Virtual Archaeology Review, **10**(21): 56-66, 2019
https://doi.org/10.4995/var.2019.11916

Received: May 29, 2019
Accepted: July 7, 2019

A VIRTUAL LOGBOOK FOR THE DOCUMENTATION OF A CONTINUOUSLY CHANGING ARCHAEOLOGICAL SITE: THE SAN CLEMENTE SITE IN ALBENGA (ITALY)

UN DIARIO VIRTUAL PARA LA DOCUMENTACIÓN DE UN SITIO ARQUEOLÓGICO QUE CAMBIA CONTINUAMENTE: EL SITIO DE SAN CLEMENTE EN ALBENGA (ITALIA)

Mattia Previtali

Politecnico di Milano, Department of Architecture, Built Environment and Construction Engineering, Via Ponzio 31, 20133 Milano, Italy. mattia.previtali@polimi.it

Highlights:

- Virtual museums and virtual environments are fundamental tools to raise awareness about the vulnerability of archaeological sites.
- This paper presents the development of a virtual logbook, that can be used by experts and tourists, for the archaeological site of San Clemente (Albenga).
- Integration of data coming from different sources is rendered into a web environment that can be easily accessed from both desktop and mobile devices.

Abstract:

Cultural and built heritage is nowadays recognized as a value not only in the socio-cultural field but also as an important economic driver. However, this non-renewable resource is more and more threatened by both external and internal factors and only by raising awareness on the vulnerability of cultural heritage we can lead to a real involvement of citizen to heritage site protection. In this sense, Virtual Museums (VMs), and more in general virtual technologies, can have a primary role to attract tourists and citizens. Indeed, VMs by presenting cultural concepts by using amusing and engaging techniques may reach younger generations in an easier way. In this paper, the specific case of the San Clemente archaeological site (Albenga, Italy) is addressed. Being the site in the riverbed of the Centa, it undergoes frequent flooding events causing continuously new damages to the archaeological site. The development of a virtual logbook of the site is presented along with the pre-processing steps that are necessary for the preparation of the published material. The logbook is addressed on one side to professionals (i.e. archaeologists and practitioners in cultural heritage) with the main aim of providing a tool for quick damage assessment. On the other side, a mobile app is on development for tourists and citizens allowing virtual exportation of the site and providing informative contents about it.

Keywords: virtual archaeology; 3D reconstruction; digital documentation; virtual museum; mobile applications; risk and resilience

Resumen:

En la actualidad, el patrimonio cultural y construido es reconocido como un valor no solo en el campo sociocultural sino también como un importante motor económico. Sin embargo, este recurso no renovable está cada vez más amenazado por factores externos e internos y solo aumentando la concienciación sobre la vulnerabilidad del patrimonio cultural podemos capitanear una participación real de la ciudadanía en la protección del sitio patrimonial. En este sentido, los museos virtuales, y las tecnologías virtuales en general, pueden tener un papel primordial en la participación de turistas y de ciudadanos. De hecho, los museos virtuales que presentan conceptos culturales mediante el uso de técnicas divertidas y atractivas pueden llegar a las generaciones más jóvenes de manera más fácil. En este artículo se aborda el caso específico del sitio arqueológico de San Clemente (Albenga, Italia). Al estar el sitio en el lecho del río Centa, sufre frecuentes inundaciones que causan nuevos daños continuamente al sitio arqueológico. En este artículo, se presenta el desarrollo de un diario virtual del sitio junto con las etapas de preprocesamiento necesarias para la preparación del material publicado. El diario se dirige, por un lado, a profesionales (como son los arqueólogos y practicantes del patrimonio cultural) con el objetivo principal de proporcionar una herramienta para la evaluación rápida de los daños. Por otro lado, se desarrolla una aplicación móvil para turistas y ciudadanos que permite una exportación virtual del sitio y que proporciona contenidos informativos sobre el mismo.

Palabras clave: arqueología virtual; reconstrucción 3D; documentación digital; museo virtual; aplicaciones móviles; riesgo y resiliencia

* Corresponding author: Mattia Previtali, mattia.previtali@polimi.it

1. Introduction

The relationship and the interaction between physical and virtual spaces is a key issue in our digital era. In the case of dissemination strategies for cultural heritage, virtual technologies can deepen visitors' interest in the subject by presenting complex information into an attractive and engaging way. Indeed, virtual technologies can provide access to a larger target audience creating virtual spaces that are both informative and entertaining. This general trend in the word of cultural information and tourism is generally addressed as Virtual Museum (VM). VM emerged thanks to the "long wave" of the New Museology Movement (Vergo, 1987). This movement since the 1980s broke the old concept of 'museums' stressing the importance of enhancing traditional collections and exhibitions with new educational, amusing and emotionally engaging experiences to museums' visitors by using new communication languages. In this sense, virtual technology represents an effective answer to the need of combining the educational mission of museums with the ability to provide technical information to a wider public engaging them in an attractive way.

This paper presents a specific application of the VM concept to develop a virtual logbook for the archaeological site of the San Clemente Church in Albenga (Northern Italy). This site is currently located in the Centa riverbed in the nearby of the historic city centre. The specific position of the site poses several challenges: on the one side for safety reasons tourists cannot directly get access to it, and on the other hand, the river represents a major thread for the site itself. In particular, the consequences of extreme weather events, like heavy rain and floods, are significantly damaging the archaeological site. The possibility to have virtual logbook documenting the conservation state of the San Clemente Church during time is a fundamental tool for both experts and can represent the starting point for the further development of a VM presenting the site to a wider public. Indeed, the availability of a virtual environment representing a repository of information can be useful not only to specialists (e.g. archaeologists or anyone who operate on the site, for the purpose of both protection and research) but can also work as an attractor of cultural tourists. The city of Albenga is both a seaside town characterized by mass tourism in the summer period, and an ancient town with remains dating back to the Roman period. Finally, a virtual logbook can contribute to raise the consciousness of citizens, tourists, and public administration about the importance of this site in the history of Albenga and can increase the consciousness about its vulnerability.

A significant volume of documentation is available for the San Clemente Site (orthophotos, digital drawings, 3D point cloud, historical information, 360° panoramas, texts), and the main aim of this paper is to create a shared digital platform to connect all those different pieces of information into a unique virtual environment to disseminate them to tourist, experts and citizens. However, to reach such differentiated goals a proper design and selection of available materials needs to be performed to guarantee a higher impact of the solution. In particular, a web-based solution was developed taking into consideration two different typologies of users and use cases: (i) mass tourists and citizens that are more interested in informative contents; and (ii) cultural tourists and professionals involved in the management of the site that are instead more interested in technical data, in-depth descriptions and analysis, comparison of the site at different epochs, conservation information.

The remaining of the paper is organized as follows. The case study of the San Clemente Church is presented in Section 2 focusing mainly on the specificity of the site and presenting the main threads affecting it. Section 3 presents a quick literature review of VM systems describing their main characteristics and design concepts. Section 4 describes users and use case taken into consideration for the development of the San Clemente virtual logbook. The developed system and materials presented are described in Section 5. In the last section, Section 6, some conclusions are drawn starting from the presented case study and future works are highlighted.

2. The case study: San Clemente Church

The town of Albenga was founded by the Romans c. 181 B.C. quickly becoming one of the most important settlements in this area. The importance of Albingaunum (the Roman name of Albenga) was mainly due to its position close to the Roman Iulia Augusta Road, the main Roman road from Italy to southern France, and to the harbour located in the eastern part of the town which was one of the most important of the area. In addition, Albingaunum was a rich agricultural area since it is one of the few flat arable areas in the mountainous Ligurian coastline. In the Imperial period the area where nowadays is located the Church of San Clemente was a southern suburb of the town and more specifically a thermal baths complex was located in there. Indeed, until the 13th century, the Centa River had its riverbed in the northern part of the city. The thermal complex covered approximately 2000 m2 and was organized as a typical Roman bath: an open-air swimming pool (*natatio*), a cold environment (*frigidarium*) and two then hotter and hotter spaces (*tepidarium, calidarium*). This complex was probably built in the period between the 1st and the 3rd century A.C. A Christian complex was built on the remains of the *calidarium*, starting from the 5th century. The complex presented a church, a baptismal pool and a funerary area. The choice of building the baptismal poll on the remains of a bath is probably linked to the fact that catechumens had to plunge during the baptism. A medieval church was built during the 13th century on top of the early Christian one. In the late Medieval period, due to a set of flooding events, the Centa River split into two branches. The first one running to the north of the city and to the second one to the south between the city walls and San Clemente. During the first half of the 14th century, the north branch of the river silted up and the Centa maintained its riverbed in the south of the historic city centre. Evidence of the San Clemente Church can be found in some documents of the 16-18th centuries and totally disappears in the 19th century.

The relevance of this archaeological area was firstly identified at the beginning of the 20th century. The site was rediscovered in 2001 during excavations to widen the Centa riverbed revealing the Church of San Clemente under the right embankment of the river (Fig. 1). The purpose of this excavation was to mitigate the impact of chronic flooding of the Centa River on its

Figure 1: San Clemente archaeological area (Massabò, 2006).

surroundings and on the city of Albenga. The medieval church of San Clemente presents an East-West orientation and it has three main naves separated by rectangular columns.

In the central nave, some remains of the original marble pavement are still visible along with the altar in the right apse. During its life, the San Clemente Church underwent differently reshapes mainly due to the increasing level of the soil in the nearby of the church, due to sediments accumulated by the flooding of the Centa River. In its last phase, the church was drastically reduced in its size by a wall built in correspondence of the main apse and the church was transformed into a chapel (Massabò, 2002; Massabò, 2006).

As it can be clearly observed the archaeology site is intricately linked to the Centa River (Fig. 2): which has marked its most recent history, led to its re-discovery, as well as its partial loss. Indeed, the flooding of the Centa River is a major thread for the site. In the last thirty years, the river experienced three major floods: in 1994, 2000 and 2016. Indeed, the site was discovered during the works for enlarging the riverbed and increasing the river section. The long term of this intervention aims to allow the outflow of the river to the sea without flooding, thus ensuring public safety. Most of the projects that could protect the site clash against the works eligible according to the river basin plans. In order to guarantee the outflow of the water, it is not possible to create embankments that could protect the vertical walls of the archaeological complex during floods, and it is not possible to rebury the site because it would reduce the width of the riverbed near the mouth of the river.

(a)

(b)

Figure 2: Overview of the San Clemente archaeological area, Albenga, Italy: a) Site view from the road; b) View from the riverbank.

3. State-of-art in virtual museums (VM)

A formal definition of VM changed during the last years. Indeed, starting from one of the first definitions describing a VM as a real museum represented in a digital form (Tsichritzis & Gibbs, 1991), the concept of VM enlarged to encompass different types of virtual environments representing both digitized virtual environments and only digital contents (Petridis et al., 2007; Ivarsson, 2009; Styliani, Fotis, Kostas, & Petros, 2009; Perry, Roussou, Economou, Young, & Pujol, 2017). In addition, according to Hazan et al. (2014) VMs should be designed not only for leisure and entertainment but they should also provide a drive-in social life. In particular, according to the definition formulated by a large set of researchers and practitioners in the field of museology and digital heritage in the V-MUST project "A virtual museum is a digital entity that draws on the characteristics of a museum, in order to complement, enhance, or augment the museum experience through personalization, interactivity and richness of content. Virtual museums can perform as the digital footprint of a physical museum, or can act independently… Moreover, a virtual museum can refer to the on site, mobile or World Wide Web offerings of traditional museums (e.g., displaying digital representations of its collections or exhibits)…" (Hazan et al., 2014). In agreement with this definition, but enlarging even more the VM concept, Pujol and Lorente (2013) use the term VM to refer to a digital environment, either accessible through the World Wide Web or in the exhibition, reconstructing a real place or a completely digital one where visitors can interact with the digital or digitalized objects and with the environment, communicate, explore and share information. The same concept is also stressed in the definition of VM as defined in the project VIMM (Ioannides & Davies, 2018):

> Virtual museums can perform as the digital footprint of a physical museum, or can act independently, …, a virtual museum can refer to the online content offering of traditional museums (e.g., displaying digital representations of its collections or exhibits); or can consist of 'born digital' content. … It can provide access to content that is inaccessible in real World (in storage, lost, in private collections etcetera).

As highlighted in (Ioannides & Davies, 2018) a crucial aspect in VMs is the impact of interactive applications on the users and more, in general, the user acceptance of the proposed virtual experience. To achieve high user acceptance, VMs need a more comprehensive and integrated approach. In particular, the interaction between cultural content, user interfaces, social and behavioural studies needs further studies. However, some first considerations can be drawn to guide the design of a VM system. Pescarin et al. (2012) show that the acceptance of the interactive and virtual environment seems to depend on the capability of the technology to be 'invisible' and to allow a range of possibilities for accessing the content. For this reason, the choice of well-known technology and interaction systems can increase the acceptance of systems. For example, touchscreens are technology widespread in everyday life and their use into a VM system can be more user-friendly with respect to other new interaction systems. Similarly, Barbieri, Bruno, and Muzzupappa (2017) report that the choice of the interaction device, need to be carefully evaluated on the basis of user studies. A further aspect to be analysed is the proper selection of materials and experiences the VM systems have to convey (Sherman & Craig, 2018). For example, the selection of experiences and contents for an auditory of schoolchildren is much different with respect to the ones that are necessary to attract cultural tourists. Nowadays, different types of VMs exist: they can range from online digital libraries, 3D reconstruction of real museum exhibition with digitized contents, in-gallery interactive systems, virtual reality installations, mobile guided tours etc. For the sake of simplicity, we can categorize four main types of VMs (Pivec & Kronberger, 2016): (i) digital archives, (ii) mobile multimedia guides, (iii) in-gallery virtual installations or booths combining virtual and real museum, and (iv) virtual tours in the museum for non-physical field trips or virtual experiences.

3.1. Digital archives

In most cases, virtual museums are adopting an object-centred approach. This approach is quite typical in the museology filed and is based on the creation of digital archives and/or web repositories focusing on the presentation of objects and collections with a heavy informative apparatus. Digital archives are generally designed to guarantee higher accessibility to information and digitized materials to a wider public of researchers.

The Europeana project[1] is an initiative designed for museums giving them the opportunity to integrate their digital collections into a digital European cultural heritage collection. Starting from this wide collection specific virtual exhibitions are created by expert users according to specific topics (e.g. The Great War, World War II, etc.). The Europeana platform allows each user to create a personalized selection of favourite contents, images, documents etc. Similar experiences exists also at the national level. Here we cite only the Gallica project[2], acting as digital archive collecting contents coming from galleries, libraries, museum and archives in France, but similar initiatives are ongoing in different countries.

Several museums also provide digital archives of their collection. For example, the Rijksmuseum in Amsterdam develops the application Rijksstudio[3].

However, even if those repositories can be fundamental for experts they can provide sometimes too much information for a non-expert visitor determining an information overload.

3.2. Mobile multimedia guides

Mobile technologies determined continuously growing mobile multimedia guides (Economou & Meintani, 2011) or apps. Mobile multimedia guides can be downloaded by visitors on their mobile or a mobile device is provided during the physical visit. Such apps can be used both as a replacement for traditional audio guides and as a tool for preparing the visit as well as allowing data collection in order to personalize the onsite and/or the post-visit experience moving decisively towards a visitor/experience-centred approach (Vayanou et al., 2014). An increasing trend in the field of mobile

[1] http://www.europeana.eu

[2] https://gallica.bnf.fr

[3] https://www.rijksmuseum.nl/en/rijksstudio

multimedia guides is the increase in user participation mainly by using specific narrative engagement (Roussou & Katifori, 2018) as well as more immersive mobile augmented reality (Galatis, Gavalas, Kasapakis, Pantziou, & Zaroliagis, 2016).

3.3. In-gallery virtual installations

In most cases, museums integrate into their gallery exhibitions specific booths having the main aim of attracting new visitors (e.g. whole families and groups of people) and giving new possibilities to engage learning.

These in-gallery installations are generally used to provide:

- Various combinations of photographs and visualization with informative contents. For example, Gigapixel panoramic photographs allowing to catch very detailed representations of painting or detailed aerial representations (Brumana, Oreni, Caspani, & Previtali, 2018; Demetrescu, Ferdani, Dell'Unto, Touati, & Lindgren, 2016);
- Panoramic tours and stereoscopic versions of an object presented in the physical exhibition possibly augmented with informational hotspots (Brighton Royal Pavilion Panorama[4]; Kersten & Lindstaedt, 2012);
- Representation of 3D object and spaces (either real or imaginary) with some annotation capabilities, explanatory videos, background information and informational hotspots (Giza 3D[5]; Kersten, Tschirschwitz, & Deggim, 2017).

In-gallery virtual installations generally adopt screens combined with some specific controlling devices (e.g. touch screen console, trackballs, gesture-based sets, etc.) or more complex immersive toolset (e.g. Oculus Rift, HTC Vive, etc.) for user interaction.

In many cases, it exits a strict link between real object observed in the museum and the virtual information presented in virtual booths. For example, the virtual reconstruction presented in a booth can show the original appearance of a sculpture hosted in the museum with its original colours and plausible reconstruction of missing parts. Similarly, it is possible to reconstruct the position whereof a set of artefacts hosted in the museums (amphorae, coins, etc.) were found during archaeological excavations, etc. An example of this concept is the exhibition *Les Etrusques et la Méditerranée. La cité de Cerveteri/Gli Etruschi e il Mediterraneo. La città di Cerveteri*. Here an application can be experienced that allows visitors to examine and explore closely the digitized 3D model of more than 450 pieces of the Etruscan culture. Such close exploration is obviously not possible with real artefacts.

3.4. Virtual tours and virtual experiences

Another approach is to enable a virtual experience to visitors by either bringing the museum artefacts virtually out of the museum or virtually bringing visitors to museums or excavation sites.

The most popular tool for virtual tours is the Google Art project[6] where online visitors can visit virtually more than 300 cultural places (museums, palaces, UNESCO sites) all over the world by means of panoramic tours. The African Fossils website[7] presents a collection of fossils, stone artefacts and ancient human remains found in the area of the Lake Turkana. Cots et al. (2018) present the recreation, the virtual interpretation and the dissemination to non-specialized public in the form of immersive virtual reality experience of two case study: Les Cases de la Catedral (Tortosa) and the protohistorical settlement of La Cella (Salou, Tarragona).

4. Users and use cases of the San Clemente virtual logbook

As discussed in the previous sections, the Centa River and mainly its floods represent the major thread for the San Clemente site. Since few structural interventions can be performed to protect the site, due to the conflict with public safety, loss of assets seems inevitable. In this situation, digital documentation techniques can play a primary role to preserve the significance of this site to future generations. These considerations led to the development of a documentation and survey strategy whose aim was to record the current state of the archaeological site and develop a monitoring strategy aimed at documenting damages on the site after flooding events (Previtali, Stanga, Molnar, Van Meerbeek, & Barazzetti, 2018). Documentation of these phenomena was carried out with an integrated survey strategy combining photogrammetry, Unmanned Aerial Vehicle (UAV) survey, and terrestrial laser scanner (TLS). The possibility to have a virtual logbook connecting these pieces of information into a unique repository is fundamental for archaeologists and restores involved in the management of the site. A large amount of data produced during this documentation activity can be used as a source of information for tourists and citizens, conveying in an amusing and engaging way of delivering information and giving access to an archaeological site that cannot be physically explored. To reach such differentiated purposes a careful analysis of the user and use cases has to be carried out to guarantee real usefulness of the application. In particular, two main users are here selected (Table 1): (i) archaeologists and practitioners in the field of cultural heritage (Fig. 3a); and (ii) non-experts like tourists and citizens (Fig. 3b).

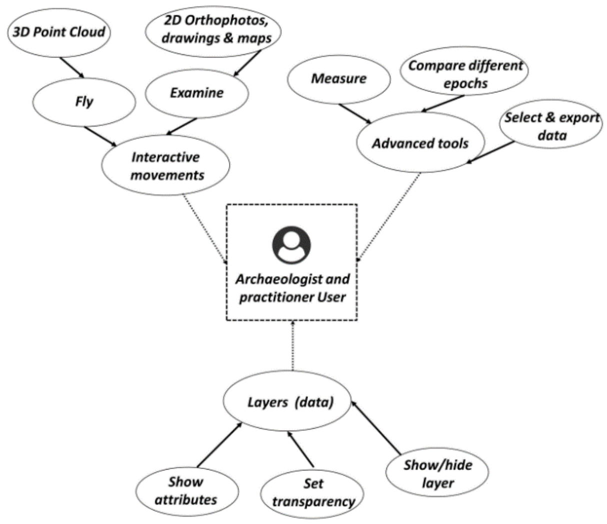
The 'professional' logbook for archaeologists and practitioners has to provide a repository for accessing technical information of the site and mainly data for documentation of damages after flooding events. The logbook has the main aim of allowing comparison of data retrieved at different epochs and tracking of damages along time. This logbook has to be accessible by using web technologies both on desktop and on mobile devices. A mobile version of the logbook allows for accessing the data directly on-site and this can be of primary importance during inspections and evaluation of flooding damages right after a flood. On the other hand, the availability of documentation materials on desktop (Personal Computers) is crucial for any technical analysis that can be performed with professional

[4] https://brightonmuseums.org.uk/royalpavilion/history/3d-history

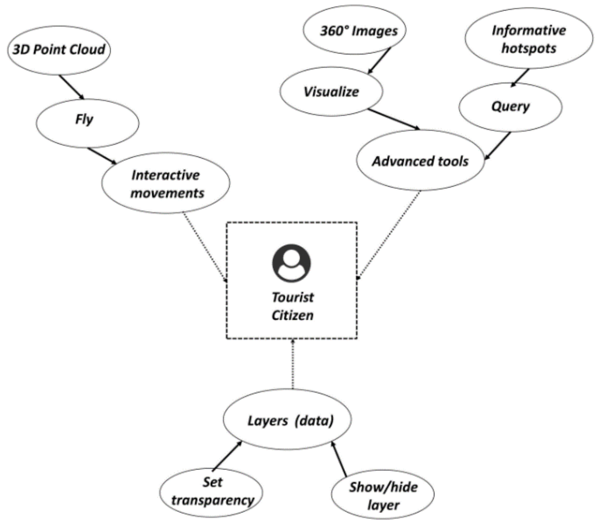
[5] https://www.3ds.com/stories/giza-3d

[6] https://artsandculture.google.com

[7] https://africanfossils.org



(a)



(b)

Figure 3: Use case diagram of the developed application: a) Archaeologist and practitioner user; b) Tourist or citizen.

Geographic Information System (GIS) software. Data of major relevance for archaeologists and practitioners are:

- Orthophoto derived from UAV data: UAV is useful in capturing the site and its surroundings and for a fast visual check of major damages,
- Orthophoto with overlaid elevations: to be used for stratigraphic analysis and evaluation of the wall conservation state,
- Damage maps: derived by computing cloud to cloud distance among point clouds acquired at different epochs,
- Reports: link to existing reports, stratified plans and cross sections,
- 3D point clouds: point clouds acquired either form TLS or derived from UAV images.

Comparison of georeferenced data, both 2D and 3D, is the main functionality of the professional logbook.

For tourists and citizens, an informative mobile application was needed. The VM of the San Clemente Church has the main aim of giving access to an archaeological site that, due to the security aspect, cannot be physically explored. To guarantee an overview of the site the following data were used:

- 3D models: point cloud and mesh derived either from TLS or from UAV photogrammetric images are used to allow a 3D navigation and exploration of the archaeological site,
- 360° images: immersive images are used to explore the site in a photorealistic way,
- Informative contents: short texts and images are used to highlight the history of the San Clemente and to describe the main structures of the Church.

Access to 360° images and informative contents was provided through hotspots. To raise awareness about the fragility of the site a timeline was arranged to show its evolution during a time and highlighting the large losses caused by flooding.

Table 1: Summary of the user and use cases defined for the design of the San Clemente logbook: (i) archaeologists and practitioners and (ii) tourists and citizens.

	Archaeologists and practitioners	*Tourists and citizens*
Aim	Documentation of damages after flooding events	Raise awareness on the site
Platform	Web (Desktop/mobile)	Web – Mobile
Data	Orthophotos	3D Models
	Damage maps	360° images
	Link to reports	Informative contents (text, images)
	3D point cloud models	
Functionalities	Compare data from different epochs	Explore 3D models
	Measure on 2D and 3D	Timeline
		Informational hotspot

5. San Clemente virtual logbook implementation

5.1. Data sources

As previously highlighted, documentation of archaeological sites generates a high amount of data that can be used as an incredibly rich source of information not only for experts but also for touristic purposes. Materials used in the logbook and in the tourist applications are primarily acquired to monitor the damages induced by flooding events.

The first campaign was carried out in 2015, under the supervision of the *Soprintendenza Archeologia, Belle Arti e Paesaggio della Liguria*, by using both TLS and UAV equipment for the documentation of the site and total station for the materialization of a local reference system. The photogrammetric block was made up of 52 images and the final orthophoto had a pixel size of about 10 mm. The laser scanning survey of the area was carried out to obtain a detailed and accurate description of the remains of the San Clemente Church. This survey was made up of 30 scans (more than 1 billion points) registered by means of checkerboards and spherical targets. The latter ones were measured by total station.

The final registration precision was about ± 3 mm. Orthophotos were generated for the building elevations. Each elevation was processed independently and the final orthophotos had a pixel size of about 2 mm.

The site was significantly damaged due to a flooding event on November 23rd, 2016. In particular, the heavy discharge of the Centa River scoured the portion of the structures directly facing the river and damaged some walls causing the removal of stones.

A second campaign was carried out after the flood to quantify damages. In this second epoch, a second UAV orthophoto of the site was derived and georeferenced, as the first one, in WGS 84 / UTM 32N to have a direct comparison of the two. To have a better description of the vertical structures, a TLS campaign was carried out resulting in 23 scans. A summary of the two surveying campaigns is reported in Table 2.

Table 2: Summary of the surveying campaigns.

	Epoch 1 *2015*	*Epoch 2* *2016*
UAV orthophoto	✓ Pixel size 10 mm WGS 84 / UTM 32N	✓ Pixel size 10 mm WGS 84 / UTM 32N
Elevations Orthophoto	✓ Pixel size 2 mm Local reference system	×
TLS survey	✓ 30 scans WGS 84 / UTM 32N	✓ 23 scans WGS 84 / UTM 32N

5.2. Virtual logbook implementation

As discussed in the previous paragraph, the San Clemente virtual logbook deals with a large set of different data: orthophotos, point cloud, 360° images and texts. In addition, two different user profiles have to be taken into consideration: a professional profile and a tourist one, with specific requirements and customized contents. For this reason, two different interfaces were designed. The 'professionals' one, dealing with multi-temporal and multi-source geospatial data query, visualisation and consultation, is based on a webGIS geo-portal concept as a gateway to information. The second one, devoted to tourist, instead is more informative. For this reason, the implementation of the logbook takes advantage of different FOSS (Free/Open Source Software) solutions both at the server and the client-side. Those libraries work in the framework of WebGL, a Web-based open-source graphics library for Web-browsers (OpenGL based). WebGL allows for managing directly into a web-browser complex graphics contents, like 3D environment, without the need of any additional app or plugin creating a user-friendly solution that can be accessed from every kind of device (smartphone, tablet, pc) directly from the web-browser. WebGL technology is implemented in different browsers (e.g. Chrome, Safari, Firefox, etc.) both in the desktop and mobile version making WebGL-based solutions very flexible. For this reason, recently, several virtual reality applications developed for archaeological sites take advantage of Web-GL (Scianna, La Guardia, & Scaduto, 2016). However, there are some limitations on the size of 3D models to be effectively loaded and visualized. For this reason, several libraries are using specific tiling techniques (El Haje, Jessel, Gaildrat, & Sanza, 2016).

In particular, the following libraries are used for the development of the solution:

- jQuery: the jQuery 1.10.2 library is used to develop the front-end (UI and application behaviour). Some jQuery plugins are added such as blockUI, numeric, and Zebra Datepicker in order to enhance the user experience;
- OL3-Cesium: OL3-Cesium is a JavaScript library for creating 3D globes and 2D maps in a web browser without a plugin. It integrates the two popular libraries OpenLayers and CesiumJs. This library is used as a support to manage layers, visualize and display orthophotos and maps as Web Map Service (WMS) and Web Map Tile Service (WMTS);
- Potree: it is a free open-source WebGL based point cloud renderer for large point clouds and it is used for the dynamic visualization and exploration of 3D point clouds and models;
- GeoServer: it is an open-source server written in Java that allows users to share, process and edit geospatial data. It allows to process and expose datasets according to the Open Geospatial Consortium (OGC) standards as WMS, Web Feature Service (WFS) and Web Coverage Service (WCS);
- Marzipano: it is a 360° media viewer for generating a virtual tour from a set of panoramas and allows to export it as an application that can be easily deployed and visualized into a web-browser.

The general architecture of the San Clemente logbook is presented in Fig. 4. The application is developed by using a classic HTML/CSS/JS approach: two different applications are developed: the first one for archaeologist and practitioners and the second one for tourists and citizens. As discussed in the previous section, some materials (e.g. orthophotos, damage maps, layered plans) can be loaded into professional GIS software for further analysis as WMTS or as WFS.

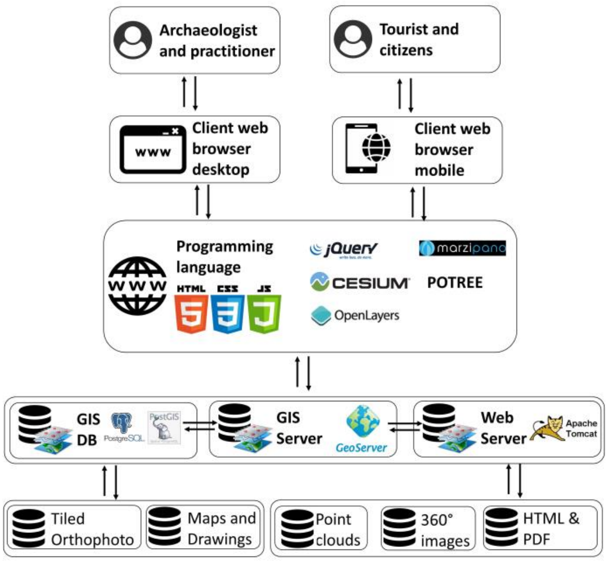


Figure 4: San Clemente virtual logbook architecture.

Since different data are used in each application, a pre-processing step is needed in order to make the data ready for online publishing. The different pre-processing stages are summarized in Fig. 5, where blue determines desktop off-line processing and orange represents online processing.

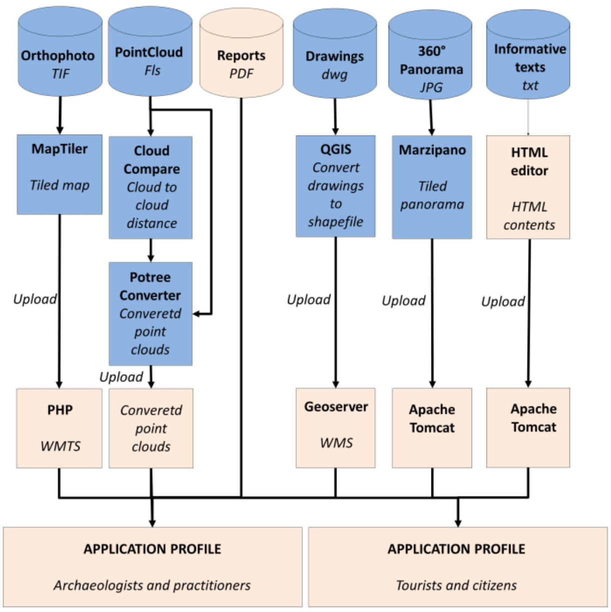


Figure 5: Workflow of data pre-processing.

5.3. Logbook in action

This section presents a couple of typical use cases for both applications.

In the case of the ‘professional’ application, the primary aim is to provide a quick comparison between data acquired at different epochs. So once the user accesses the logbook as a first thing he/she is requested to select which data should be visualized first. For example, the orthophoto of 2015 (Fig. 6a).

The user can then explore the data and make some measurements (Fig. 6b). The comparison of the maps can then be carried out simply selecting the area of comparison and the data to be compared (e.g. 2015 and 2017 orthophoto), the two selected datasets can then be swiped (Fig. 6c) and the damage map, obtained as close neighbourhood distance computed for the point clouds acquired in the two epochs, can be displayed (Fig. 6d). Green and red areas are the ones characterized by the largest distance between the data. To better understand the entity of the difference the user can skip to the 3D visualization (Fig. 7a-b). The nearest neighbour distance was used for the classification since the two-point clouds present a similar density.

However, some miscalculations can be observed in the cases of the big holes caused by the overturning of the area close to the river. In such areas, the calculated distance is only highlighting the changes but is not a proper estimation of the real metric. Measurements can be also performed directly on the point cloud and comparison can be performed also on cross-sections.

For example, Figure 7c-d shows a comparison between two point cloud slices, the white one (2015) and the green one (2017). In this case, by simply selecting the area that needs to be compared to a vertical slice of the

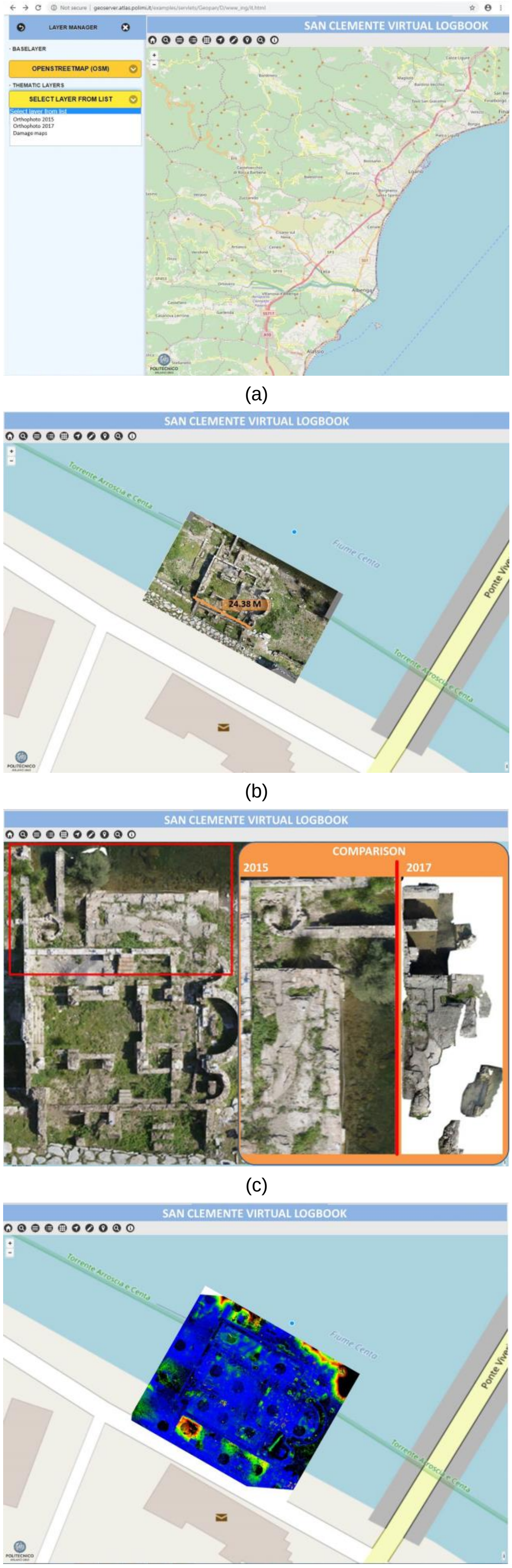
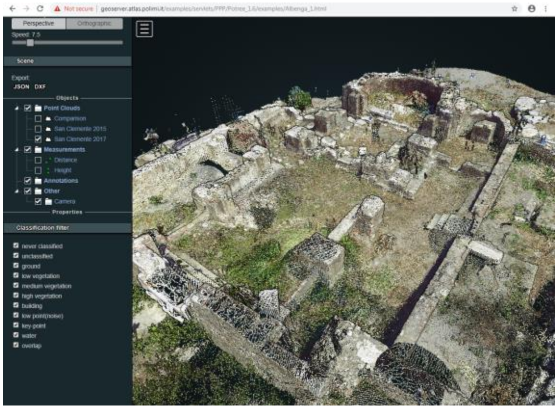
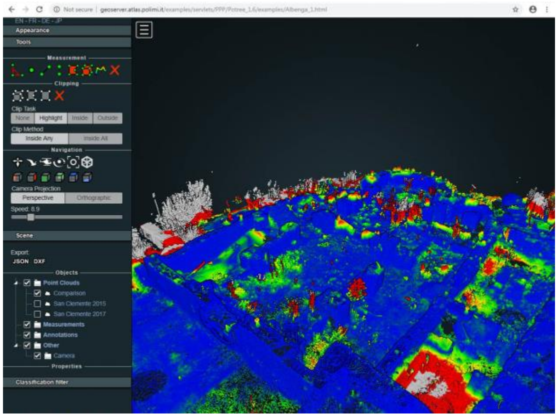


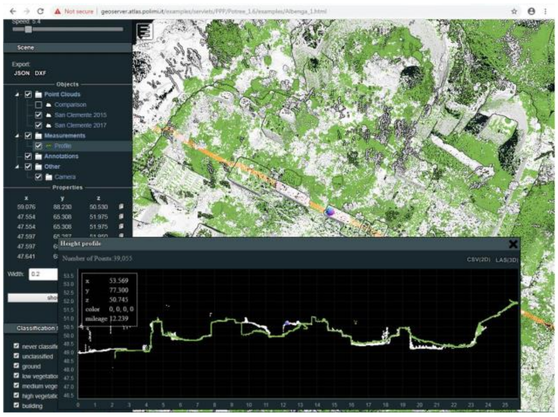
Figure 6: Virtual logbook ‘professional’ 2D interface: a) Selection of the contents to be visualized; b) Loaded orthophoto and measurements; c) Orthophoto data comparison; d) Damage map.



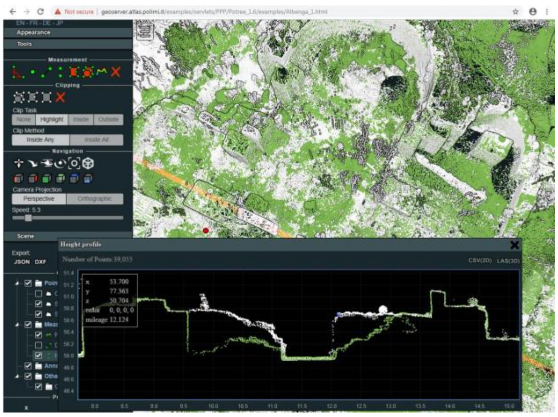
(a)



(b)



(c)

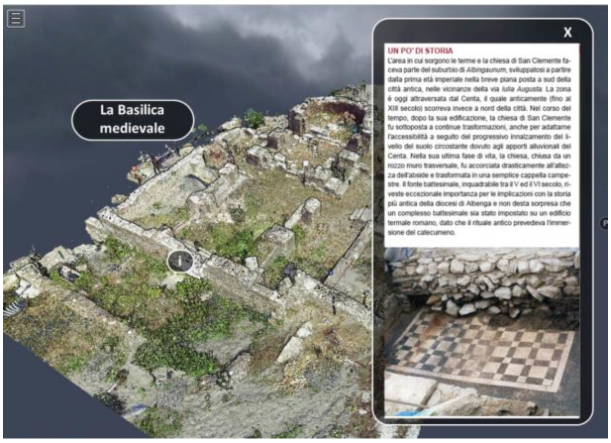


(d)

Figure 7: Virtual logbook 'professional' 3D interface: a) 3D point cloud- 2017 data; b) 3D damage map; c) Comparison of the point clouds acquired in 2015 (white) and 2017 (green); d) Detail of the cross-section comparison.

(a)

(b)



(c)

Figure 8: Virtual logbook 'tourist' interface: a) 3D point cloud-2017 data; b) 360° image hotspot; c) Informative contents hotspot.

point cloud is cropped and is displayed into a separate window. The thickness of the slice can be dynamically adjusted and 3D measurements can be performed on the point cloud. In the case of Figure 7c-d, the damage caused by the flooding is evident in the comparison and can be quantified using both the vertical scale in the diagram and exporting the selected dataset as .CSV or .LAS file. A similar comparison can be performed also between horizontal slices.

The 'tourist' application currently is available only as a beta release. In this second case, the application is designed for mobile devices only. Once a user gets access to the app immediately he/she immediately has a 3D visualization of the most recent 3D model of the site (Fig. 8a). The model can be interactively explored in different ways. A sidebar gives an indication to the material that can be accessed through the app: (i) 360° images of the area, (ii) description of the site and (iii) pictures of the site. If 360° images are selected a set of hotspots appears on the 3D point cloud in correspondence of their location. Once an image is selected, a 360° panorama is displayed in a new window or can be viewed at full screen (Fig, 8b). Similarly, the user can select to visualize and short descriptions and pictures of the site (Fig. 8c). If the user is interested can get access to the entire set of 3D models.

6. Conclusions and future works

Many cultural heritage sites are facing new treads due to global warming and climate changes. The main consequence is the increase, both in frequency and in extends, of extreme climate events. This poses new challenges and new management strategies to mitigate risks and to assess damages connected with such events. In addition, awareness raising is a primary mission to increase consciousness in public opinion about the importance of cultural heritage site protection. In this sense, virtual technologies and VMs can play a key role.

Concerning the San Clemente site, the fact that it is now uncovered represents both an opportunity and a thread. In fact, it is an opportunity for the archaeologist to study the site and increase consciousness about the long and stratified history of the city of Albenga for tourist and citizens. However, it represents also a thread for the site itself since as long as it was covered by the river embankment it was not exposed to erosion and flooding. Since it is not possible to realize structural interventions protecting the site to floods, the opportunity to record and disseminate as much as possible about the site is of primary importance, since it is the only way to transfer the value of the site to future generations. At the same time, the availability of a tool aimed at identifying damages is fundamental to develop new strategies for experts in charge of the site. The virtual logbook presented in this paper tries to give the first answer to those needs. The material here presented was developed starting from a collaboration between University and the '*Soprintendenza Archeologia, Belle Arti e Paesaggio della Liguria*' on a demo site. The implementation of new materials (e.g. orthophotos, point clouds) needs further discussion on the sustainability of the proposed solution.

In the future work, the integration with remote sensing data will be evaluated to provide some forecast indicator of possible flooding events and to allow for quicker real-time analysis of the damages. The development of new functionality in the touristic application will also be explored. In particular, the possibility to create a timeline of the site. Finally, the chance to create a BIM-based model of the site in the future will allow users to take advantage of informative content modelling as tools for data aggregation.

Acknowledgements

The author would like to acknowledge '*Soprintendenza Archeologia, Belle Arti e Paesaggio della Liguria*' and mainly Dr. Marta Conventi for accessing the site of San Clemente, DABC, Gicarus Lab, *Politecnico di Milano* and Prof. Raffaella Brumana for their support and funding of this research, and Dr. Luigi Barazzetti for his support.

References

Barbieri, L., Bruno, F., & Muzzupappa, M. (2017). Virtual museum system evaluation through user studies. *Journal of Cultural Heritage*, *26*, 101–108. https://doi.org/10.1016/j.culher.2017.02.005

Brumana, R., Oreni, D., Caspani, S., & Previtali, M. (2018). Virtual museums and built environment: narratives and immersive experience via multi-temporal geodata hub. *Virtual Archaeology Review*, *9*(19), 34–49. https://doi.org/10.4995/var.2018.9918

Cots, I., Vilà, J., Diloli, J., Ferré, R., & Bricio, L. (2018). La arqueología virtual: de la excavación arqueológica a la gestión y socialización del patrimonio. Les cases de la Catedral (Tortosa) y el yacimiento protohistórico de La Cella(Salou), Tarragona. *Virtual Archaeology Review*, *9*(19), 102–113. https://doi.org/10.4995/var.2018.9754

Demetrescu, E., Ferdani, D., Dell'Unto, N., Touati, A. M. L., & Lindgren, S. (2016). Reconstructing the original splendour of the House of Caecilius Iucundus. A complete methodology for virtual archaeology aimed at digital exhibition. *SCIRES-IT: SCIentific RESearch and Information Technology*, *6*(1), 51–66. http://doi.org/10.2423/i22394303v6n1p51

Economou, M., & Meintani, E., (2011). Promising beginnings? Evaluating museum mobile phone apps. In *Proceedings of the Re-Thinking Technology in Museums: Emerging Experience Conference*, (pp. 87–101). University of Limerick, Ireland.

El Haje, N., Jessel, J. P., Gaildrat, V., & Sanza, C. (2016). 3D cities rendering and visualisation: a web-based solution. In *Eurographics Workshop on Urban Data Modelling and Visualisation (UDMV 2016*), (pp. 95–100). Liege, Belgium. http://doi.org/10.2312/udmv.20161426

Galatis, P., Gavalas, D., Kasapakis, V., Pantziou, G. E., & Zaroliagis, C. D. (2016). Mobile augmented reality guides in cultural heritage. In *Proceedings of the 8th EAI International Conference on Mobile Computing, Applications and Services*, (pp. 11–19). ACM. https://doi.org/10.4108/eai.30-11-2016.2266954

Hazan, S., Hermon, S., Turra, R., Pedrazzi, G., Franchi, M., & Wallergard, M., (2014). Theory design and current practice - Update on D3.1 (V_MUST.net-D3.1b). Retrieved on June 29, 2019, from http://www.v-must.net/sites/default/files/D3.1_update.pdf

Kersten, T. P., & Lindstaedt, M. (2012). Virtual architectural 3D model of the imperial cathedral (Kaiserdom) of Königslutter, Germany through terrestrial laser scanning. *Lecture Notes in Computer Science*, *7616*, 201–210. https://doi.org/10.1007/978-3-642-34234-9_20

Kersten, T. P., Tschirschwitz, F., & Deggim, S. (2017). Development of a virtual museum including a 4D presentation of building history in virtual reality. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W3*, 361–367. https://doi.org/10.5194/isprs-archives-xlii-2-w3-361-2017.

Ioannides, M., & Davies, R. (2018). ViMM-Virtual Multimodal Museum: a manifesto and roadmap for Europe's digital cultural heritage. In *International Conference on Intelligent Systems (IS)*, (pp. 343–350). Madeira, Portugal: IEEE. https://doi.org/10.1109/is.2018.8710556

Ivarsson, E. (2009). Definition and prospects of the Virtual museum. (Master Thesis, Uppsala University). http://elinivarsson.com/docs/virtual_museums.pdf.

Massabò, B. (2002). Prime considerazioni sulle terme pubbliche di Albingaunum. *Rivista di Archeologia*, XXVI, 139–145.

Massabò, B. (2006). Albenga (Sv)-L'area archeologica nell'alveo del Centa: le terme pubbliche romane e la chiesa di San Clemente. FOLD&R FastiOnLine documents & research, (70), 1–13.

Perry, S., Roussou, M., Economou, M., Young, H., & Pujol, L. (2017). Moving beyond the virtual museum: Engaging visitors emotionally. In *23rd International Conference on Virtual System & Multimedia (VSMM)*, (pp. 1-8). Dublin, Ireland: IEEE. https://doi.org/10.1109/vsmm.2017.8346276

Pescarin, S., Pagano, A., Wallergård, M., Hupperetz, W., Ray, C., Verhagen, P., & Earl, G. (2012). Evaluating Virtual Museums: Archeovirtual Case Study. *Archaeology in the Digital Era* (pp. 74–82). Amsterdam University Press. https://doi.org/10.1515/9789048519590-009

Petridis, P., White, M., Mourkousis, N., Liarokapis, F., Sifniotis, M., Basu, A. & Gatzidis, C. (2007). Exploring and interacting with virtual museums. In *Proceedings of the 33rd Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA2005)*, (pp. 73–82). Tomar, Portugal.

Pivec, M., & Kronberger, A. (2016). Virtual museum: Playful visitor experience in the real and virtual world. In *8th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games)*, (pp. 1–4). Barcelona: IEEE. https://doi.org/10.1109/vs-games.2016.7590376

Previtali, M., Stanga, C., Molnar, T., Van Meerbeek, L., & Barazzetti, L. (2018). An integrated approach for threat assessment and damage identification on built heritage in climate-sensitive territories: the Albenga case study (San Clemente church). *Applied Geomatics*, *10*(4), 485–499. https://doi.org/10.1007/s12518-018-0217-3

Pujol, L. & Lorente, A., (2013). The virtual museum: a quest for the standard definition. Archaeology in the Digital Era. In *Proceedings of the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology* (CAA), 40–48.

Roussou, M., & Katifori, A. (2018). Flow, staging, wayfinding, personalization: Evaluating user experience with mobile museum narratives. *Multimodal Technologies and Interaction*, *2*(2), 32. https://doi.org/10.3390/mti2020032

Scianna, A., La Guardia, M., & Scaduto, M. L. (2016). Sharing on web 3D models of ancient theatres. A methodological workflow. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLI-B2*, 483–490. https://doi.org/10.5194/isprs-archives-xli-b2-483-2016

Sherman, W. R., & Craig, A. B. (2018). *Understanding Virtual Reality: Interface, Application, and Design*. San Francisco: Morgan Kaufmann.

Styliani, S., Fotis, L., Kostas, K. & Petros, P. (2009). Virtual museums, a survey and some issues for consideration. *Journal of Cultural Heritage*, *10*(4), 520–528. https://doi.org/10.1016/j.culher.2009.03.003

Tsichritzis, D., & Gibbs, S. (1991). Virtual Museums and Virtual Realities. In *Proceedings of the International Conference on Hypermedia and Interactivity in Museums* (pp. 14–16). Pittsburgh, PA.

Vayanou, M., Karvounis, M., Katifori, A., Kyriakidi, M., Roussou, M., & Ioannidis, Y. E. (2014). The CHESS Project: Adaptive personalized storytelling experiences in museums. In UMAP Project Synergy Workshop. Retrieved on May 24, 2019, from https://umappros.wordpress.com/

Vergo, P. (1997). *New Museology*. London: Reaktion books.