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INFORMATION TECHNOLOGY AND ARCHAEOLOGICAL EXCAVATIONS: A BRIEF OVERVIEW

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ABSTRACT

The age we live in is the age of the technological revolution: the social networks, virtual communities, 3D worlds, digital applications, immersive and collaborative games, are able to change our perception of the world as well as the way information is shared and transmitted. The shift of our society towards new technologies has greatly facilitated the integration of these technologies (Virtual Reality, Augmented Reality, Photogrammetry, etc.) in places such as archaeology, which in the past seemed like a very difficult idea. In recent years, archaeologists have begun to incorporate new technologies that can assist them in archaeological excavations. Such technologies include 3D Imaging Surveying methods (LiDAR, Mobile and Terrestrial 3D Scanners), Unmanned Aerial Systems (UAS), Photogrammetry as well as 3D Visualization Methods (Virtual and Augmented Reality) for the three-dimensional or two-dimensional display of sites where archaeological excavations are carried out. A big advantage of new technologies is the highly increasing capabilities and user friendliness over cost ratio, which encourages archaeologists to enter the emerging realm of Digital Archaeology. This paper summarises cutting-edge technologies that may assist archaeologists during the excavations process and reports related projects. At the same time, it overviews the literature for applications, tools and software implemented to operate directly to the excavation field (in situ) for the documentation, management, integration of the archaeological information and to facilitate the exchange, direct access and interoperability of the scientific data. We strongly believe that the present review would be very helpful to young researchers in the of field Digital Archaeology, since it assembles valuable knowledge from the scientific literature.

KEYWORDS: Archaeology, Excavation, New Technologies, Digital, LiDAR, 3D, Visualization, Virtual, management, Cultural

1. INTRODUCTION

Managing excavation information is a task that needs knowledge of interdisciplinary fields such as computer science and archaeology, including new methods in database design, Geographical Information Systems, 3D Reality Modelling, digital reconstruction and spatial. In the last two decades archaeological research has begun to incorporate new technologies that can assist researchers in excavations. Such technologies are the use of Unmanned Aerial Systems (UAS), photogrammetry as well as virtual and augmented reality for the three-dimensional or two-dimensional display of the site where archaeological excavations are carried out. A big advantage of these is the low cost of these technologies, which encourages archaeologists to capture archaeological sites and landscapes.

Nowadays, modern 3D research and survey technologies are systematically used to improve information gathering and scientific assessment, providing novel documentation methodologies. Moreover, when it comes for cultural asset promotion, reconstruction and understanding digital technologies provide solid solutions 3D visualization and digitization (or Reality Modelling) is the principal mean of producing digital assets in museums, while they are the most important channel of information gathering for the purposes of restoration of historic monuments and sites (Liritzis et al., 2015). The coupling of computer sciences, engineering, mathematics and in general natural sciences applied to archaeological issues in the field and the laboratory or classroom has been variously expressed. The digital archaeology and cultural heritage are the areas of application of information technology (IT) and digital media; using modern technologies applied to archaeological research (Hahulina et al., 2019). New terms used in nowadays such as Digital Archaeology, Digital Curation, Cyber-archaeology etc. Cyber-archaeology the branch of archaeological research concerned with the digital simulation of the past has been introduced with fast development (Forte, 2010). Cyber-Archaeology integrates the latest advances in computer science, engineering and the hard sciences to address anthropological, archaeological and historical questions. It supplies methods for the measurement, recording of field data with proper acquisition, analysis, curation and dissemination of these input data related to world cultural heritage (Levy et al., 2012, 2018). Significant progress is made on the interdisciplinarity between new technologies and cultural heritage projects, extended to STEM, STEMAC, cyber-archaeometry, 3D Reconstruction of Cultural Heritage Sites for research and application, all related to new teaching directions in archaeological science research and higher education models (McCoy and Ladefoged 2009; Liritzis 2018; Liritzis and Volonakis 2021; Liritzis et al., 2015, 2017, 2021a,b; Georgopoulou et al., 2021; Psycharis 2018; Hatzopoulos et al., 2017).

The relevant research work in the past is introduced below per each case, methods and applications. In this paper we aim to review the already existing technologies that have a decisive role in the digital capture of archaeological excavations and some other projects that they use some of the above technologies. Present review or survey paper in the specific interdisciplinary field ranges from archaeology and cultural studies to computer/information science and engineering.

2. TECHNOLOGIES FOR ARCHAEOLOGICAL EXCAVATIONS

2.1. *Imaging technologies*

There is a wide variety of technologies for capturing and displaying archaeological excavations. In this paper, we focused on six categories: photogrammetry, 3D laser scanner, LiDAR, GIS, Virtual Reality (VR), Augmented Reality (AR) and UAV, 3D printing.

2.1.1. Photogrammetry and UAVs

Photogrammetry is today, worldwide, the main methodology to produce geospatial 3D models. Developments in recent years in the development of this technology, especially in the field of analytical and digital photogrammetry, in combination with those of aerial photography (using Unmanned Aerial Vehicles-UAV), have created conditions to produce extremely high precision topographic backgrounds in both vector and raster form.

The photogrammetric approach permits to have reasonably reliable results with relatively simple equipment and post-processing. It is based on passive sensors (namely a photographic camera), that allow to obtain images with a stereoscopic overlapping. The basic procedure consists of taking an appropriate amount of pictures as needed to cover an object or an area. The images should obey in a set of properties, such as suitable overlapping, stable illumination conditions and focal lengths (Cosmas et. al, 2001). According to Richards-Rissetto (Richards-Rissetto, 2010), the purpose of this paper is to evaluate the performance offered by the "Structure from Motion" approach to 3D archaeological site surveying using existing CV (Computer Vision) interfaces, such as some 3D web-services and PhotoScan/Metashape (Brutto et. al., 2012).

2.1.2. Terrestrial 3D Laser Scanners

In order to be able to preserve our cultural heritage intact it is important to use accurate depiction techniques. One such technology is the 3D Laser Scanner. Laser Scanning is an active sensor approach, able to directly capture 3D measurements of the scanned scenes or objects, which then can be combined with colour digital images. To construct a full 3D point cloud data of a heritage building with a laser scanner, multiple scans from different locations and orientations are required.

Regarding all this time consumption, the laser scanning is the best technology because it provides full resolution scans in real time. The 3D model obtained from the laser scanner with the use of targets spheres guarantees a better result and in short time. The use of such a scanner allows us to capture an object as it really is (Ruggiero et. al., 2012).

Ground-based laser scanners are active imaging instruments that give in real time the three-dimensional coordinates of the object we want to capture. What is produced is a cloud of points with x, y, z coordinates that refer to the scan reference system and the intensity of the reflected signal. These scanners are divided into two categories depending on the method of calculating the distance. They are distinguished into passive (triangulation method) and active (time of flight). The technology of 3D laser scanner is widely used in many fields (mapping of archaeological sites, mapping of listed buildings or monuments etc.) where data collection must be done with great speed and accuracy.

2.1.3. LiDAR

The LiDAR (light detection and ranging) sensor is a remote sensing laser technology used to create high-resolution geographic models. LiDAR, integrated in drones (Can be connected to a tripod or a helicopter). The drone, to which the sensor will be connected, then flies over an area to scan and uses laser pulses that strike the Earth's surface. These lasers that strike the surface create data points and thus create a very detailed point cloud. From this point cloud a very accurate 3D model is created.

This image created through LiDAR can provide information to archaeologists that would be difficult to discern due to the conditions (for example dense vegetation) in the area. This vegetation makes it difficult to map the elevation and terrain with accuracy. From the above we can understand why this sensor is a very powerful technology in the hands of archaeologists. The mapping process is quite fast as with the help of the drone but also through a specialized group of pilots, large areas can be covered per day. This mapping is now done with great precision, which helps archaeologists to locate in an area that may have archaeological sites where there are sites or objects that have been destroyed over time.

A very successful example where the sensor was used was in Belize (see Fig. 1), where in that area they located streets and buildings belonging to the civilization of Maya (Chase et. al., 2012).

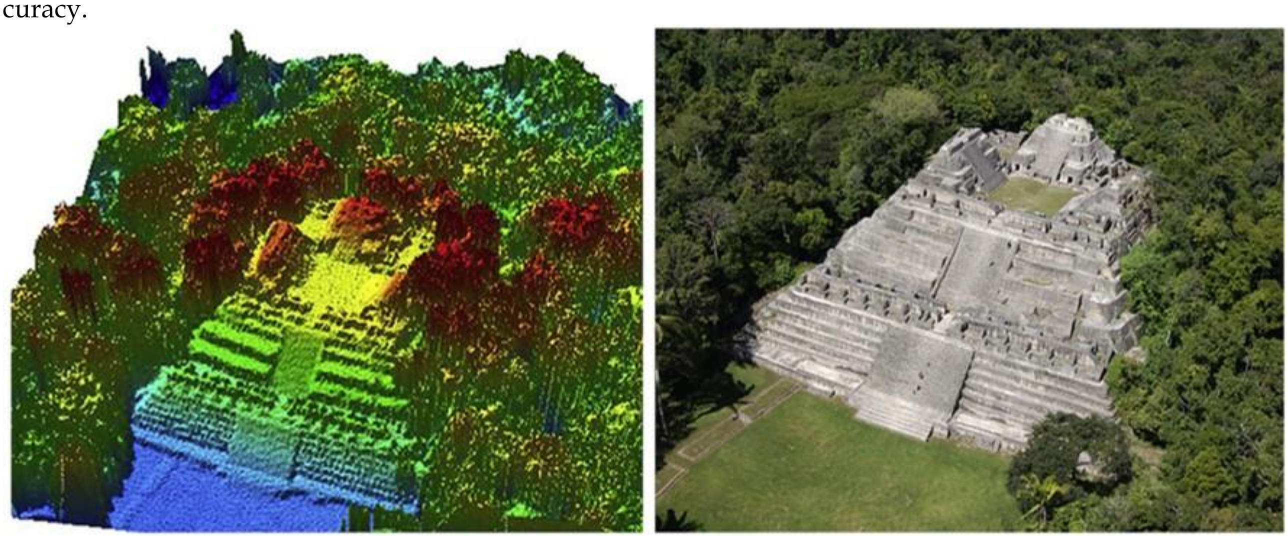


Figure 1. An example of LiDAR archaeological survey as depicted in Chase et al., (2012).

2.2. *Geophysical non-intrusive underground surveying*

Geophysical non-intrusive underground surveying methods leave the ground intact. Magnetic Gradiometry (MG) is often used in the targeted preparation of rescue or research excavations (Levy et. al., 2018; Von der Osten-Woldenburg, 2020). MG devices are widely used when documenting archaeological sites, that can be preserved under the ground anticipating the appropriate time plan and related actions for their excavation. In addition, Ground Penetrating Radar (GPR) is another geophysical surveying method that implements radar pulses to visualize underground levels. GPR may find numerous applications conditions for the detection of artifacts and structures that are buried in heterogeneous subsurface of urban of natural environments (Conyers, 2014). All geophysical non-intrusive underground surveying methods may identify even small archaeological artifacts at relatively great depths, without any danger of damaging them, as well as to discriminate the depth of irregularities in the soil.

2.3. *Geographic Information System (GIS)*

Geographic Information System (GIS) is a system used to record, store, control, and view different data related to locations on the Earth's surface. This system can display many different data on a map (buildings and vegetation). This enables us to see, analyze and understand more easily the patterns and relationships that emerge through them. This tool is used by archaeologists to avoid losing information that could affect archaeological sites and various studies carried out at these sites. GIS contributes to the design and management of cultural resources that are valuable for the preservation of data on sites where archaeological excavations are carried out. In archaeology, GIS increases the ability to map and record data when used directly at the site of excavations. This process gives archaeologists the opportunity to directly access the data collected for analysis and visualization, something that directly helps to better understand the archaeological site and its findings (Neubauer, 2004). Many applications are reported in the World cultural heritage and geosites (Selvi et al., 2020; Diwan 2020; Shiyab et al., 2018)

2.4. *3D Visualization in Archaeology*

2.4.1. Archaeology and Virtual Reality (VR)

Virtual reality is an immersed, multi-aesthetic experience. It is characterized by the illusion of participation in a synthetic environment and not simply by the external observation of such an environment (Gigante, 1993).

The aim of the project presented by J. McCarthy (McCarthy et. al., 2019) was to create an immersive and realistic virtual diving experience, while utilizing the possibilities of 3D modelling to transfer as much information as possible in the available time. An animation set was created to encourage the user to look around and visually explore the environment.

A 2.5D illustration was created in this project. 2.5D VR is a 360 ° video, but it does not give the user the full sense of immersion. There are two major advantages to this method. Which are: Experience can be more easily directed which results in the basic information being transmitted to the user of the application. This is because the user does not have the comfort of motion that he would have in a fully immersive virtual reality application, where his movements would not be so limited. Finally, this sense of immersion offered by this technology fulfils the purpose of these underwater virtual reality experiences (see Kiourt et al., 2016; Champion 2016).

2.4.2. Archaeology and Augmented reality (AR)

Augmented reality is the real-time direct or indirect viewing of a natural, real-world environment, the elements of which are augmented by elements reproduced by computer devices, such as audio, video, graphics, or location data.

Augmented reality technology is a technology used in mobile devices. This technology enables us, while we see the real world, to augment it with virtual objects and information that are in the real world. Through the camera and GPS that smartphones or tablets have, it is possible to view information (texts, sounds and videos) or virtual objects or both of them in a specific geographical location. In order for this type of data to be displayed, we need to have either a smartphone, or a tablet or specialized equipment (Augmented Reality glasses).

The main purpose of project G. Liestøl (Liestøl et. al., 2018) was to create a dynamic, digital 3D environment for continuous display of changes in sea level and vegetation in the Krøgenes region (Liestøl et. al., 2018). In the software, the user can select the period using a timeline spanning in a period of 10000 years from today. This research has revealed that Krøgenes's prototype that the development of Mobile Augmented Reality for archaeology is suitable to visualizing data from stone age until today.

2.5. *3D Printing in Archaeological excavations*

According to work presented in Tronchere (Tronchere et. al., 2015), the main purpose was to build a 3D printed model of each individual layer and structure in archaeological research or excavations and prepare a "plastic" model of an excavation of a cultural space. Despite the fact that 3D printing was devised originally for the needs of industry (Chua et al., 2003), it has begun to be used for the production of copies of archaeological objects and excavations, but also in museography (Chaumier and Françoise, 2014). Nowadays, 3D printing is readily available and relatively a low-cost technology that may bring benefits in archaeological excavations and more specifically as a better recording and surveying technique in the related field of stratigraphy. As reported in (Tronchere et. al., 2015), one of the problems could be the loss of all metadata when it the model is transferred from GIS to the 3D model and then to STL file for 3D printing.

3. SOFTWARE, SYSTEMS AND APPLICATIONS FOR ARCHAEOLOGICAL EXCAVATIONS

3.1. 3D MURALE

3D-MURALE is a system of registration, reconstruction, database and visualization. Recording tools are developed for measuring soil, stratification, buildings, building blocks, ceramics, fragments of ceramics and statues at the archaeological site. The results of these measurements are stored in the 3D-MURALE database system (Cosmas et. al., 2001). The reconstruction system uses a 3D graphic tool to combine individual measured elements and reconstruct building blocks or entire buildings from building blocks, ceramics from fragments of ceramics, statues from elements of statues, and stratigraphy from all finds during excavation.

The model is prepared for processing in high quality stereoscopic imaging and for lower quality internet visualization. Visual experience also includes stratigraphic imaging. Any individual artifact can be queried in the database and the query result is displayed separately. Questions can be created and visualized remotely over the Inter- net.

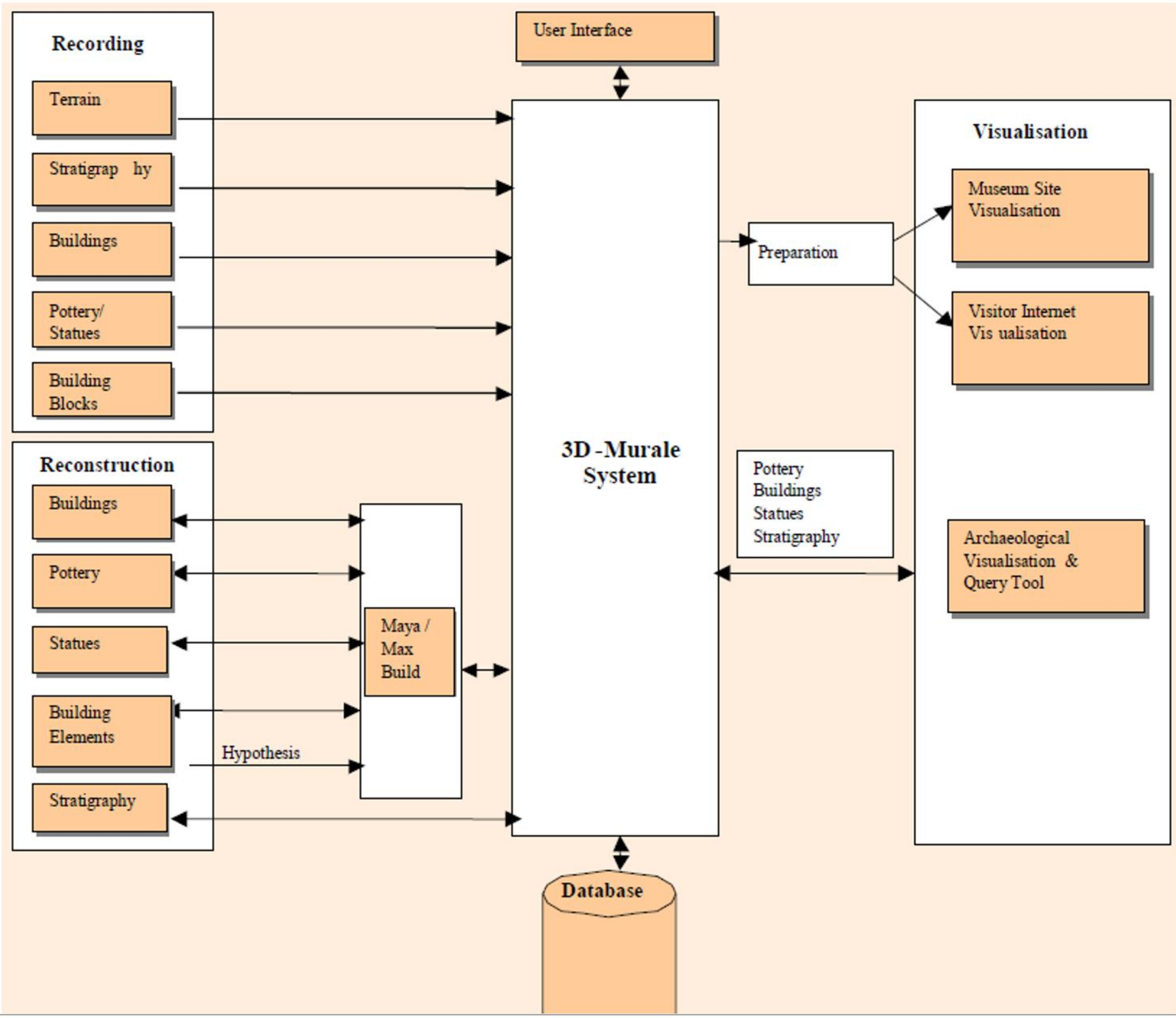


Figure 2. Flowchart showing the components of 3D Murale system as depicted in Cosmas et. al, (2001).

3.2. VITA

In 2004, the VITA (Visual Interaction Tool for Archaeology) software was designed to allow archaeologists to have a shared collaborative hybrid platform, incorporating headsets to visualize 3D land data and related multimedia (Benko et. al., 2004). VITA tool focus on augmenting the traditional archaeological excavation recording methods (e.g., drawings, and notes, photos) with new channels to manage, visualize, and survey excavation stages with textured, 3D scanned objects and areas, multimedia files, images (panoramic and high-resolution). The experts were able to mix speech, touch, and 3D hand gestures to interact multimodally with the environment and with other curators and archaeologists as seen in Fig. 3.

Figure 3. Two archaeologists collaborating using VITA software as shown in Benko et. al., (2004).

3.3. *QueryArch3D*

QueryArch3D aims to address several open issues related to data integration, access and visualization. The software presents the ability to: a) handle 3D models in various size and resolution (or Level of Details - LoD), b) search geometrical features and attributes of the objects, c) explore three-dimensional information and d) offer direct access to data (Agugiaro et. al, 2011; Richards-Rissetto, 2010).

All geometric models were mapped with attribute information collected from various channels (e.g., photogrammetry, 3D scanning etc). All information is stored in a PostgreSQL, while interactive 3D visualization is performed with Unity-3D engine, which is connected to the database through PHP coding. The software comes with a visualization module allowing the user to navigate interactively in a virtual space, where objects of interest may be queried in four categories in relation to their Level of Detail (LoD1, LoD2, LoD3 and LoD4).

3.4. *Ad Hoc 3D*

For the curation of archaeological sites and for the management of the monument conservation Ad Hoc 3D solutions has released two modules belonging to a single software platform for PCs and laptops, integrating a database for 3D objects. In the specific database all objects are organized in relation to their accurate position, and they can be searched using all their corresponding features, characteristics, status and geodetic information and spatial positioning (Ardissone et. al, 2013). Specific operations of this tool allow curators and experts to figure out correctly surfaces and volumes of excavations, measure accurately spaces, objects, relics and monuments, and prepare effectively the next conservation steps.

3.5. *iDig- Recording Archaeology*

This software was developed by Bruce Hartzler, who has worked in the Athens Ancient Agora excavations as an IT. iDig is an application designed to assist archaeologists in recording and analysing during excavations (see Fig. 5). This application is a tool that can record the data of excavation processes, with real-time accuracy and finally process and share this data in a very fast time. Any errors that arise as well as the analysis that is performed at that time are supported by direct and interactive access to files and photographs that exist from excavations that have been done in the past (Uildriks, 2016).

The iDig application is for one more reason a very important tool in the hands of archaeologists during excavations. This extra that is offered through this application is the collection of data from the field, but also the correlation of these data with each other. This tool reduces the time required for the final conclusions, as opposed to whether this process was carried out in the excavation field and then in the laboratory. Having the data collected in digital form, their transfer and sharing becomes much more direct and faster to the project partners.

Figure 4. A screenshot of the iDig software as demonstrated in Uildriks (2016).

3.6. ArchField

ArchField is an open-source logging tool of the whole process of an archaeological excavation. It consists of a local database in which archaeologists store the data related to their findings, by completing internet forms, from the excavation field and can also process them from the excavation server (Smith and Levy, 2014). ArchField provides several features to users such as generating barcodes for the storage of the findings, the 3D projection and the GIS analysis of the field of excavation, and so on. Since the interface it uses is through a browser it can run on almost all mobile devices, but without being designed specifically for it and without using the capabilities of mobile devices. ArchField is software created to record and visualize real-time geographic data from a field where excavations are being carried out. A big advantage of the system is that it connects directly to total stations or GPS, which allows archaeologists in the field to record data and information directly on a laptop or a handheld device (smartphone or tablet). This process results in the data being processed and visualized in real time. This saves time by processing them in the laboratory at the end of the day. Once researchers have this real-time data from the field, they have the luxury of considering what data needs to be repaired and what may be missing before leaving the field. This process helps to capture geographic data with great accuracy, which results in significantly reduced acquisition and visualization time. The ArchField system integrates a PostGIS as a database for managing, searching, storing and retrieving data. This database was chosen because it adopts a variety of GIS applications, such as QGIS, GRASS, ArcGIS, and the Open GIS Consortium (OGC). PostGIS is a SQL database that has geospatial extensions designed to handle data and metadata, which are then imported into a main database after fieldwork at the end of each day.

Figure 5. A screenshot of the ArchField software as presented in Smith and Levy (2014).

3.7. *ArtifactVis2*

The purpose of the ArtifactVis2 application is not to recreate a site as it was many years ago, but to visualize and examine the findings and data from a site where excavations are being carried out. This application manages and visualizes data from a collaborative and immersive 3D virtual environment (Smith et. al, 2013). The archaeologist is completely immersed in this virtual system. The 3D scans of the findings and the photographs are rendered in real time with GIS data which have been recorded from the field where the excavations are carried out. The virtual environment in which archaeologists - users are immersed is a collaborative environment in which a variety of questions are provided which are based on the application menu but also on the possibilities given in terms of marking, measuring, commenting and handling virtual data. All these features mentioned, give archaeologists the great advantage to analyze and relive the small but important details of the field in which excavations are carried out. The visual capacity of researchers increases as they can now easily perceive and recognize the changes that occur in the space where the work takes place, as well as the deep patterns. This application offers us a fully immersive environment based on GIS technology, through which the data and information discovered in an excavation field are utilized, thus achieving an in-depth investigation of historical and cultural issues of ancient civilizations, something that could not have happened in the past.

Figure 6. A demonstration of ArtifactVis2 (Smith et. al., 2013).

3.8. OpenDig

The OpenDig application aims to make it easier for archaeologists to record the findings of an excavation at an archeological site. This application uses the electronic devices of archaeologists which record information, data and various notes. It also consists of a local server where the necessary information and data are stored and an external server that "sets up" a website on which the responsible archaeologists selectively present some information from the excavations (Vincent et. al, 2014a; Vincent et. al, 2014b; Levy et al., 2018).

This application was developed as an open-source application, with the aim and perspective in the future to support a variety of archaeological databases. Thanks to the capabilities offered by open-source applications, this application provides a complete archaeological framework for data, information and studies that take place in an excavation field. The tools contained in the OpenDig application are the following:

- An application through which the field is recorded in order to achieve the description of archaeological contexts, related photographs, geospatial data and find.
- A very light program to achieve the reading and processing of data and information resulting from a field of archaeological excavations in the context of the analysis that takes place in a laboratory.
- Through the internet platform, the data and information obtained from the field are highlighted, something that contributes to their analysis and dissemination.

From the above tools it is understood that OpenDig does not offer anything different from other applications that help archaeologists in an excavation but demonstrates the need to use open-source tools in order to create a system that in the future can support needs an excavations at an archaeological sites. It is especially important to record and highlight the data that emerges in an excavation. The future of excavated data lies in open-source tools that provide a common interface that allows archaeologists to link their data to other data from other excavations in order to quickly and quickly draw conclusions and information about the findings of an excavation.

Figure 7. A screenshot of the OpenDig application (Vincent et. al, 2014a).

The application is supported by iOS devices. Although the capabilities of mobile devices are widely used, there is no use of internet technologies other than the page that can upload the selected content. The OpenDig app was only available for iOS devices (iPads, iPhones and iPods) and not for devices running the Android operating system (See Fig. 8). Although the capabilities of mobile devices are widely used, there is no use of internet technologies other than the page that can upload the selected content. This application is no longer supported.

3.9. *Citizan Coast Archaeology*

The application CITiZAN (Coastal and Intertidal Zone Archaeological Network) aims to save archaeological sites located along the coast of England and on the shores of the tidal estuary. These areas are constantly eroded by winds, waves and large and severe storms (CITiZAN Coast Archaeology). The destruction that these areas are subject to cannot be stopped, but through the specific application a record can be made of the sites of archaeological interest before they are destroyed by the conditions mentioned above. The utilization and use of the application are encouraged by local bodies in order to collect data for future users-volunteers of CITiZAN (https://citizan.org.uk/).

A very powerful tool in the hands of people for the spread of sites that have an archaeological interest are smart devices and specifically smartphones and tablets. This is because these types of devices definitely have a camera and GPS, which helps to locate and immediately record new archaeological features. One of the advantages of using the app is that most of the population of England constantly owns a smart device.

Users who use this application, can navigate, through a map, the coasts and coasts of England, in order to locate and record landscapes of archaeological value.

The application has over 80,000 points on its interactive map. These points provide information on England's coastal heritage. It also offers a snapshot of embedded data from Historic England, the National Trust, and several local historic offices and local archaeological teams. Users of the application can:

- See the interactive map of England's coastal heritage.
- Add and create new CITIZAN feature points.
- Update existing points with their research and monitoring information.

Users can download the application for free on their mobile phone or tablet from the platforms of the Play Store for devices running Android, and the App Store for devices running iOS (https://play.google.com/store/apps/details?id=com.wk.android.citizan).

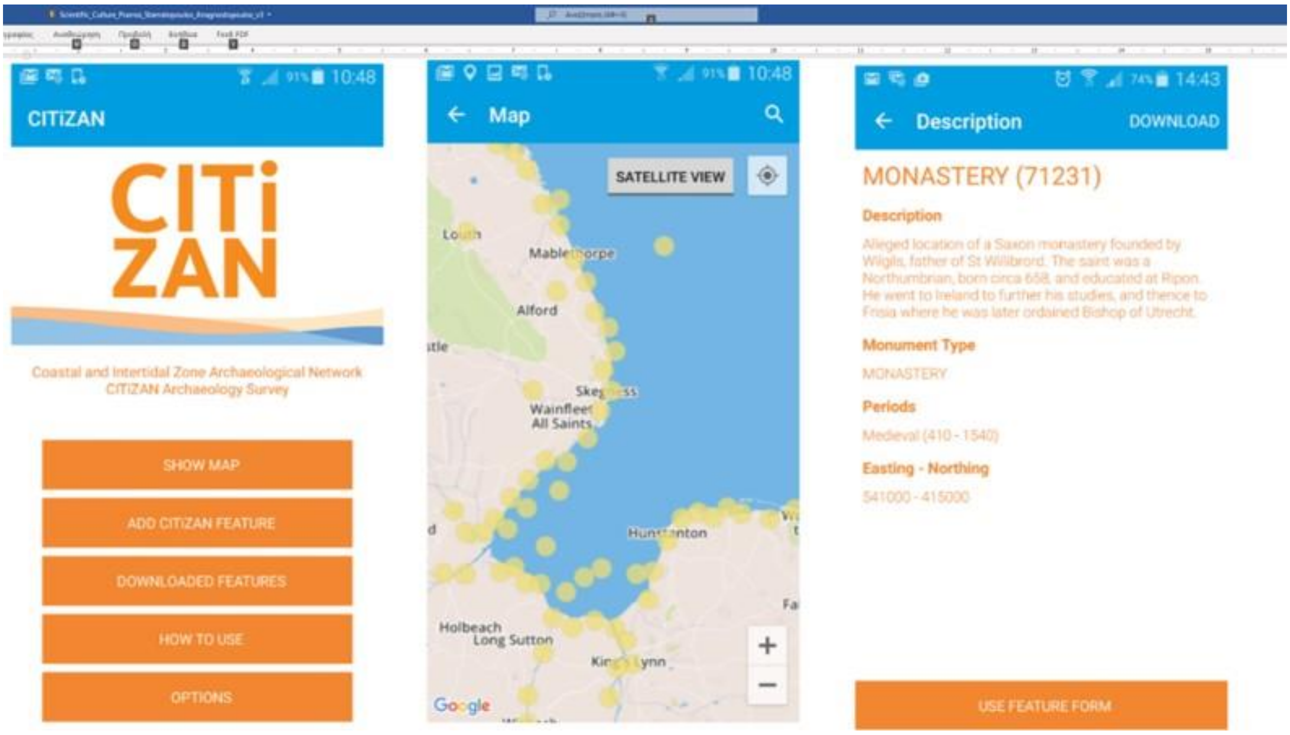


Figure 8. Screenshot of the CITiZAN application (https://play.google.com/store/apps/details?id= com.wk.android.citizan).

3.10. FieldNotes

FieldNotes is software specially designed to assist archaeologists in their on-site excavations. Thanks to the widespread use of smartphones and tablets, this application can be a useful tool in the hands of archaeologists (FieldNotes). FieldNotes allows you to manage most of the excavation site information, such as notes, pictures or geographical locations, which are usually recorded in the excavation log by the archaeologist who stores them, along with their location and presents them only through the map. that exists in the application. The notes recorded from the field will allow the management of information by archaeologists involved in research or excavations.

In FieldNotes (https://play.google.com/store/apps/details?id=pt.flmconsult.fieldnotes_arch&hl=en_US), similarly to CITiZAN, users can download for free on their mobile phone or tablet from the platforms of the Play Store and the App Store (See Fig. 10).

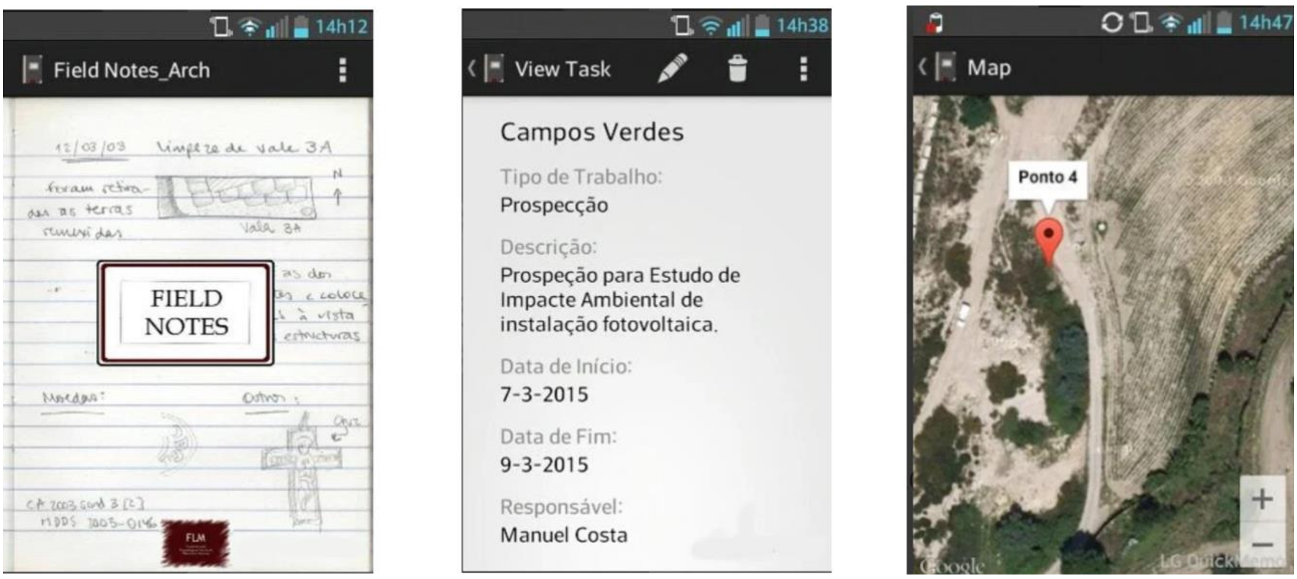


Figure 9. Screenshots of the FieldNotes application (https://play.google.com/store/apps/details?id=pt.flmconsult.fieldnotes_arch&hl=en_US).

3.11. ARCHAVE

The ARCHAVE system is a fully immersive virtual reality environment. This project started in November 1999 (Vote et. al, 2001). This system is important because it allows archaeologists to preserve and visualize the data, they collect in three dimensions. The application of the system in a virtual reality environment allows archaeologists to better understand the context of the excavation data and to correlate the large amount of objects with features of the site and architecture. During the development of this system, an effort was made to create new illustrations and interaction techniques suitable for the application. The ARCHAVE system was created as a framework for evaluating virtual reality interaction techniques and data visualization techniques for scientific applications.

3.12. ArchaeoSTOR

AchaeoSTOR software offers the ability to organize and manage findings, as well as different files and data. Excavations conducted under the supervision of the UCSD (University of California, San Diego) began to accumulate a large amount of objects and data from them, which led to the urgent need to create software such as AchaeoSTOR, as management through traditional methods began to become impossible (Gidding et. al, 2013). Since this software consolidates all data in one place, the excavation team is able to quickly and easily locate, search and manage the information from an excavation field. Another important tool offered by this software is easy sharing of information and files, which makes it easy to draw conclusions quickly and efficiently.

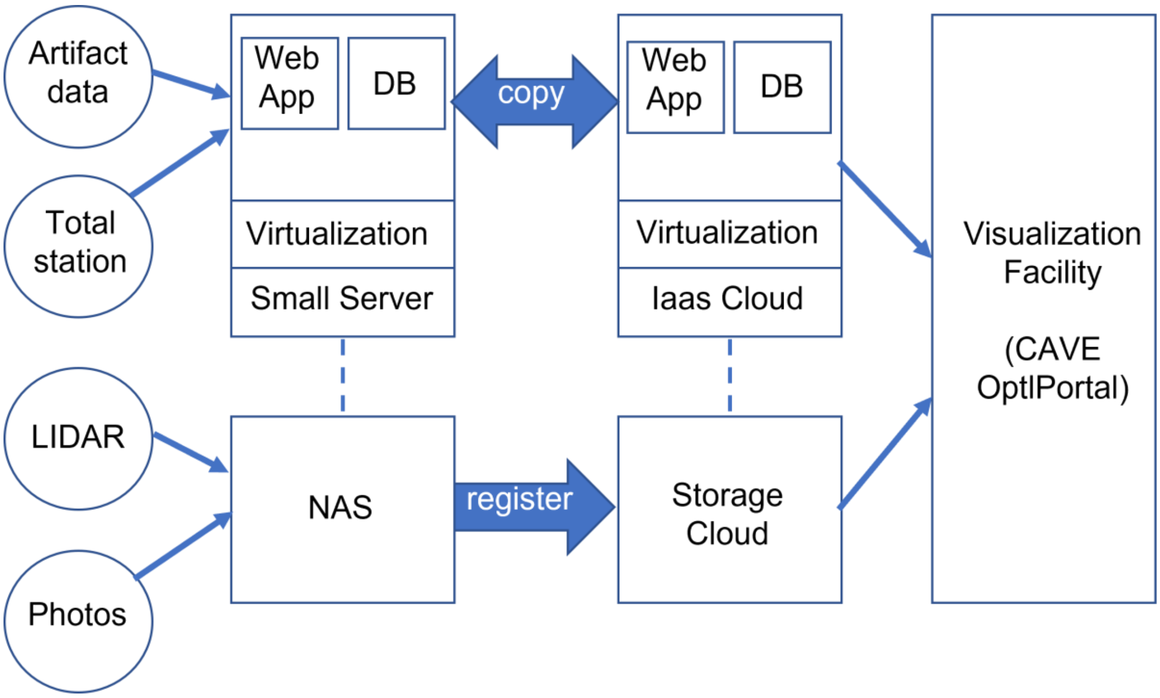
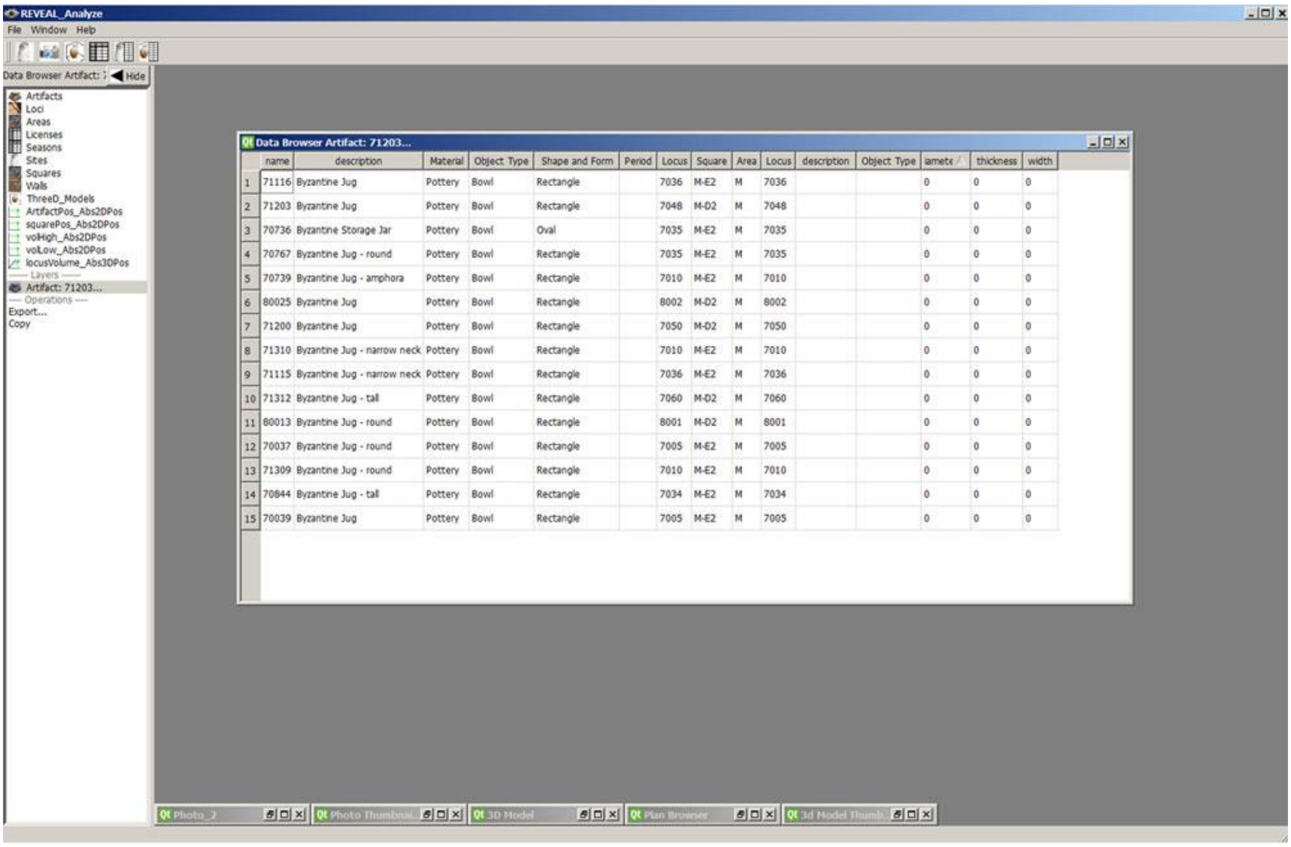


Figure 10. Flowchart showing the function of ArchaeoSTOR system (source: Gidding et. al., 2013).

3.13. REVEAL

The REVEAL project is a research project created to support the storage, recording and processing of data and information during an excavation. This information and data recorded by archaeologists is stored in a local database. Archaeologists must have a computer at their disposal in order to gain the necessary access to the site interface and to the cameras that monitor the field in which the excavations are being carried out(Sanders, 2011). The tools provided by the REVEAL project are the creation and storage of findings in 3D and the continuous recording of the field by a low frame-rate camera, which allows archaeologists to locate the exact location where the finds were found. One of the disadvantages of these tools is that they require a lot of setup and equipment. Also, although the entry of information and data is done through the use of web forms, there is no talk of internet expansion or the existence of coverage through smart devices.



	name	description	Material	Object Type	Shape and Form	Period	Locus	Square	Area	Locus	description	Object Type	amete	thickness	width
1	71116	Byzantine Jug	Pottery	Bowl	Rectangle		7036	M-E2	M	7036			0	0	0
2	71203	Byzantine Jug	Pottery	Bowl	Rectangle		7048	M-D2	M	7048			0	0	0
3	70736	Byzantine Storage Jar	Pottery	Bowl	Oval		7035	M-E2	M	7035			0	0	0
4	70767	Byzantine Jug - round	Pottery	Bowl	Rectangle		7035	M-E2	M	7035			0	0	0
5	70739	Byzantine Jug - amphora	Pottery	Bowl	Rectangle		7010	M-E2	M	7010			0	0	0
6	80025	Byzantine Jug	Pottery	Bowl	Rectangle		8002	M-D2	M	8002			0	0	0
7	71200	Byzantine Jug	Pottery	Bowl	Rectangle		7050	M-D2	M	7050			0	0	0
8	71310	Byzantine Jug - narrow neck	Pottery	Bowl	Rectangle		7010	M-E2	M	7010			0	0	0
9	71115	Byzantine Jug - narrow neck	Pottery	Bowl	Rectangle		7036	M-E2	M	7036			0	0	0
10	71312	Byzantine Jug - tall	Pottery	Bowl	Rectangle		7060	M-D2	M	7060			0	0	0
11	80013	Byzantine Jug - round	Pottery	Bowl	Rectangle		8001	M-D2	M	8001			0	0	0
12	70037	Byzantine Jug - round	Pottery	Bowl	Rectangle		7005	M-E2	M	7005			0	0	0
13	71309	Byzantine Jug - round	Pottery	Bowl	Rectangle		7010	M-E2	M	7010			0	0	0
14	70844	Byzantine Jug - tall	Pottery	Bowl	Rectangle		7034	M-E2	M	7034			0	0	0
15	70039	Byzantine Jug	Pottery	Bowl	Rectangle		7005	M-E2	M	7005			0	0	0

Figure 11. A screenshot from the REVEAL website as depicted in out (Sanders, 2011).

3.14. CASTLE3D

CASTLE3D is a framework that aims to help archaeologists visualize data from an archaeological excavation. This framework is based on the 3D Toolkit (3DTK) and it delivered a mapping software tool. The display of the data provided is 2D and 3D, which helps archaeologists to select their possible areas of interest and the above representations in order to achieve the optimal interaction of specialist archaeologists with data from the field. These depictions offer a series of cuts that are quite similar to traditional drawings from an excavation. 3D rendering offers a much more realistic side of the environment realized in the field (Houshiar et. al, 2015).

This software was designed to be a very useful semantic mapping tool for archaeologists. Each project has a specific amount of semantic information that can be used to report the findings to the data. Areas of significant interest can be grouped under one tag. Information such as orientation, color and notes are embedded in a label in order to achieve optimal documentation of the findings. Three-dimensional representations of a point of great interest can be segmented from all data. Through the combination of this data from a series of georeferencing views the complete 3D model of the findings is stored.

The documentation performed through CASTLE3D is exported in XML format because this format is accepted by various systems and databases. The data is entered into an AdiuvaBit database to which more information is added in order to achieve a greater analysis. Based on the comparison made with the traditional methods of documentation, it is observed that an automated system offers a very clear acceleration in the part of the documentation and the errors are dramatically reduced.

CASTLE3D is based on AdiuvaBit (https://www.denkmaldaten.de/en/products/adiuvabit/), which is another custom software tool that provides a way to document and manage features and artifacts, as well as to record and to evaluate older excavations. Emphasis is given in the administration, documentation and evaluation of archaeological excavations, prospections, and research projects and therefore AdiuvaBit is highly customized for every organization that purchase it.

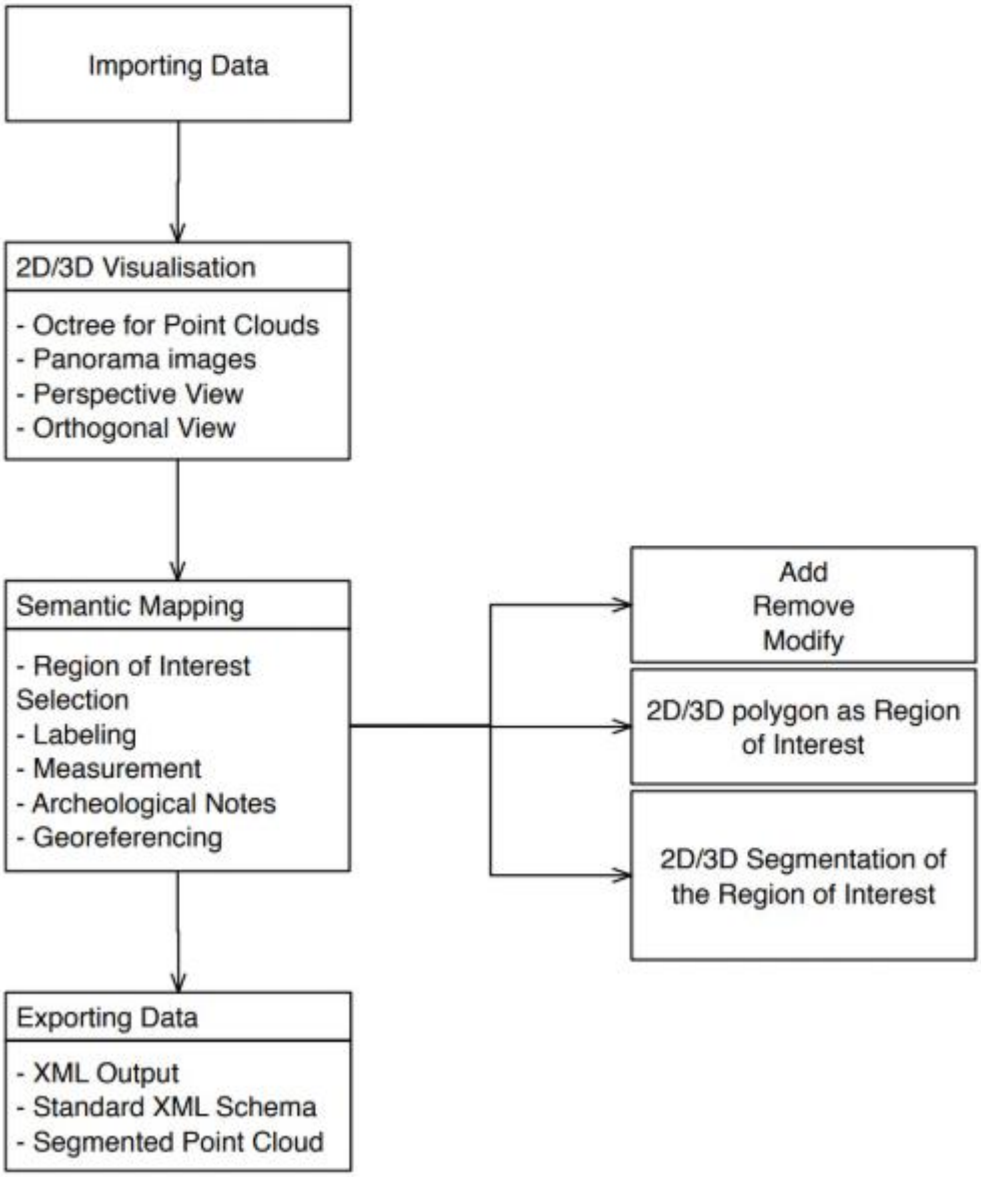


Figure 12. Overview of CASTLE3D functions as presented in Houshiar et. al., (2015).

3.15. Excavations go mobile

This application, like the previous ones presented above, aims at a tool that will support archaeologists in an excavation. One of the issues that archaeologists have to deal with is the organization and processing of information, as well as the exchange of information between archaeologists working together on an excavation. This application comes and offers a user-friendly interface in order to easily and quickly solve the above problems. Another tool in the application is the comparison of objects in terms of size, but also the display of grouped information from archaeologists to users (Karabinakis et. al., 2020). Archaeologists connected to the app will obviously have more rights in managing the information as opposed to ordinary users. The possibilities given to archaeologists are the following:

- Save findings from an excavation and link it to old or new notes.
- Creating a projection for the public.
- Informing the archaeologists about the work that has been assigned to them, the time they have at their disposal for their completion, as well as their daily report on the progress they have made in this work.

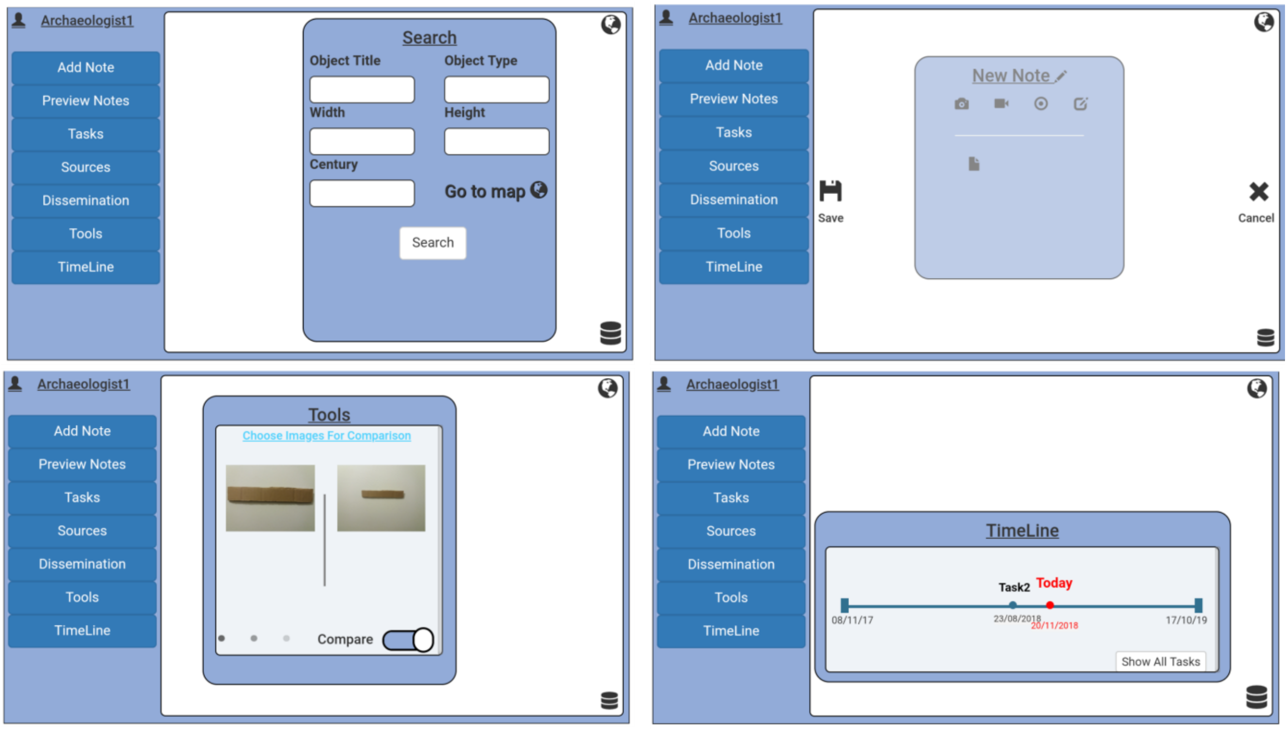


Figure 13. Screenshots of the application (from Karabinakis et. al., 2020).

3.16. *Ontological tools for excavations*

Ontological models and tools aim to define a number of important functions in the understanding and analysis of data and information. The most popular ontology models are VRACore 4.0 (http://core.vraweb.org/) and CIDOC CRM (https://www.cidoc-crm.org/). The latter is an ontological model used to facilitate and understand information and concepts in the documentation and analysis of museums and cultural heritage in general. Thanks to the flexibility and the high scalability of CIDOC CRM, the ontological model CRMarchaeo (https://www.cidoc-crm.org/crmarchaeo/) was developed to support archaeological excavations as well as to identify the various entities that exist around this process (Doerr et. al, 2016). The model has been created and evolved through the interpretation and analysis of metadata that emerge through archaeological documentation. CRMarchaeo offers all the important tools needed to manage and integrate the documentation carried out in the excavation field. Its main purpose is to facilitate the exchange, codification, access and interoperability of archaeological excavation documentation. CRMarchaeo understands the archaeological stratification as well as the events that occurred in shaping a stratigraphy. This model contains all the necessary information and properties that must exist in order to make the correct description of the stratigraphy but also any interventions or alterations the field has undergone over time either naturally or by human intervention as well as the findings found. within the layers of the field. As a result, archaeologists have been able to estimate the time it took for the field to form this stratification. Through the determination of time, useful conclusions can be drawn about the way of life of the people of that time. This model analyzes and documents the archaeological excavation process as well as the techniques followed for the excavation of the field, but also why a specific excavation method was followed.

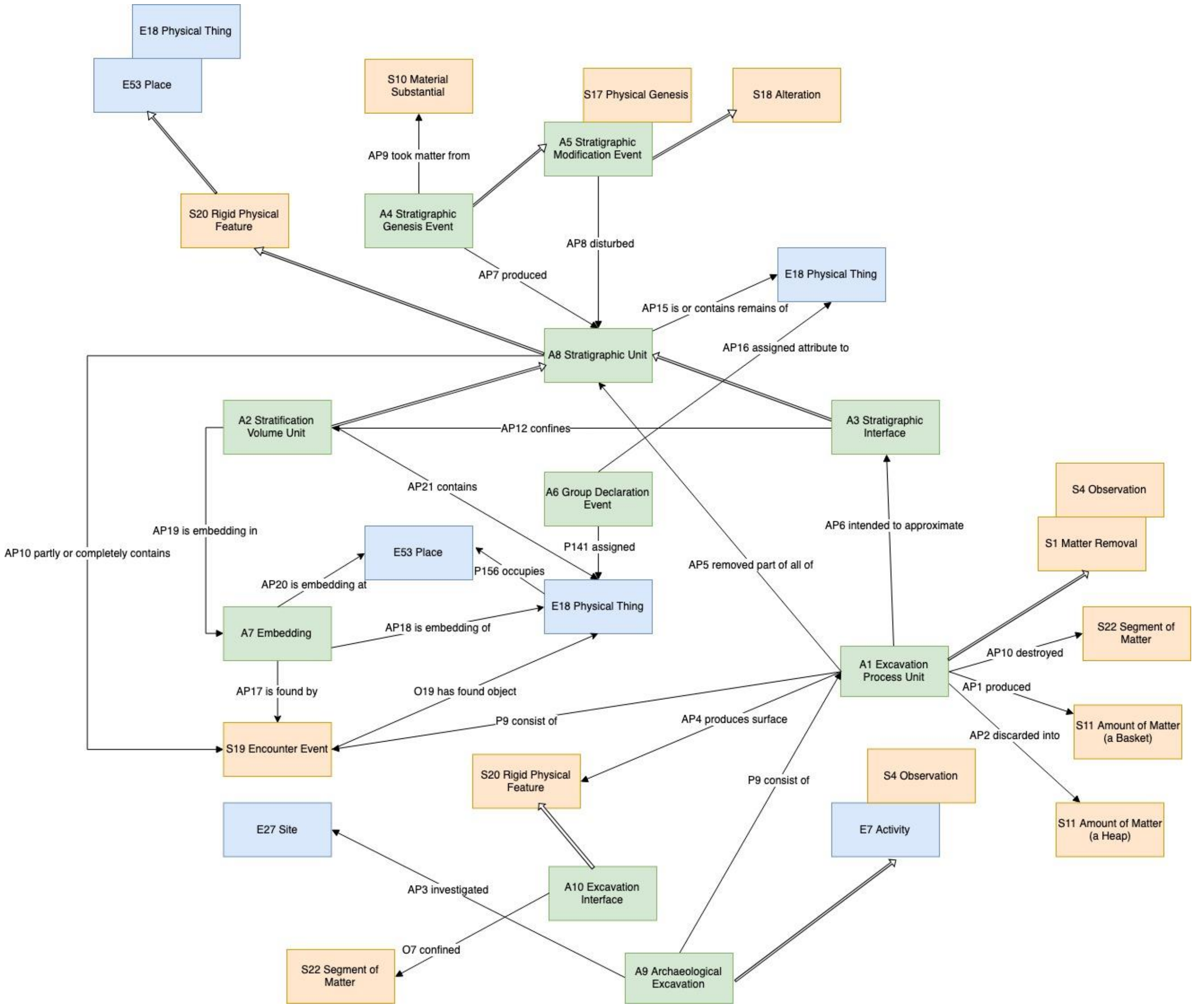


Figure 14. Entities in CRMarchaeo Excavation model (https://www.cidoc-crm.org/crmarchaeo/).

4. PROJECTS

4.1. Delphi4Delphi

The main goal of the Delphi4 Delphi4Delphi research project is to record and capture the most important monuments located in the area of Delphi as well as to capture the exhibits of the Archaeological Museum of Delphi (Liritzis et. al., 2016, 2017). In this project two ways of recording and capturing were followed. The first method followed was Structure from Motion (SfM) and the second method was the use of 3D CAVEcam, through which 3D production of buildings and monuments takes place (Liritzis et al., 2016).

Figure 15. Creating a 3D model with the SfM technique (Liritzis et al., 2016; 2017).

4.2. *ArchAIDE*

ArchAIDE (Archaeological Automatic Interpretation and Documentation of Ceramics) project goal is to create a new system that will automatically recognize any ancient pottery from excavations taking place anywhere in the world. Ceramics are particularly important because they help us to understand and dating the archaeological context in order to understand trade flows and social interactions. This whole process is done manually, through some experts who use analogue catalogues (files and libraries) that contain the desired information. ArchAIDE aims to optimize this process, making this knowledge directly accessible to all archaeologists wherever they work (Gualandi et. al., 2016). ArchAIDE will support the work of archaeologists with an app designed for tablets and smartphones, designed to be an essential tool for archaeologists during the excavations process (see Fig. 4). The fragments will be photographed, then these characteristics will be sent to a collection where comparisons with other fragments will be made, then an automatic object recognition system will be activated which will result in the system responding to all available information and finally will be stored in a database. This process allows any new discovery to be shared online. ArchAIDE will give another important tool to archaeologists, which will be the sharing of all necessary information during the excavations as well as direct access to this information's. The objectives of this project are following:

- Automated process, as much as possible, for the transfer from the classical notes that the archaeologist has to a digital description.
- This application helps archaeologists in recognizing potsherds, through a friendly interface using efficient algorithms for characterization, search and retrieval.
- Automated process to derive the potsherd's description by transforming the data collected into an electronic document.
- A web-based real-time data visualization to improve access to archaeological heritage.
- An open archive that allows the continuous use of this archaeological data, turning it into a common heritage.

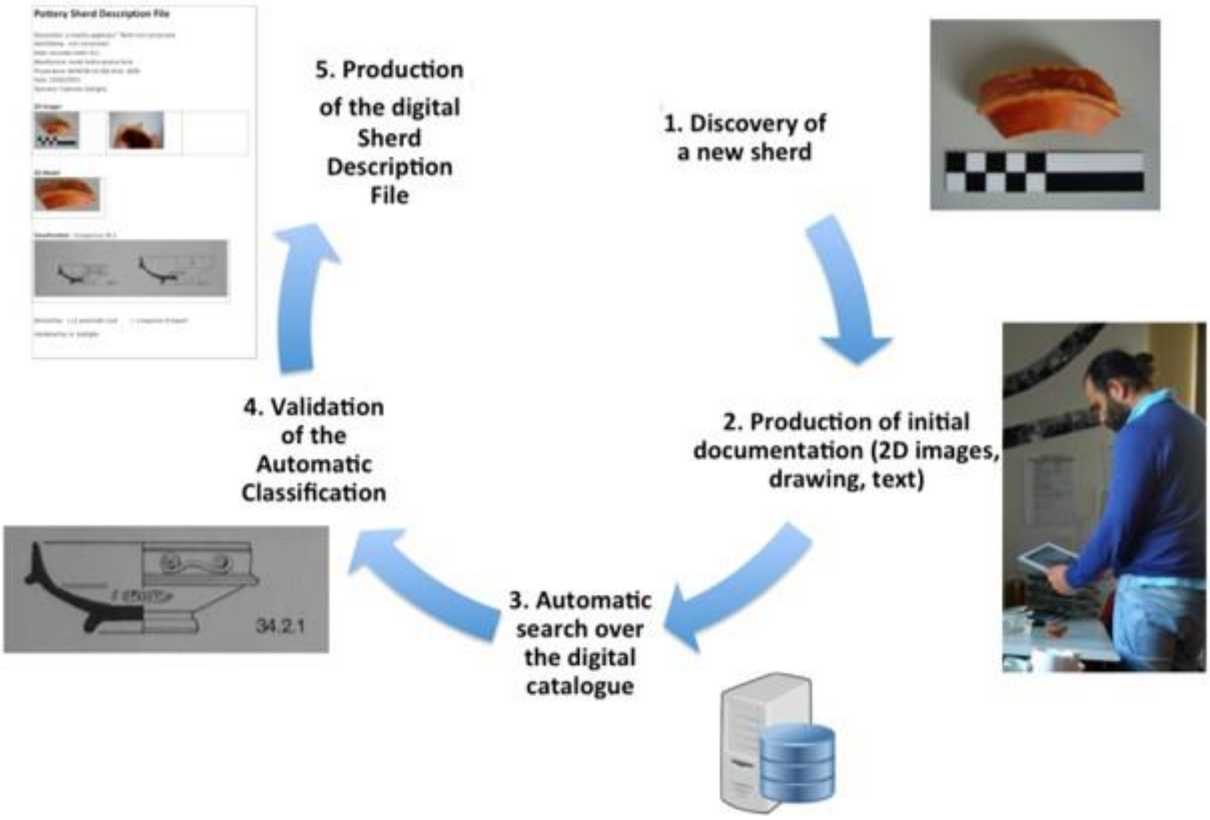


Figure 16. The pipeline of the ArchAIDE methodology as demonstrated in (Gualandi et. al, 2016).

4.3. *REVEAL*

The REVEAL (Reconstruction and Exploratory Visualization: Engineering meets ArchaeoLogy) project is a research project created to support the storage, recording and processing of data and information during an excavation. This information and data recorded by archaeologists is stored in a local database. Archaeologists must have a computer at their disposal in order to gain the necessary access to the site interface and to the cameras that monitor the field in which the excavations are being carried out (Sanders, 2011). The tools provided by the REVEAL project are the creation and storage of findings in 3D and the continuous recording of the field by a low frame-rate camera, which allows archaeologists to locate the exact location where the finds were found. One of the disadvantages of these tools is that they require a lot of setup and equipment. Also, although the entry of information and data is done through the use of web forms, there is no talk of internet expansion or the existence of coverage through smart devices.

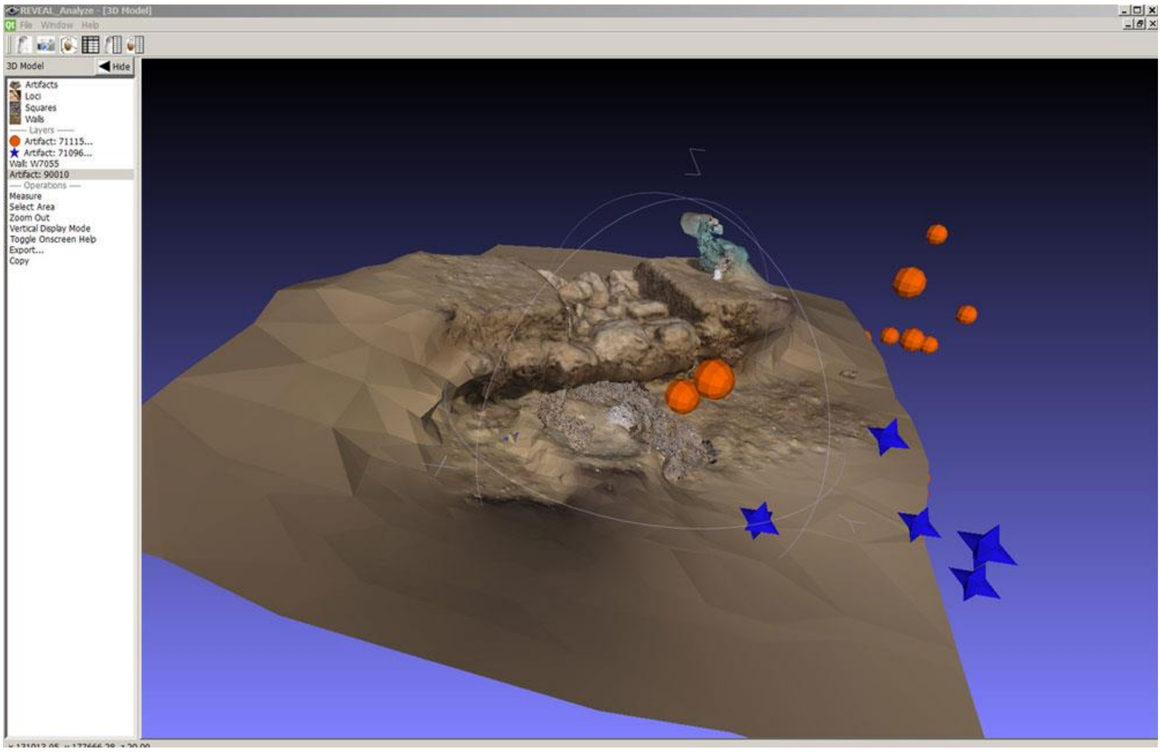


Figure 17. A 3D browser window displaying interactive 3D models of icon locations, architecture and stratified information (after Sanders, 2011).

5. CONCLUSION

Thanks to the technological advancements in recent years, the field of Digital Archaeology is experiencing an unprecedented growth, judging from both the published scientific papers, as well as the large investments from Departments and Ephorates of Antiquities worldwide. This would not be possible without advancements in technologies such as 3D Imaging, 3D Data Visualization and modern mobile technologies that implement VR and AR modules, which are now the most important catalysts for digital cultural heritage To this end, this paper has attempted to provide a brief overview of research on IT in the specific field of archaeological excavation research and to offer some structural categories according to their major frameworks (hardware/equipment, software architecture or both). It should be emphasized that due to the lack of uniformity in the way all the reported papers are evaluated, it is inappropriate to declare a winner among them.

The major contribution of this paper is the provision of a brief reference source for researchers and IT developers involved in Digital Archaeology, to acquire them with the latest advances in the field and allow system developers to know which methods are competitive in the scientific community. To our knowledge there is no review or survey paper in the specific interdisciplinary field that ranges from archaeology and cultural studies to computer/information science and engineering. Attempting to provide some solid conclusions that can be inferred from this paper, someone may say that:

- It is evident that the field of archaeology is very mature to incorporate emerging technologies, such as virtual and augmented reality, photogrammetry, laser scanners and expensive IT equipment, as assistive tools in archaeological excavations for the management of archaeological conclusions.
- The release of more IT excavation management software tools and applications is highly anticipated (e.g. mobile apps, GIS, AR/VR headsets and glasses), that incorporate the cutting-edge technologies to support expert archaeologists and curators.

AUTHOR CONTRIBUTIONS

Conceptualization: C.N.A.; methodology: C.N., D.P.; formal analysis, D.P; resources: C.N.A, M.I.S; data curation: M.I. S.; writing—original draft preparation: DP.; writing—review and editing: C.N.A, M.I.S; supervision: C.N.A. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Abou Diwan, G (2020) GIS-based comparative archaeological predictive models: a first application to iron age sites in the Bekaa (Lebanon). *Mediterranean Archaeology and Archaeometry* Vol. 20, No 2, pp. 143-158. DOI: 10.5281/zenodo.3819601.

Agugiaro, G., Remondino, F., Girardi, G., von SCHWERIN, J., Richards-Rissetto, H., & de Amicis, R. (2011). Queryarch3D: Querying and visualising 3D models of a Maya archaeological site in a Web-based interface. *Geoinformatics* FCE CTU, 6, pp. 10-17.

Ardissone, P, Bornaz, L, Degattis, G., Domaine R., (2013). A 3D information system for the documentation of archaeological excavations. *ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-5/W2, pp.55-60.

Benko, H., Ishak, E.W., Feiner, S. Collaborative Mixed Reality Visualization of an Archaeological Excavation, Proceedings of the *International Symposium on Mixed and Augmented Reality* (ISMAR 2004), pp. 132-140.

Brutto, M. L., & Meli, P. (2012). Computer vision tools for 3D modelling in archaeology. *International Journal of Heritage in the Digital Era*, 1(1_suppl), pp. 1-6.

Chase, A. F., Chase, D. Z., Fisher, C. T., Leisz, S. J., & Weishampel, J. F. (2012). Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. *Proceedings of the National Academy of Sciences*, 109(32), pp. 12916-12921.

Chaumier, S., & Françoise, C. (2014). Museomix: l'invention d'un musée du XXIe siècle. La Lettre de l'OCIM. Musées, *Patrimoine et Culture scientifiques et techniques*, 156, pp. 7-11.

Conyers L.B. (2014) *Interpreting Ground-Penetrating Radar for Archaeology*. Routledge, Taylor and Francis Group; New York, NY, USA, p. 214.

Cosmas, J., Itegaki, T., Green, D., Grabczewski, E., Weimer, F., Van Gool, L., Kampel, M. (2001). 3D MURALE: A multimedia system for archaeology. In: *Proceedings of the 2001 conference on Virtual reality, archaeology, and cultural heritage*, pp. 297- 306.

Champion E.M (2016) A 3D pedagogical heritage tool using game technology. *Mediterranean Archaeology and Archaeometry*, Vol. 16, No 5, pp. 63-72 DOI: 10.5281/zenodo.204967.

Deliyiannis, I., Papaioannou, G (2014) Augmented reality for archaeological environments on mobile devices: a novel open framework. *Mediterranean Archaeology and Archaeometry,* Vol. 14, No 4, pp. 1-10.

Doerr, M., Felicetti, A., Hermon, S., Hiebel, G., Kritsotaki, A., Masur, A., Ore, C. E. (2016). Definition of the CRMarchaeo, an extension of CIDOC CRM to support the archaeological excavation process. *Forth-Institution of Computer Science*, CRM Archaeo Excavation model. The version 7.2 of the reference document. [Online] Available from: https://cidoc-crm.org/Version/version-7.2 (assessed 28 Febr. 2022).

Forte, M (ed.) (2010) *Cyberarchaeology*. Archaeopress, BAR Intern. Series, Oxford, UK.

Georgopoulou, P., Koliopoulos, D and Meunier, A (2021) The dissemination of elements of scientific knowledge in archaeological museums in Greece: socio-cultural, epistemological and communicational/educational aspects. *SCIENTIFIC CULTURE*, Vol. 7, No. 1, pp. 31-44. DOI: 10.5281/zenodo.4107170.

Gidding, A., Matsui, Y., Levy, T. E., DeFanti, T., & Kuester, F. (2013). ArchaeoSTOR: A data curation system for research on the archaeological frontier. *Future Generation Computer Systems*, 29(8), 2117-2127.

Gigante, M. A. (1993). Virtual reality: definitions, history and applications. In: *Virtual reality systems*, Academic Press, 3-14.

Gualandi, M. L., Scopigno, R., Wolf, L., Richards, J., Heinzelmann, M., Hervas, M. A., ... & Zallocco, M. (2016). ArchAIDE-archaeological automatic interpretation and documentation of ceramics. In: *EUROGRAPHICS Workshop on Graphics and Cultural Heritage*, Chiara Eva Catalano and Livio De Luca (eds), The Eurographics Association, pp. 1-4. Doi:10.2312/gch.20161408.

Hatzopoulos, J, Stefanakis, D., Georgopoulos, A., Tapinaki, S., Volonakis, P., Liritzis, I. (2017) Use of various surveying technologies to 3D digital mapping and modelling of cultural heritage structures for maintenance and restoration purposes: the tholos in Delphi, Greece. *Mediterranean Archaeology and Archaeometry,* Vol. 17 No 3, pp. 311-336.

Houshiar, H., Borrmann, D., Elseberg, J., Nuchter, A., Nath, F., & Winkler, S. (2015). Castle3d-a computer aided system for labelling archaeological excavations. In: *3rd ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Science*s, 5, W3.

Hahulina, N.B., Maslikhova, L.I., Akimova, S.V. (2019) Modern Technologies Applied to Archaeological Research in Voronezh Region. *International science and technology conference "Earth science"* IOP Conf. Series: Earth and Environmental Science 272, 032037, IOP Publishing, doi:10.1088/1755-1315/272/3/032037.

Hüseyin Zahit Selvi, Aslı Bozdağ, İrfan Bozdağ and Güngör Karauğuz (2020) Spatial analysis of the eflatunpinar and fasillar hittite monuments using GIS. *Mediterranean Archaeology and Archaeometry* Vol. 20, No 3, pp. 243-256 DOI: 10.5281/zenodo.3960192.

Karabinakis, A. S. S., Styliaras, G., & Avouris, N. M. (2020). Excavations go mobile: A web-based mobile application for archaeological excavations. In: *11th International Conference on Information, Intelligence, Systems and Applications* (IISA) pp. 1-8.

Kiourt, C., Koutsoudis, A., Markantonatou, S., Pavlidis, G (2016) The 'synthesis' virtual museum, *Mediterranean Archaeology and Archaeometry*, Vol. 16, No 5, pp. 1-9. DOI: 10.5281/zenodo.204961.

Levy T.E et al., (2012) *Cyber-Archaeology in the Holy Land. The Future of the Past*, California Institute for Telecommunications and Information Technology (Calit2), UC San Diego, Biblical Archaeology Society.

Levy. T.E and Jones I W N. (eds) (2018) *Cyber-Archaeology and Grand Narratives. Digital Technology and Deep-Time Perspectives on Culture Change in the Middle East*, Springer, Netherlands.

Levy T.E., Sideris T., Howland M., Liss B., Tsokas G., Stambolidis A., Fikos E., Vargemezis G., Tsourlos P., Georgopoulos A., Papatheodorou G., Garaga M., Christodoulou D., Norris R., Rivera-Collazo I., and Liritzis I. (2018) At-Risk World Heritage, Cyber, and Marine Archaeology: The Kastrouli–Antikyra Bay Land and Sea Project, Phokis, Greece. In: Levy T., Jones I. (eds), *Cyber-Archaeology and Grand Narratives. One World Archaeology*. Springer, Cham. https://doi.org/10.1007/978-3-319-65693-9_9.

Liestøl, G., Bjørkli, B., Ledas, S., Stenarson, T., & Uleberg, E. (2018). Archaeology and Augmented Reality. Visualizing Stone Age Sea Level on Location. In: Matsumoto, M and Uleberg, E (eds), *Proceedings of the 44th Conference on Computer Applications and Quantitative Methods in Archaeology*, pp. 367-376.

Liritzis, I (2018) STEMAC (science, technology, engineering mathematics for arts & culture): the emergence of a new pedagogical discipline. *SCIENTIFIC CULTURE*, Vol. 4, No. 2, pp. 73-76. DOI: 10.5281/zenodo.1214567.

Liritzis, I, P. Volonakis, S. Vosinakis, G. Pavlidis.G (2015) Cyberarchaeometry from Cyber-archaeology: New dynamic trends in archaeometric training and research. In: *Virtual Archaeology (Methods and Benefits*), Daria Hokk (ed), Proceedings of the Second International Conference held at the State Hermitage Museum 1–3 June 2015 Saint Petersburg, The State Hermitage Publishers, pp. 38-40.

Liritzis, I., Al-Otaibi, F. M., Volonakis, P., & Drivaliari, A. (2015). Digital technologies and trends in cultural heritage. *Mediterranean Archaeology & Archaeometry*, 15(3), pp. 313-332.

Liritzis I., Pavlidis G., Vosinakis S., Koutsoudis A., Volonakis P., Petrochilos N., Howland M.D., Liss b., Levy T.E. (2016). Delphi4Delphi: first results of the digital archaeology initiative for ancient Delphi, Greece. *Antiquity*, 90 (354). Pp. 1–6. DOI:10.15184/aqy.2016.187.

Liritzis, I, Pavlidis, G., Vosinakis, S, Koutsoudis, A., Volonakis, P., Howland, M.D., Liss, B., Levy, T.E. (2017) Delphi4Delphi - Acquisition of Spatial Cultural Heritage Data for Ancient Delphi, Greece. In: Matthew Vincent, Victor Manuel Lopez- Menchero Bendicho, Marinos Ioannides and Thomas E. Levy (editors) *Heritage and Archaeology in the Digital Age: Acquisition, Curation, and Dissemination of Spatial Cultural Heritage Data*. Publisher: Springer, pp. 151-166.

Liritzis, I and Volonakis, P (2021a) Cyber-archaeometry: novel research and learning subject overview. *EDUCATION SCIENCES*, 11, 86. https://doi.org/10.3390/educsci11020086.

Liritzis, I, Volonakis, P and Vosinakis, S (2021b) 3D Reconstruction of Cultural Heritage Sites as an Educational Approach. The Sanctuary of Delphi. *Appl. Sci.*, 11, 3635. https://doi.org/10.3390/app11083635.

McCarthy, J., & Martin, K. (2019, July). Virtual Reality for Maritime Archaeology in 2.5 D: A virtual dive on a flute wreck of 1659 in Iceland. In: *23rd International Conference in Information Visualization*–Part II, pp. 104-109.

McCoy, M. D., & Ladefoged, T. N. (2009). New Developments in the Use of Spatial Technology in Archaeology. *Journal of Archaeological Research*, 17(3), 263–295. https://doi.org/10.1007/S10814-009-9030-1.

Neubauer, W. (2004). GIS in archaeology—the interface between prospection and excavation. *Archaeological Prospection*, 11(3), 159-166.

Psycharis, S (2018) STEAM in education: a literature review on the role of computational thinking, engineering epistemology and computational science. computational steam pedagogy (CSP). *SCIENTIFIC CULTURE*, Vol. 4, No. 2, pp. 51-72. DOI: 10.5281/zenodo.1214565.

Richards-Rissetto, H. (2010) *Exploring Social Interaction at the Ancient Maya Site of Copán, Honduras: A Multi-scalar Geographic Information Systems (GIS) Analysis of Access and Visibility*. Ph.D. Dissertation, University of New Mexico.

Ruggiero, G., Verdiani, G., & Dal Sasso, S. (2012). Evaluation of carrying capacity and territorial environmental sustainability. *Journal of Agricultural Engineering*, 43(2), e10- e10.

Tronchère, H., Bouvard, E., Mor, S., Fernagu, A., & Ramona, J. (2015). From the excavation to the scale model: a digital approach. *CAA2015*, 3.

Uildriks, M. (2016). iDig-Recording archaeology: a review. *Internet Archaeology*, 42. https://doi.org/10.11141/ia.42.13.

Sanders, D. H. (2011). Enabling archaeological hypothesis testing in real time using the REVEAL documentation and Display system. *Virtual Archaeology Review*, 2(4), pp. 89-94.

Smith, N. G., Knabb, K., DeFanti, C., Weber, P., Schulze, J., Prudhomme, A., ... & DeFanti, T. A. (2013). ArtifactVis2: Managing real-time archaeological data in immersive 3D environments. In: 2013 Digital Heritage International Congress (DigitalHeritage), IEEE Xplore, Vol. 1, pp. 363-370. doi: 10.1109/DigitalHeritage.2013.6743761.

Smith, N. G., & Levy, T. E. (2014). ArchField in Jordan: Real-time GIS data recording for archaeological excavations. *Near Eastern Archaeology*, 77(3), pp. 166–169.

Shiyab, A., Schath, K., Al-jarrah, H., Alawneh, F., Al Sekheneh, W (2018) New discoveries and documentation of megalithic structures in Juffain dolmen archaeological field, Jordan. *Mediterranean Archaeology and Archaeometry*, Vol. 18, No 1, pp. 175-197 DOI: 10.5281/zenodo.1161357.

Smith, N., & Levy, T. (2014). ARCHFIELD: A digital application for real-time acquisition and dissemination--from the field to the virtual museum. *Mediterranean Archaeology & Archaeometry*, Vol. 14, No 4, pp. 65-74.

Stamatopoulos, M.I., Anagnostopoulos, C.N. (2017). A totally new digital 3D approach for reassembling fractured archaeological potteries using thickness measurements, *ACTA IMEKO* 6 (3), pp. 18-28.

Stamatopoulos, M.I., Anagnostopoulos, C.N. (2018). Simulation of an Archaeological Disaster: Reassembling a Fragmented Amphora Using the Thickness Profile Method, *Proceedings of the Euro-Mediterranean Conference (EUROMED2018)*, pp. 162-173.

Vincent, M. L., Kuester, F., & Levy, T. E. (2014a). OpenDig: Contextualizing the past from the field to the web. *Mediterranean Archaeology and Archaeometry*, 14(4), pp. 109-116.

Vincent, M. L., Kuester, F., & Levy, T. E. (2014b). OpenDig: Digital field archaeology, curation, publication, and dissemination. *Near Eastern Archaeology*, 77(3), pp. 204–208.

Von der Osten-Woldenburg H. (2020) Magnetic Gradiometry in Archaeo-geophysics. In: Gupta H. (eds) *Encyclopedia of Solid Earth Geophysics* (Earth Sciences Series), Springer, Cham. https://doi.org/10.1007/978-3-030-10475-7_249-1.

Vote, E. L., Acevedo, D., Laidlaw, D., & Joukowsky, M. S. (2001). ARCHAVE: A virtual environment for archaeological research. *BAR INTERNATIONAL SERIES*, 931, pp. 313-316.