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ACCESSIBILITY TO UNDERWATER CULTURAL HERITAGE: THE INTERACTIVE WEB NAVIGATION OF THE ROMAN SUBMERSED VESSEL OF CALA MINNOLA

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Abstract:

The possibilities offered by photogrammetric reconstruction based on computer vision algorithms allowed in recent years to develop new interesting solutions for the spread and dissemination of knowledge on Cultural Heritage (CH). In the same way, the recent technological development in the field of Virtual Reality (VR) has offered new possibilities for the creation of interactive virtual environments, which can be freely accessed via the browser using any type of device. These technologies acquire an additional relevance if applied to archaeological sites or monuments that are difficult to access, or even totally inaccessible, except by specialized personnel. In this case, the virtual fruition on the web becomes strategic for the valorization of CH, as in the case of submerged archaeological sites, where the virtual tour represents in fact the only opportunity of diffuse accessibility. The present case shows the virtual reconstruction of the wreck area of the Roman ship found on the seabed of Cala Minnola on the island of Levanzo (TP, Italy). The model, obtained from a Structure from Motion (SfM) processing of a chunk of photos originally intended for a traditional photogrammetric survey, was edited and inserted into a specific template based on HTML5 and linked to Javascript libraries (Three.js) which allowed browsing on the web. Subsequently, the navigation model was suitably adapted to the purpose, in order to make the online virtual-navigation as intuitive as possible, considering the navigation with any type of device and using the most common browsers (Chrome, Safari, Firefox). This experimentation is a viable procedure for spreading the knowledge of a submerged archaeological site in a simple way, by web-browsing. This type of navigation models with the future development of 5G networks will find greater diffusion and application, with the possibility of including increasingly complex environments in the navigation.

Keywords: Survey, Cultural Heritage, 3D modelling, photogrammetry, WebGL, Virtual Reality

1. Introduction

The work reported in this article shows the potential and importance of online virtual fruition of inaccessible archaeological sites, in a period in which the enhancement of cultural heritage is particularly connected with the spread of knowledge regarding cultural goods (Ioannides et al., 2017). Advances in information technologies, applied in particular to survey and photogrammetric reconstruction techniques, now allow very realistic virtual reconstructions of real objects and environments (Banfi, 2020; Barrile, Fotia, Bilotta & De Carlo, 2019; Scianna, Gaglio & La Guardia, 2020; Masiero et al., 2019).

The importance of virtual visualization is now undisputed, as it allows visitors to observe, and, therefore, study objects of artistic and cultural value from new points of view. Moreover, thanks to it, it is possible to reach a much

larger number of users, both for the entertainment character that distinguishes it, and because it allows access to visual and sensory information that is otherwise unreachable. The problem of accessibility to CH, in fact, does not concern only those people with physical disabilities. In this regard, some archaeological sites, in fact, represent proper features that are not compliant with the accessibility to visitors, such as the presence of very fragile elements or parts that risk being easily altered. Furthermore, many sites are unreachable for most people, as they are located in particular, remote places, inside private property or because the paths to reach them make access to places too complicated (Dominici, Alicandro & Massimi, 2017; Scianna & La Guardia, 2019). This is the case, in particular, of submerged archaeological sites, which can only be reached in particular conditions and only by specialized personnel, and represents a challenging field for photogrammetric reconstructions (Skarlatos, Menna, Nocerino & Agrafiotis,

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2019; Vlachos, Berger, Mathelier, Agrafiotis & Skarlatos, 2019; Balletti, Beltrame, Costa, Guerra & Vernier, 2015; Pacheco-Ruiz, Adams & Pedrotti, 2018).

Therefore, the virtual model, in this case, represents a valid tool for the dissemination of knowledge (Skarlatos & Agrafiotis, 2020; Liarokapis et al., 2017), as it is able to make users interact with three-dimensional contexts that represent real environments in other way not accessible. In this context, the aspect of sharing information on the network is a factor that today is becoming increasingly important due to the widespread use of mobile devices such as smartphones and tablets and the improvement of network connections. In our case, the possibilities offered by the WebGL JavaScript libraries, based on HTML5, allow showing three-dimensional contents in real-time and without the need to download client-side applications, making the sharing of cultural heritage easier and more immediate (Campanaro, Landeschi, Dell'Unto & Touati, 2016; Scianna, La Guardia & Scaduto, 2016; Mortara et al., 2014).

In the following sections of this article, a review of the advances in ITC technologies for CH will be initially shown, with particular reference to three-dimensional reconstructions and VR. Subsequently, the case study here presented, regards the reconstruction and dissemination on the network, with WebGL libraries, of the three-dimensional model of the underwater archaeological site of Cala Minnola, in Levanzo (TP, Italy). This model has been obtained from the photogrammetric reconstruction of a set of underwater images belonging to the Superintendence of the Sea of the Sicilian Region, originally intended for a traditional photogrammetric survey.

2. Recent technological advances for CH sites (state of art)

The use of virtual reality is now widespread in various fields, and in recent years, it has affected the world of Cultural Heritage. The digitization of Cultural Heritage is the basis of the new way of transmitting knowledge brought forward by new media technology (Bekele, Pierdicca, Frontoni, Malinverni & Gain, 2018; Brovelli, Hogan, Minghini, & Zamboni, 2013). This primary operation makes it possible to return information in different forms and for different purposes, satisfying the requirements of speed and immediacy and improving its usability. Applied to Cultural Heritage, Virtual Reality has in fact proved to be an interesting means for the reconstruction, preservation and safeguarding of works belonging to the past which have now been destroyed by time. The Digital Michelangelo project is an excellent example of the possibilities offered by this technique (Levoy et al., 2000). Great advantages have also been obtained in the digital reconstruction of damaged parts (Magnenat-Thalmann & Papagiannakis, 2005) or in the support of restoration interventions, as in the case of Bamyan's Buddah (Grün, Remondino & Zhang, 2004). Furthermore, the three-dimensionality and virtualization are capable of exploiting the emotions that images can arouse in the observer (Meschini, 2011). The immediate degree of understanding of images compared to language-based mediation alone has made these applications also very effective in the field of dissemination and cultural education (Carrozzino & Bergamasco, 2010).

Archaeological sites, museums and art collections have long begun to rely on these technologies also to increase the involvement of the viewer and to offer more complete knowledge of what is observed. Interactive monitors, 3D printing, mobile applications, consoles with three-dimensional reconstructions and augmented reality, therefore, aim to increase interest in culture in an innovative way (Ballarin, Balletti & Vernier, 2018; Fernández-Palacios, Morabito & Remondino, 2017; Becattini et al., 2016). These technologies have also allowed exhibiting objects from collections that cannot normally be shown due to fragility or limited space available. Making use of virtuality, therefore, offers the possibility of interacting with objects in the collection even at a distance, thus involving a greater number of users, including disabled people and students (Scianna & Di Filippo, 2019; Walczak, Cellary & White, 2006). The virtual movement to other places for temporary exhibitions is also possible, as in the case of the exhibition of the Vietnamese Treasury in Germany in 2016 (Kersten, 2018).

However, special equipment and space dedicated to them are often required, as in the case of the CINECA Virtual Theater (Farella, Brunelli, Benini, Ricco & Bonfigli, 2005). VR applied to CH offers two possibilities of Virtual Museum reconstruction. In fact, it is possible to produce both virtual reconstructions of existing museums, including all the objects in the collection, and reconstructions of places that no longer exist, strongly deteriorated or difficult to access to allow the public to use them easily (Lepouras & Vassilakis, 2005). The latter case is of particular importance precisely because of the precious possibility to share visual information of places that cannot be any longer visited in reality. In particular, virtuality has proved very useful in the reconstruction of submerged archaeological sites, considering their strong limitations of real accessibility. The remains from the ancient marine trade, a great testimony to the cultural exchange of peoples in the Mediterranean, are in fact unreachable by the vast majority of the public and the possibility of disseminating their knowledge on a large scale has always interested researchers in the sector. In this field, photogrammetric reconstruction techniques have been applied to nautical archaeology since the 1960s, when photography was used in submerged sites as a recording, documentation and cataloguing tool. The first photogrammetric surveys used a manual process of measuring and observing images in order to recreate models (Bass, 1966).

The development of computer science subsequently made it possible to speed up and automate most of the reconstruction operations. In this way, underwater photogrammetry has become both more powerful and accessible, as demonstrated by the reconstruction of the remains of Dolia in the Meloria Shoals (Canciani, Gambogi, Romano, Cannata & Drap, 2003). To date, current software, using algorithms based on Structure from Motion (SfM), allow the three-dimensional automatic reconstruction of the detected environments, limiting the effect of the refraction of the sea and calculating the relative position of the cameras. Underwater photogrammetry, therefore, presents itself as a powerful tool capable of supporting archaeology, avoiding significant invasive strategies that could alter a site characterized by cultural relevance. Hence, this technology, in the context of the study of submerged

historical finds, allows acquiring geometrical information necessary to share a relevant part of the Cultural Heritage not accessible for the majority of users (Menna, Agrafiotis, & Georgopoulos, 2018; Yamafune, Torres & Castro, 2017). The wreck of Cala Minnola, was also the subject of experimentation within the VISAS project, dedicated to the enhancement and virtual use of underwater archaeological sites (Bruno et al., 2017). In fact, an application was created that allows you to navigate within a virtual environment, reproducing in detail the real conditions of the site. Navigation involves the use of 3D monitors, related glasses and a multi-touch tablet for movement. In this case, therefore, necessary to make use of special tools and to install the necessary required software.

Otherwise, the recent possibility of sharing virtual representations also on the web has offered the opportunity to create several applications, where it is possible to navigate within increasingly engaging 3D environments, using devices that are easily accessible to the majority of the public.

In fact, it is possible to follow pre-established routes inside a touristic path, or to customize the virtual visit by choosing individual preferences. The ARCO project allows, for example, managing virtual exhibitions with the contribution of Augmented Reality (AR) technology (White et al., 2004). Remote archaeological sites, excavation activities or lost collections can thus be explored easily by users, offering them a deep knowledge of the cultural goods (Bruno et al., 2010). Dissemination via a web browser represents a tool for broad information sharing in a period of great diffusion of portable devices. It is now increasingly simple and natural to access information on the web through portable devices like smartphones and tablets than through PCs, used almost only for longer and more complex operations. In particular, today, through the development of WebGL, specific JavaScript libraries based on HTML5 models, it is possible to develop effective solutions for the creation of virtual three-dimensional environments freely real-time navigable on the web in an interactive way (Scianna, La Guardia & Scaduto, 2016). Solutions particularly followed in the development of video games, such as the first-person interactive navigation of online virtual environments, have proved to be very effective in involving the user in the exploration of a cultural site (Scianna & La Guardia, 2018). The use of these technologies results to be smart, because allows users to easily discover virtual 3D environments on the web without the need to install applications on the client-side.

These considerations led to the development of the model described in the following paragraphs. Through advanced photogrammetric reconstruction techniques, 3D modelling and web development, the online interactive virtual reconstruction of the underwater archaeological site of Cala Minnola was developed, making a part of Italian cultural heritage currently accessible only to specialized personnel perfectly navigable and virtually explorable in the first person.

3. The experimentation

The creation of the virtual navigation model of the submerged archaeological site located close to Cala

Minnola, in the Sicilian island of Levanzo, follows a complex procedure (Fig. 1), starting from the acquisition of historical documentation and ending with the porting of the virtual navigation model on different kind of devices.

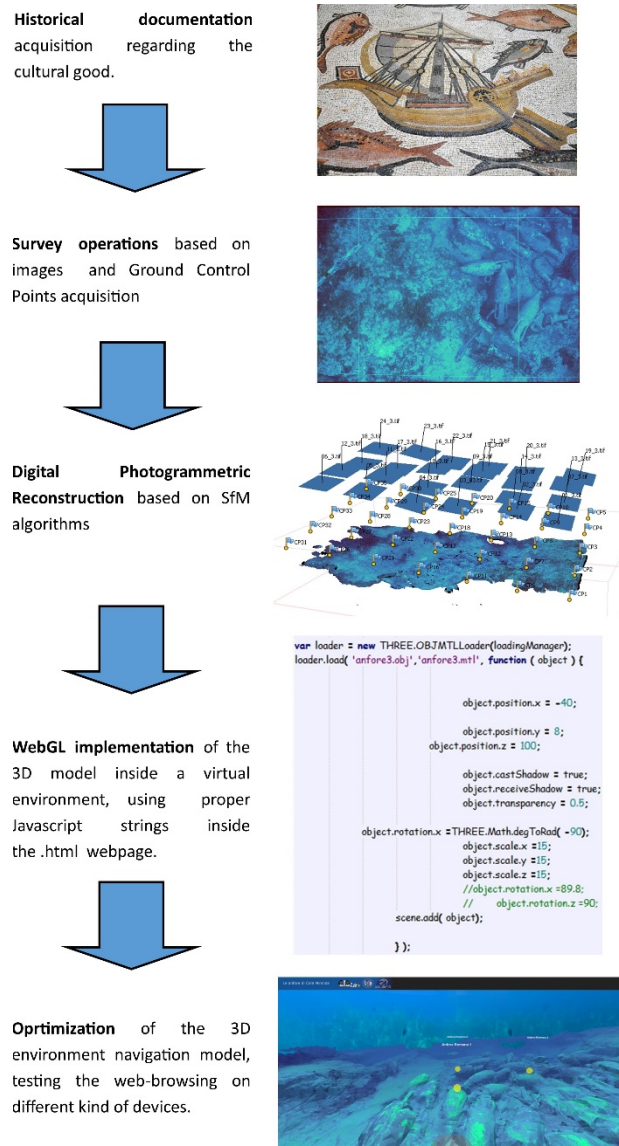


Figure 1: The workflow for the creation of the virtual interactive navigation model.

Firstly, the acquisition of historical background is the base of the research, because it gives the main information necessary for the development of the virtual navigation model and outlines the main archaeological finds to focus. The second phase that consists of survey operations, as affirmed before, was originally intended for a traditional photogrammetric survey. Anyway, the considered dataset contains the necessary information to test this methodology, allowing the digital photogrammetric reconstruction of the considered seabed. The next phase consists of the digital photogrammetric reconstruction of the model, considering a proper network of Ground Control Points (GCP). Once obtained the 3D model, the building of the virtual environment on the web represents the further step of the workflow, where the 3D model should be adapted for the web browsing and every component of the scene should be implemented into the

webpage using WebGL JavaScript libraries. In the end, the final navigation model should be tested considering the most used browsers for mobile (tablets and smartphones) and PC devices. Every step of the workflow is described below in the following paragraphs.

3.1. The wreck of Cala Minnola

The wreck of Cala Minnola is located in front of the island of Levanzo (TP) (Fig. 2), in the archipelago of the Egadi Islands, in Sicily. Discovered around 1970, the site preserves the remains of an ancient Roman ship at a depth of about 30 meters. The wreck, dating back to the 1st century B.C., represents what remains of a Roman ship transporting wine amphorae near Punta Altarella, where the ruins of a factory for the processing of Garum were found.



Figure 2: The Levanzo island (TP), Italy.

Further findings have occurred over the years during survey activities. In fact, about 50 amphorae and fragments of them were found, in addition to the wooden remains of the ship. The morphology of the site is quite particular, as it is surrounded by rather high rocks and largely covered with seagrass (Fig. 3).



Figure 3: The composition of the seabed in the area of Cala Minnola.

3.2. The photogrammetric reconstruction

At the basis of the experimentation, images and measurements provided by a previous survey of the site were used, where the dataset available consisted of only 24 nadiral photos with a resolution of 3671 x 2481 pixels, covering a surface of about 96 m². Each photo covered a specific area (Fig. 4) of the archaeological site of known size (2 m x 2 m). The photos in question, despite being numerically reduced, were sufficient to reconstruct the archaeological area where the amphorae lie in three dimensions. Furthermore, the availability of a larger survey area would have been superfluous for the purposes of this experimentation, because the same

procedure could be carried out with any dataset provided by a correct photogrammetric reconstruction. Otherwise, as explained below, the networking of 3D environments requires a strong simplification of the original model to optimize web navigation. Consequently, the acquisition of huge datasets of images covering is not ever useful for this aim.

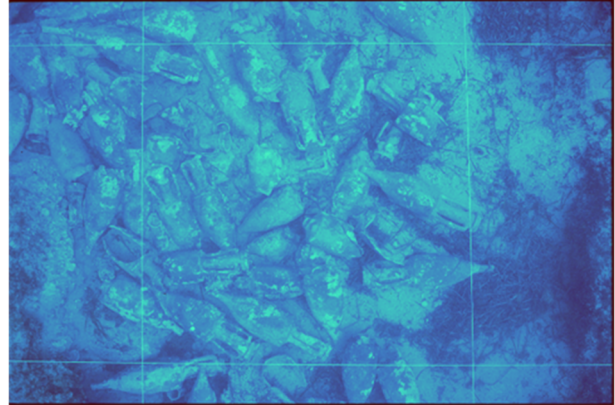


Figure 4: An example of the nadiral photos in the dataset.

The 3D reconstruction was performed using Agisoft Photoscan, a photogrammetric reconstruction software based on SfM algorithms, associating a network of 35 Ground Control Points (GCP) based on a local reference system of known targets (Fig. 5). The local coordinates of every target have been obtained considering the mutual position of the nodes of the 2 m x 2 m grid used during survey operation. The digital photogrammetric reconstruction achieved a level of accuracy of 0,075 m (Table 1) of total error (the distance between source and estimated location for marker). This level of accuracy satisfies the requirements for the reconstruction of a 3D model finalized to the virtual fruition on web and for virtual dissemination of CH, considering the dimensions of the dataset (24 images of 9 MP for 8 m x 12 m surface) and the underwater conditions on 30 meters deep (problems of refraction and presence of suspensions in water). Furthermore, it's necessary to underline that the dataset wasn't originally obtained for digital photogrammetry reconstruction, but for a traditional photogrammetric survey.

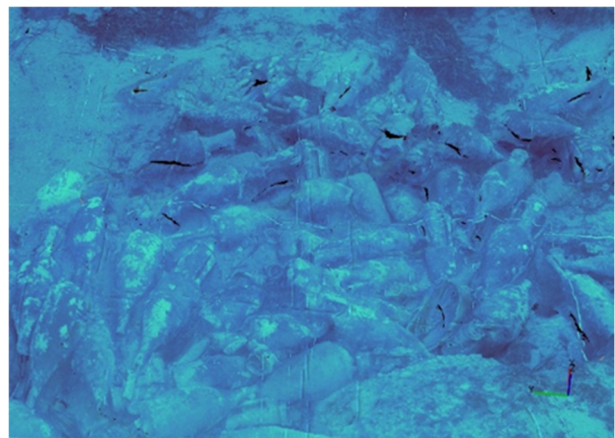


Figure 5: The result of the photogrammetric reconstruction of the site.

Once generated the 3D reconstruction, the texture associated with the model has been corrected by calibrating the colours appropriately, in order to obtain a more realistic display during the web navigation.

Table 1: The positioning data and the errors found in the photogrammetric reconstruction phase.

Markers	X (m)	Y (m)	Z (m)	Error (m)
CP1	0.000	0.000	0.000	0.0761
CP2	2.000	0.000	0.000	0.0721
CP3	4.000	0.000	0.000	0.0726
CP4	6.000	0.000	0.000	0.1260
CP5	8.000	0.000	0.000	0.0852
CP6	0.000	2.000	0.000	0.0857
CP7	2.000	2.000	0.000	0.0565
CP8	4.000	2.000	0.000	0.0471
CP9	6.000	2.000	0.000	0.1042
CP10	8.000	2.000	0.000	0.0574
CP11	0.000	4.000	0.000	0.0893
CP12	2.000	4.000	0.000	0.0414
CP13	4.000	4.000	0.000	0.0445
CP14	6.000	4.000	0.000	0.0883
CP15	8.000	4.000	0.000	0.0832
CP16	0.000	6.000	0.000	0.1077
CP17	2.000	6.000	0.000	0.0248
CP18	4.000	6.000	0.000	0.0369
CP19	6.000	6.000	0.000	0.0843
CP20	8.000	6.000	0.000	0.1350
CP21	0.000	8.000	0.000	0.1181
CP22	2.000	8.000	0.000	0.0248
CP23	4.000	8.000	0.000	0.0415
CP24	6.000	8.000	0.000	0.0751
CP25	8.000	8.000	0.000	0.0842
CP26	0.000	10.000	0.000	0.1245
CP27	2.000	10.000	0.000	0.0460
CP28	4.000	10.000	0.000	0.0366
CP29	6.000	10.000	0.000	0.0666
CP30	8.000	10.000	0.000	0.0552
CP31	0.000	12.000	0.000	0.1001
CP32	2.000	12.000	0.000	0.0280
CP33	4.000	12.000	0.000	0.0642
CP34	6.000	12.000	0.000	0.0841
CP35	8.000	12.000	0.000	0.0461
Total Error				0.0758

3.3. The web visualization using WebGL libraries

The 3D model, generated from the photogrammetric reconstruction, was properly simplified and adapted to web browsing, for the construction of the interactive navigation model. Virtual web navigation, in fact, requires the use of simplified 3D models, with the dimension not exceeding 10-15 MB, as seen in the data summary (Tables 2 and 3). More complex models, with a larger number of polygons, are not useful for web navigation, as they would crash the webpage. In light of this, the absence of the 3D model of the surrounding environment did not constitute a serious loss for navigation purposes, in fact, it would have been omitted to optimize performance during online viewing.

Table 2: Survey and Digital Photogrammetric reconstruction data. Summary of the process.

Setting	Value
Number of images	24
Image resolution	3671 x 2481 pix
Surveyed area dimension	8 x 12 m
Number of GCP	35
Level of Accuracy of photogrammetric reconstruction	0 – 0.13 m

Table 3: WebGL environment data. Summary of the process.

Setting	Value
Dimensions of the 3D mesh	11.3 MB
Texture resolution	8192 x 8192 pix
Background texture resolution	2672 x 900 pix

The surrounding environment, on the other hand, was reproduced by inserting a 360° image of the underwater environment into the inner surface of a sphere. The spherical geometry contains the entire interior of the reconstructed model of the amphorae, so as to become the background displayed during web navigation (Fig. 6).

This solution offers a realistic visualization on the web, and, at the same time, doesn't oversize the dimension of the 3D model during the web-browsing with further geometric information of surrounding environments.

The spherical geometry and the reconstructed model generated inside Agisoft Photoscan software, were finally uploaded to the server in .obj format, and loaded into the main webpage, using the Javascript language and loading external WebGL libraries, necessary to visualize the environment online. Once the elements, to be displayed within the virtual environment, have been defined, it was necessary to study a simple and intuitive navigation system, for both desktop PCs and mobile devices (Fig. 7). Using the JavaScript WebGL libraries based on Three.js, a first-person navigation system was developed, which allowed the viewer to move freely along a horizontal plane, with the possibility of interacting through information popups along the way. The viewer is anchored to a sphere that can be pushed by the user by pressing the forward button. In this way, the sphere undergoes a force that moves the viewer in the direction

chosen by the user along with an invisible horizontal plan with a proper coefficient of friction. Finally, effects were also included in the rendering phase, simulating the underwater environment to guarantee more realistic navigation.

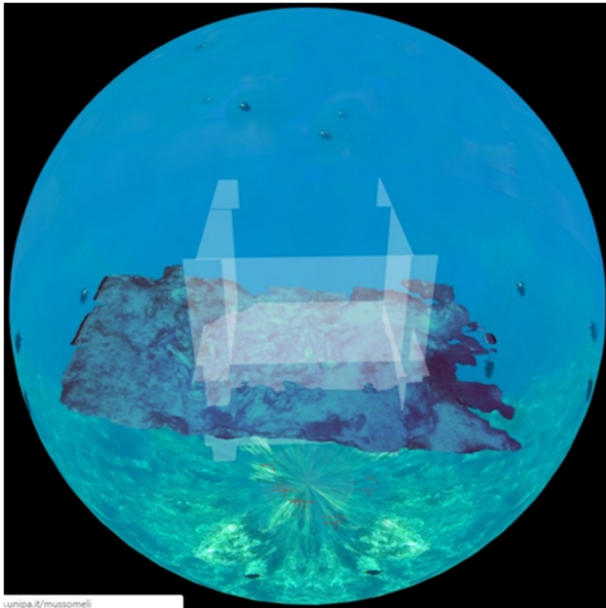


Figure 6: The architecture of the 3D environment. It's possible to notice the sphere that contains the entire environment and the transparent boundaries that limit navigation.

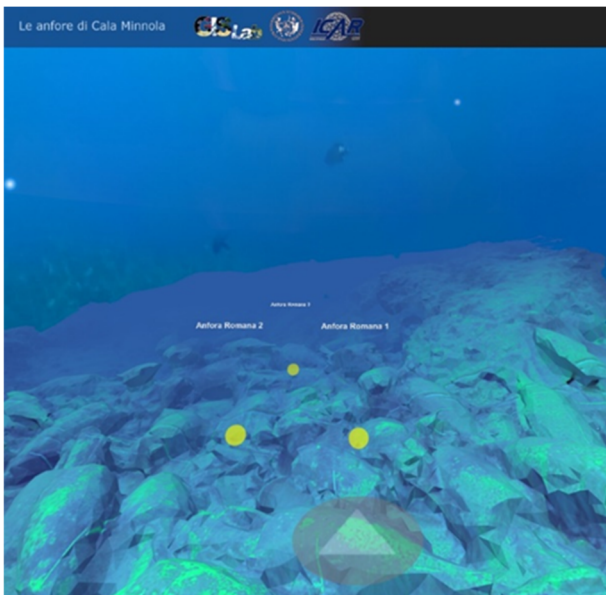


Figure 7: The online visualization of the interactive first-person navigation and the system of yellow popups along the path.

The structure of the 3D visualization and the navigation system have been implemented directly in the .html page,

within links to external JavaScript libraries and JavaScript strings inside the same page. The system of popups placed along the 3D environments allowed users to click and open external .html pages with further information about the site (Fig. 8).

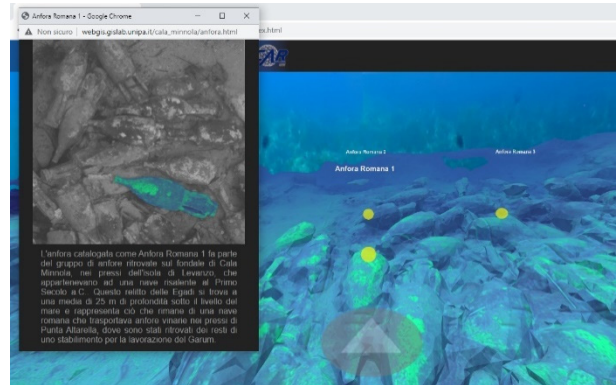


Figure 8: An example of the popups implemented in the web navigation model.

The web navigation model is freely online available, for both desktop PCs and mobile devices, on the GISLab Website using the following Link: http://webgis.gislab.unipa.it/cala_minnola/index.html.

4. Conclusions and open scenarios

The growing diffusion of devices, that allow access to information on the web from anywhere and at any time, has underlined the importance of sharing 3D models of cultural heritage and archaeological sites online, directly navigable, without the need to install any application. In this way, it is possible not only to facilitate disabled people to visit virtually an archaeological asset, but, in general, to offer anyone the opportunity to visit places that are otherwise difficult to access, enhancing their visibility. Although there are, still, some limitations mainly related to the size of the 3D models to be displayed, as highlighted by the case study, the use of the WebGL libraries constitutes a valid option for the online use of Cultural Heritage, as they allow you to discover virtual environments and 3D models directly through web-browser. Obviously, virtual navigation cannot replace the real visit to the place of interest, but it certainly constitutes a powerful means of spreading knowledge and therefore arousing interest and curiosity. Therefore, online use is not, in any case, to be understood as a substitute factor for the real visit, but as an element of enhancement, which can act as a catalyst for the real use of the asset. In the future, the development of increasingly high-performance internet connections will broaden the possibilities already offered by the world of VR, allowing the insertion of increasingly complex and information-rich navigable environments.

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