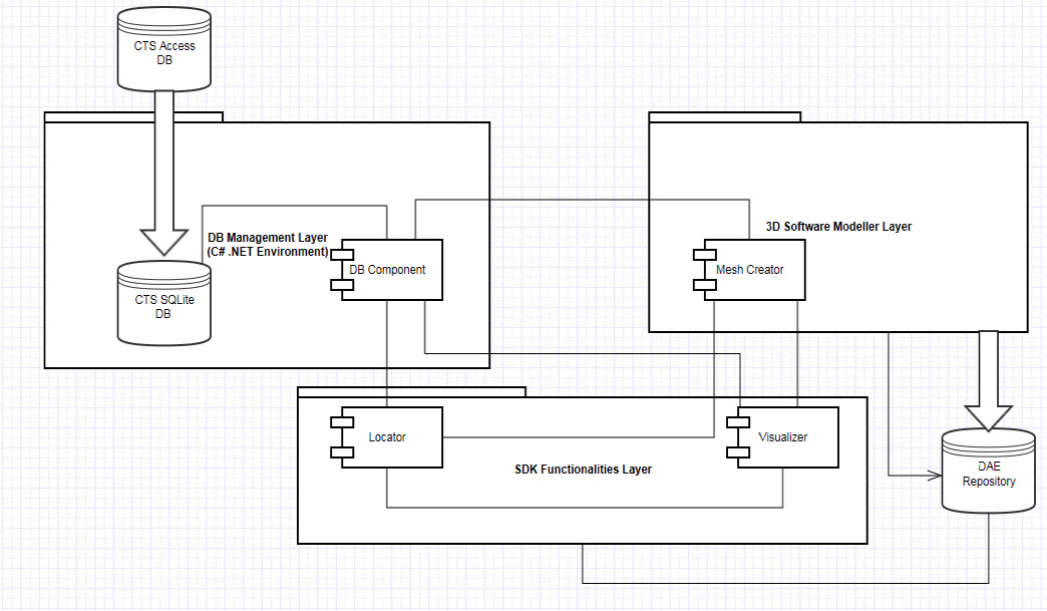

Figure 3. Les Cottés (CTS) mixed reality software platform.

Accordingly, the software platform organises these four software components into three distinct digital environments or layers:

- The DB component in a *DB management layer* that uses the C# language enclosed in the Microsoft™ Visual Studio for Mac framework (v. 7.5 build 1254 integrated development environment (IDE));
- The mesh-creator component in a *3D modeller layer* that utilises a script in the Python environment (v. 3.5.3 integrated script interpreter) in Blender (v. 2.82);
- Both the locator and visualiser components in a *software development kit (SDK) layer* that employs, on the one hand, Xcode (v. 11.4 11E146) and Swift (v. 4.2) for programming, and, on the other, an operating system (iOS 13) for its execution on the iPad.

Both hardware and software platforms interact through a predefined software tool, namely SDK [28] (ARKit v. 2.0 for the current implementation), which represents the predefined instrument that supplies mixed reality functionalities. These comprise (a) the rendering facility that combines the real-world scenario with the virtual one, (b) the tracking facility that localises and anchors 3D models in the composed scene and, finally, (c) the displaying facility that visualises the composite environment.

2.1. DB Management Layer

The Les Cottés excavation has operated a Microsoft™ Access Database as a primary source of data recording over the last twelve years (2006–2018) [24]. Such a database uses a univocal identifier (ID) (Les Cottés database calls this code square ID (SQUID)), automatically assigned by the total station during the recording phase, to distinguish each find and its related data. Different relational tables organise such values for reconstructing the Les Cottés artefacts and, more generally, any archaeological element, e.g., landmarks, sediment samples and strata limits. The present implementation primarily considers five main attributes:

(a) **Identification (ID).** One univocal code unambiguously identifies each archaeological find. It serves as a primary key in the database and corresponds to the same ID, which determines the related 3D model in a tridimensional repository. Therefore, such an ID permits the association of database information with the 3D model's repository data and vice versa.

(b) **Position (3D coordinate point(s)).** A local tridimensional reference system (x, y and z) related to a specific spot-mark within Les Cottés describes the position of each point (3D coordinate).

(c) **The number of recorded point(s).** The implementation also defines three types of archaeological finds based on the number of points measured on-site: punctual (one point), bipunctual (two points) and multipunctual (more than two points). In the front row, the punctual type corresponds to an artefact for which the overall dimensions are longer than a minimum size (e.g., 2 cm), and whose centroid represents the 3D coordinate. Likewise, the bipunctual type coincides with elongated objects (one axis is twice longer), whose edges are the coordinate points. In the end, the multipunctual type represents composite objects, which own several 3D points that can be linked to describe a volumetric shape.

(d) **Stratigraphic unit (US) of provenance.** Archaeologists extract artefacts from stratigraphic units that arrange the sequence of sedimentary depositions into different ranges of chronology and are commonly associated with a distinct cultural tradition (e.g., archaeological industry).

(e) **Material.** The production material(s) (e.g., flint, generic rock, bone) can also categorise the find.

These five attributes can completely describe the 3D model of a find extracted from any excavation, including Les Cottés. Therefore, the current implementation, through an ad hoc C# programme, queries the Les Cottés database to fetch these five attributes and create one comma-separated value (CSV) file for each find. Thus, this strategy allows saving this information in a standardised way and makes any external data compatible with this process.

It is important to mention that since the Les Cottés Access database is not compatible with Apple™ technologies, it underwent a transformation into a corresponding SQLite database (v. 4.3.0) by utilising external procedures, which make it suitable to be completely incorporated into the iPad. Therefore, it is worth noting that the current application entirely includes such an SQLite database.

2.2. 3D Modeller Layer

According to the previous description, 3D coordinates can assign a position to every generated model and, following this reasoning, the dimensions and orientations of bipunctual and multipunctual elements as well. From this perspective, particular tridimensional shapes, meshes, can symbolise both the dimensionality and material composing a find (e.g., a cube can represent a punctual flint artefact, and an entire spherical pipe can denote a bipunctual flint artefact) (see Table 1).

Similarly, specific colours, namely textures, on the 3D model presentation can typify the stratigraphic unit of provenance (e.g., a green texture can indicate the US08 stratigraphic unit, and a blue texture can indicate the US06 stratigraphic unit) (see Table 2).

Table 1. Typology vs 3D shape used by the Les Cottés mixed reality (MR) application.

Typology	3D Shape
Punctual lithic (PL)	Cube (1 point)
Elongated lithic (EL)	Entire spherical pipe (2 points)
Punctual rocks (PR)	Pyramid (1 point)
Dimensional rocks (DR)	Six-point connected pipe
Punctual bones (PB)	Sphere (1 point)
Elongated bones (EB)	Half spherical pipe (2 points)
Geological/dating sample (GS/DS)	Bell shape (1 point)
Geological-level limits (GL)	Multiconnected pipe (several points)

Table 2. Stratigraphic unit vs colour used by the Les Cottés mixed reality (MR) application.

Stratigraphic Unit	Colour
US01	Light green
US02	Yellow
US03	Orange
US04 Upper	Red
US04 Lower	Brown
US05	Violet
US06	Blue
US07	Cerulean
US08	Green
Dating sample	Cyan
Geological sample	Beige
Geological-level limits	White

From this optic, the mesh-creator software component, through a 3D toolset graphic environment (Blender), receives the group of CSV files created during the preceding phase and employs a Python script to generate and organise the 3D models into a digital asset exchange (DAE) repository. DAE constitutes a 3D interchange file format that complies with ARKit v. 2.0 for digitally codifying 3D models.

With the five attributes (ID, position, number of points, US and material; see Section 2.1), such a script fetches every CSV file to produce the related typology of the artefact (see Table 1), a predefined 3D shape (punctual, bipunctual or multipunctual) that takes into account the number of recorded points, their position, and the find's material. Likewise, the colour is univocally assigned to that 3D shape based on its stratigraphic unit (see Table 2). Subsequently, the resulting 3D model is uniquely identified by allocating the ID as its filename. In this light, every 3D model is generated on an accurate positional basis (georeference) (see Figure 4).

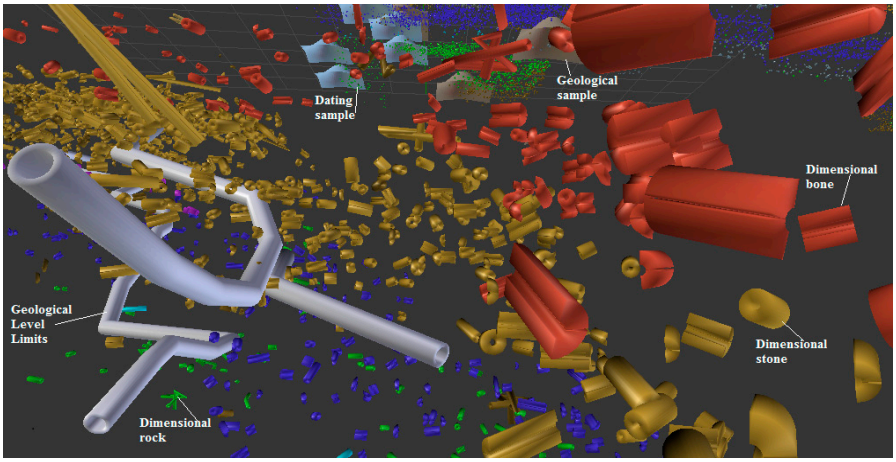

Figure 4. Example of Les Cottés georeferenced 3D models.

Additionally, the script uses an editable configuration table for customising both couplings, typology vs 3D shapes (see Table 1), and the colour vs US (see Table 2). Accordingly, the user can apply at will, and in conformity with the dimensionality of the find, other combinations besides those shown in the current manuscript. Such associations do not follow any standard. Hence, they are solely decisions made by the user for adapting the application to a specific excavation guideline. Should it be necessary, the programmer could add additional 3D shapes to the script to represent other materials.

In a nutshell, the mesh-creator software component generates a spatial tridimensional database that contains the whole group of 3D models related to the excavation. Such a database univocally distinguishes a particular 3D model using its corresponding unique ID. Furthermore, it is relevant to point out that the 3D spatial DAE repository is entirely embedded in the application. Therefore, the time for interacting with 3D models is much faster. Similarly, such a 3D database (<1 GB) can be easily shared among the specialised target audience.

2.3. Software Development Kit (SDK) Layer

Bearing in mind that the script generates each 3D model with a positional accuracy criterion (3D coordinates), the present process can spatially arrange the entire group of such models (archaeological assemblage(s)) as a cluster that can move as one so that the same separation and orientation are always constant among the finds. According to the same principle, ARKit v. 2.0 allows the mobile device to display artefact aggregation in unison.

Therefore, the archaeologist can anchor such a cluster to the excavation profile by utilising several permanent landmarks on the terrain and use them as a visual guide for tying up the cluster.

To reach this goal, the user selects each required 3D landmark model on the mobile display and, through the tracking facility, the locator software component fixes that selected virtual landmark to the physical tag on the ground, slotting in a precise match between the virtual and real world.

It is worth noting that the more anchors tie the cluster up to the excavation contour, the more stable the cluster remains (see Figure 5).

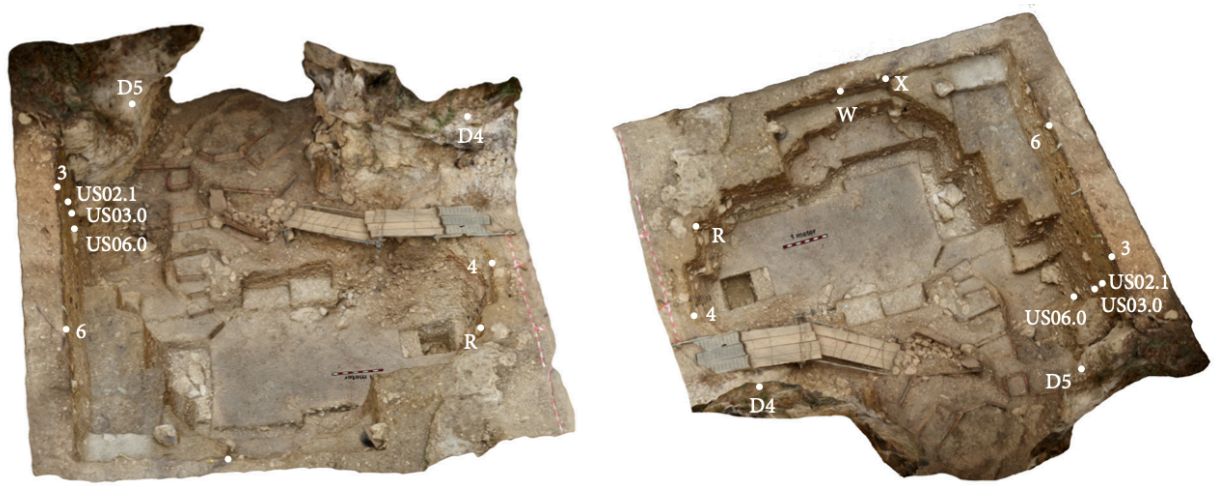

Figure 5. Cavity landmarks (tags) that align the 3D cluster in the MR application.

Additionally, the current mixed reality application employs a 3D photogrammetry model of the Les Cottés cavity to integrate and combine the 3D cluster with a virtual 3D excavation trench. The incorporation of these two 3D models allows anchoring the composite recreation anywhere, providing the public with the possibility to experience a virtual 3D-tour around the excavated site. Therefore, the user can leave such an integrated 3D photogrammetry model on the screen to accomplish a virtual visit to the site (see Figure 6). Alternatively, when on-site, this can be turned off to view just the 3D models right on the real physical terrain without any other obstacle.

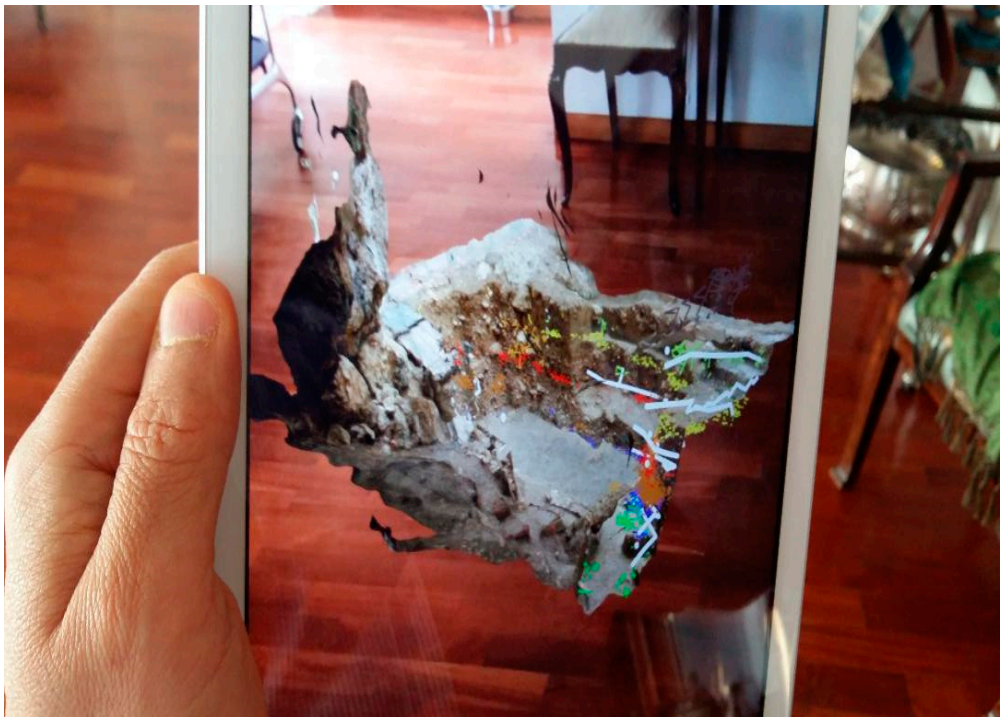

Figure 6. Scaled-down version of the Les Cottés MR application.

For its part, the visualiser software component can scale the complete cluster, permitting the archaeologist to exploit real-scaled, upscaled or downscaled model versions on the MR application (see Figure 6). Likewise, this component automatically activates the unzooming and zooming actions on the mobile screen depending on whether the MR application is moving away or towards a specific position.

In this light, the SDK Layer uses ARKit v. 2.0 to perform the location and visualisation of 3D models through embedded methods, namely application program interfaces (API), coded under an Xcode framework utilising Swift.

3. Results

The construction process of the Les Cottés MR architecture has generated two principal outcomes:

(i) It produced a spatial 3D database containing tridimensional models (DAE) that chronologically and stratigraphically describe the entire excavation by representing every single archaeologically unearthed element and associating such virtual evidence into groups utilising specific shapes and textures. It is worth mentioning that this standard 3D model repository can be employed by 3D graphic tools on a desktop environment.

(ii) It built a mixed reality computational application that works with the previous 3D models to interactively position and visualise them in situ through a mobile device.

In brief, the current approach reconstructed the entire excavation using fully computerised 3D modelling and mixed reality techniques.

From the desktop perspective, a 3D computer graphics software toolset like Blender can upload the whole spatial 3D repository and visualise the 3D models (DAE) on the screen. Hence, the researcher can also recreate the entire excavation on a personal computer (PC). The desktop environment enables archaeologists to use the graphics tools embedded in the 3D software toolset (Blender) for measurement and analytical purposes (rulers, view display facilities, rotations, translations and reflections and graphical filters) (see Figure 7). Moreover, the desktop approach also allows examining the digital site context by applying zooming and scaling commands to generate projections.

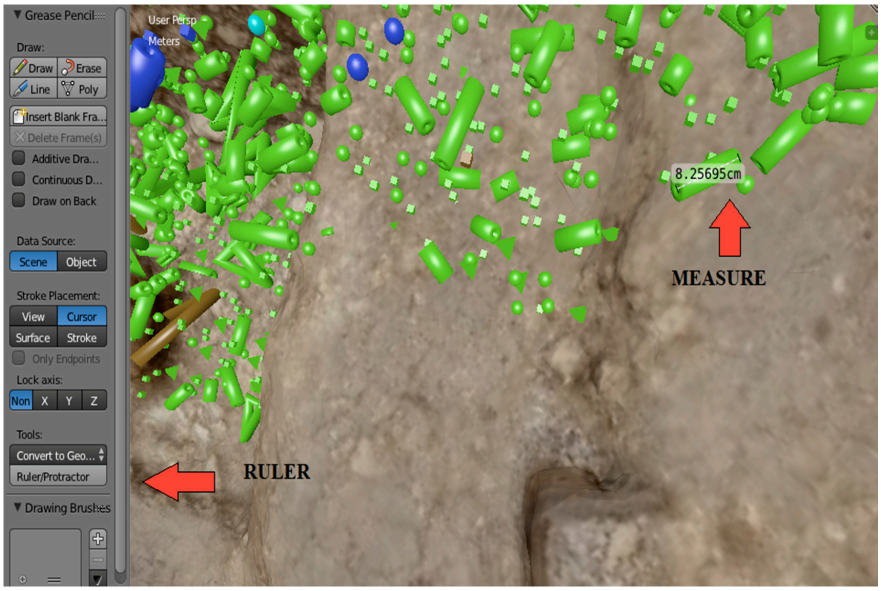

Figure 7. A ruler measures the length of a 3D model in a desktop environment.

Furthermore, the creation of a spatial 3D database permits the mixed reality application and the desktop environment to formulate all types of queries and apply filters for showing particular aspects (e.g., stratigraphic units (US)) or targeted researches (e.g., explicit artefacts) on the virtual excavation area. Such a goal can be achieved by employing both the complete Les Cottés database (SQLite) and primary key (ID), which univocally identify every 3D model. For this purpose, and as a first step, the user can apply on a query form any possible inquiry to the SQLite DB for grouping finds by specific properties (e.g., stratigraphic unit, material) for filtering data by other information included in such a database (e.g., date of excavation, excavator), carrying out joint queries by connecting different attributes (e.g., searching two diverse materials into three distinct stratigraphic units for instance) or identifying an individual artefact. Once the inquiry has fetched the appropriate IDs involved in the database, the application can display those elements by rendering visible the related 3D models. Thus, the database software component can eventually convert any archaeological query into a perceivable 3D result (see Figure 8).

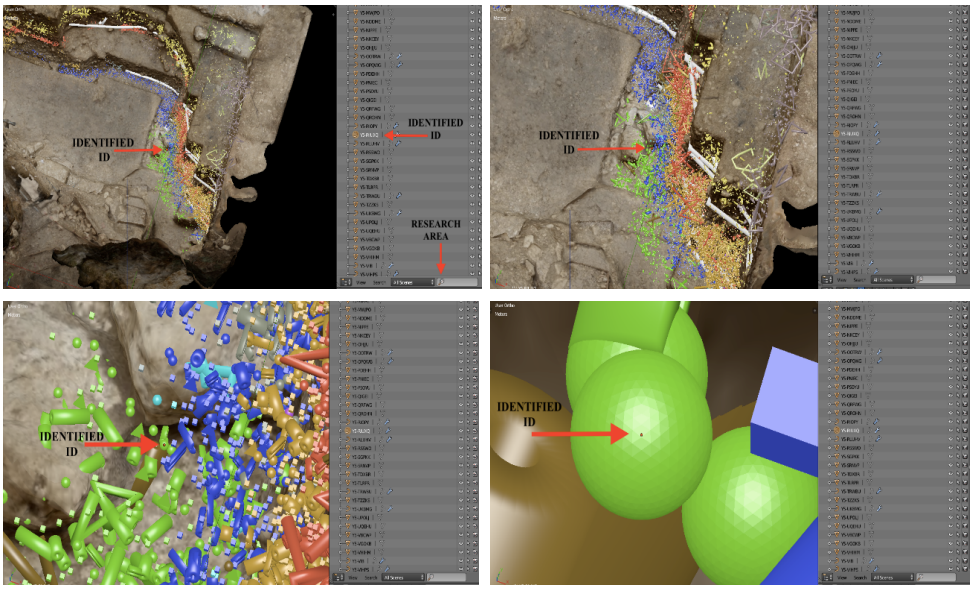

Figure 8. Targeted search for archaeological evidence.

Conversely, by clicking a 3D model, the user can obtain its associated ID, which can be employed to automatically fetch additional information from the SQLite DB (pictures, notes and any analyses previously made on the artefact) in conjunction with the standard data relevant to the find. In this light, archaeologists can graphically detect possible anomalies enclosed in the 3D model itself, and therefore in the original database, by selecting a 3D mesh that explicitly does not match the corresponding physical find (see Figure 9).

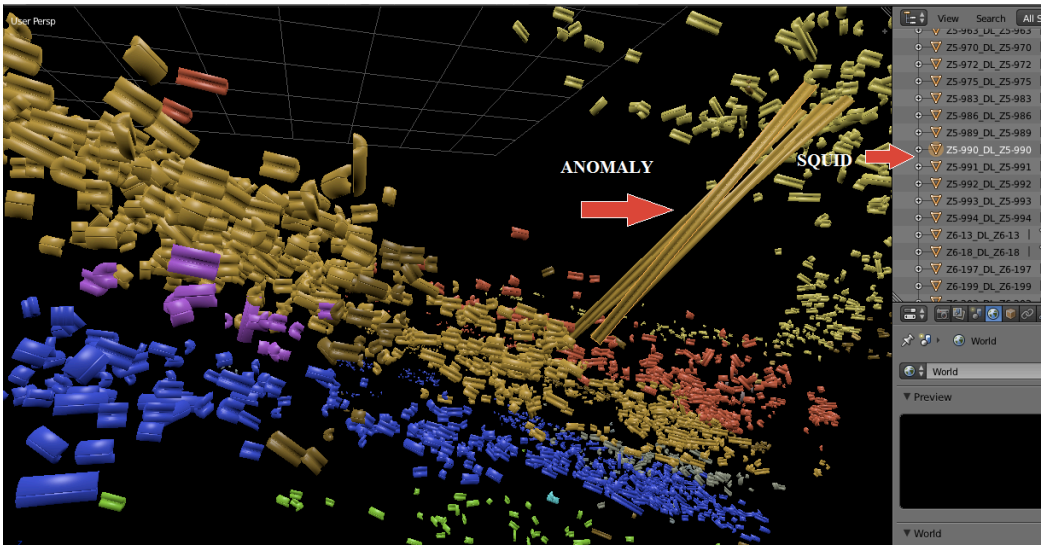

Figure 9. Selecting an abnormal 3D model to retrieve its identifier (square ID (SQUID)).

From a mobile perspective, by using a tablet (i.e., iPad), the ARKit v. 2.0 allows the MR application to accomplish automatic actions while moving around: zooming, unzooming, scaling and visualising different angles and outlooks. Additionally, it enables archaeologists not only to place the MR application on-site and aligned but also situate the implementation anywhere as a simulated environment.

Additionally, from a publishing standpoint, the current 3D model approach enables the possibility of using a universal 3D (U3D) portable document format (PDF) [29], which can readily visualise the entire tridimensional cluster of the excavation on a PDF document. Such a U3D PDF protocol interactively presents digital models with an improved graphical result, allowing archaeologists to zoom, rotate and scrutinise complex stratigraphy in detail.

In short, the previous operations permit users to interactively analyse, in a targeted manner, correlations between 3D models and real finds. Therefore, the researchers can verify such correspondences by visually comparing in situ or through a desktop environment, such as dimensions, positions, orientations, materials, the stratigraphy of provenance and general information.

4. Discussion

The above-mentioned aspects describe relevant topics that further emphasise the advantages that a mixed reality process can provide to the archaeological world, in which the archaeologist passes from a bidimensional representative concept to a complete tridimensional perception of the excavation (see Figure 10).

The development phases of such methodologies can present some technical and practical limitations. However, they also permit discovering unexpected results and highlighting novel avenues for future research.

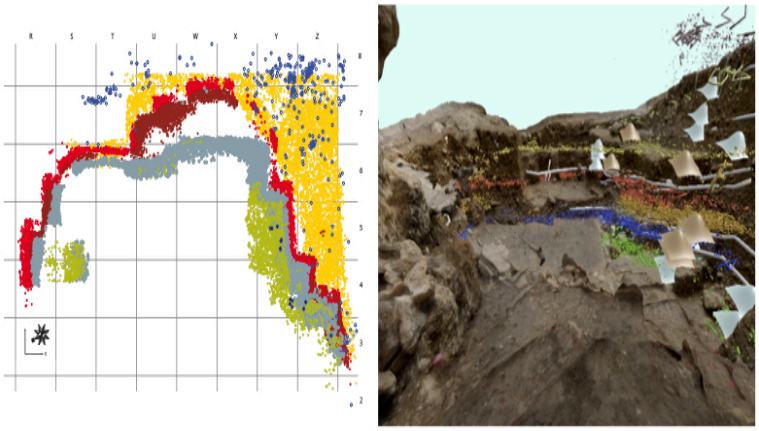

Figure 10. (left) Distribution of assemblages (bones and flint) at Les Cottés, after [24]; (right) distribution of assemblages (angular view) (bones, flints, samples, rocks and geological layers) at Les Cottés.

4.1. Limitations

(i) Memory. More than 35,000 artefacts and features were excavated and recorded during the Les Cottés excavation project [24]. Therefore, the current technological representation of such a vast quantity of elements would hinder the memory capacity of the mobile device. Consequently, it is noteworthy to emphasise that the script should reduce the number of faces and clean up some edges to render the 3D model of the artefact as simple as possible. Moreover, a further enhancement could be achieved by separating the 3D model's data loading and the scene instancing. Finally, a progressive rendering approach should also improve the performance of the application.

(ii) Precision on the positioning. A further aspect deals with the manual positioning of the 3D model clusters by utilising georeferenced graphical markers as anchors. It is important to mention that such a technique has to intrinsically operate a detection of the contour of the structure (plane) on which the virtual object needs to lie by using tracking methods supplied by ARKit v. 2.0. Nevertheless, the anchoring process faces several repositioning problems due to mainly two factors:

- A loss of precision in the sensor device (inertial measurement unit (IMU)).
- A deterioration of alignment accuracy due to a reduction of light detection.

Such anomalies render the position of the 3D cluster unstable and can create a flickering effect that may complicate the interactive examination by the archaeologist in situ.

At this point, it is useful to highlight that by employing the manual placement, the in situ positional precision of the 3D cluster depends on both the visual accuracy of the operator and the number of anchors utilised. We estimate, from our mensuration, that it may vary up to several centimetres (±5 cm), even if an exhaustive statistical analysis of uncertainty and error measurements has not been accomplished due to the inaccessibility of the site at the time of this writing. Hence, such examinations remain outstanding and should still be completed.

Instead, the employment of a nonelectronic marker-based positioning, namely graphical pattern signs, could bring the profiles into line with higher precision (estimated to ±1 cm). However, in this case, the excavation must provide different permanent markers as anchors on its contour.

Finally, it is significant to remark that the desktop environment permits the photogrammetry skeleton and the entire 3D excavation cluster models to fit together with high precision for analytical and positional purposes (same scale and references).

(iii) Blurry visualisation. In particular scenarios, some 3D models show a blurry contour on the image. Such unclear result derives from the rendering methodology applied by ARKit v. 2.0 on the format of the model (DAE) since the same visualisation in Blender does not raise this problem.

(iv) Extension of the site. Every archaeological site can implement the procedures applied for the Les Cottés cave. However, in the case of extensive excavations, the process should subdivide these broad areas into smaller spots, simulating a continuity among the different subsites and simultaneously dealing with each one by employing distinct anchoring references.

4.2. Future Research

(i) Portability of the mixed reality application. Xcode can install the current mixed reality applications onto other Apple™ devices (i.e., iPhone, MacBook) without accomplishing any further technical action. Therefore, such implementational versatility could increase the number of users interested in this MR methodology. Furthermore, Blender provides the possibility to export 3D models that reside in memory into diverse formats, not only DAE, without any additional step. Such flexibility permits employing the same 3D models by other software development kits. Similarly, multiple operating systems (i.e., Windows™ and Android™) can carry out comparable versions of the current MR application simply by applying slight variations in the code. Hence, such technological portability enables users to operate other types of innovative appliances, allowing stereographic rendering (e.g., smart-glasses by Windows™, i.e., Hololens). Nevertheless, these devices can be very costly to a final user. From this perspective, our primary intention was to render the application accessible to a vast public by downloading it to everyday appliances like tablets (iPad) or smartphones (iPhone).

(ii) Positioning. The excavation could integrate a network of electronic marker-based devices, namely beacon Bluetooth/Wi-Fi gadgets, to strengthen the accuracy in placing the 3D cluster on the profile. From this perspective, any archaeological site, regardless of its extension, could apply such aligning techniques, rendering the present study easily transferable to other types of contexts.

(iii) Additional valuable information in the original database. It could be valuable to integrate the original excavation database with Supplementary Data such as photographs, analyses, graphics or even digital scans accomplished on the evidence. The MR application could smoothly retrieve such details, improving the information provided to the archaeologist after any given query.

(iv) Creation of tridimensional distribution maps about a particular group of artefacts. Similarly, it might be useful to include information about significant features concerning each artefact in the excavation database. Such attributes can indicate if the archaeological find seems to be connected to other artefacts (refit) depending on whether it presents evidence of heating or retouch or shows indications of being recycled. With such physical characteristics, the entire process could create 3D distributional clusters by pinpointing the 3D models involved in those allocations. It is worth noting that previous research has, in the case of burnt evidence [30] or artefact refits [31], bidimensionally emphasised such representations. However, the 3D distributions improve the level of comprehension inside the context, providing a filtered panorama about what the archaeologist volumetrically requires to identify over the excavation's lifetime.

(v) Generation of tridimensional plaster representing stratigraphic levels. Three-dimensional (3D) meshes of stratigraphic levels (layers), in the manner of tridimensional plasters, are remarkably convenient to visualise the context in which each find is embedded [32]. For reconstructing an approximation of the stratigraphic levels at Les Cottés, we could utilise the geological-level limits (see Tables 1 and 2) associated with the horizontal topographic boundaries to build parallelepipeds that represent the partial volume of every extracted stratigraphic level at a specific moment of the excavation process. The MR application could render such plasters visible on-demand.

5. Conclusions

The current methodology produced two computational approaches that permit reconstructing and visualising on a personal computer screen, as well as at the site itself using a tablet, the product of a completed excavation.

In the first instance, it created a 3D model database containing the tridimensional representation of each find. Secondly, but no less significant, it generated a mixed reality application that superimposes the previous 3D repository over features left at the site.

Throughout the development process, a Python script automatically produced individual digital models for each artefact, landmark, sediment sample and geological layer extracted during the excavation. The creation of such meshes employed specific 3D symbolic representations (shapes and textures) in reliance on the tridimensional coordinate (x, y, and z) and the material registered on the excavation database. Hence, each archaeological find generated one 3D model. The collection of these singular models constitutes the 3D spatial database.

The mixed reality application can be used on a mobile device to display the 3D spatial database at the archaeological site while keeping freedom of movement and the selection of a specific area of the excavation. This kind of visualisation allows the user to make spatial correlations between the digital models and the physical evidence still present at the archaeological field. Therefore, the archaeologist can immediately visualise and locate artefacts and features unearthed in previous campaigns in relation to finds still present at the site, as well as the specific location of these archaeological elements. The user can interactively query the database to show only the 3D digital finds of interest. Likewise, the information connected to a specific 3D object can be retrieved by clicking the concerning element on the display of the tablet.

In summary, the 3D reconstructive process described here supplies archaeologists with technologies allowing for a visual and positional comprehension of a previously excavated site. Such innovative methodologies are notably relevant when the exact spatial positioning of artefacts represents a significant matter. Both the current 3D process and its associated mixed reality implementation provide archaeologists with computational tools to interactively study the complete excavation in situ by utilising visible spatial databases and positional correlations. More generally, they automatically recreate the entire site and its excavation history, pioneering a new dimension of reconstructive archaeology.

Supplementary Materials: The following are available online at http://www.mdpi.com/2076-3417/10/21/7803/s1. See below a series of links to short videos demonstrating central aspects of the process. It is noteworthy to remark that we were not able to record videos at Les Cottés due to the inaccessibility of the excavation at the time of this writing. These preliminary recordings were made off-site. They show some of the results mentioned in the current paper: https://youtu.be/5mYer0QjRFQ Simulation on a slope. https://youtu.be/7prb15wVGR0 Virtual visit on a surface. https://youtu.be/pcdwJ82ReMU Scaled simulation. https://youtu.be/uJCxtUhHLmU (Un) zooming facility. https://youtu.be/RskY0gKXXdM Anchoring.

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