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Commercial Archaeology and 3D Web Technologies

Luca Bezzia, Alessandro Bezzia, Christian Boscaro, Kathrin Feistmantl, Rupert Gietl, Giuseppe Naponiello, Fabiano Ottati and Margarita de Guzman

Archaeology, Arc-Team, Cles, Italy; Istituto Universitario di Architettura di Venezia, Venezia, Italy; Circle CRM Group, Calgary, Canada

ABSTRACT
This contribution summarizes the multiple uses of 3D web technologies in commercial archaeology. Considering the breadth of this topic, we will describe each different branch of these technologies with the example of case studies based on work of the Italian company Arc-Team. Our overview begins with 3D visualization for scientific purposes, showing a project funded by the Autonomous Province of South Tyrol (Italy) in order to improve knowledge about WWI. Second, we analyze a similar project, funded by the Autonomous Province of Trentino (Italy), but with the aim to increase tourism at a high alpine WWI site. The third example is the development of another prototype for tourism: a 3D web-map for the cultural valorization of the historical border (1753) between the region Tyrol and the Most Serene Republic of Venice. In the forth case study, we discuss the implementation of 3D within web platforms for archaeological project management of RAPTOR (Ricerca Archivi e Pratiche per la Tutela Operativa Regionale), a webGIS developed to aid in preservation and conservation efforts of cultural heritage for the Italian Ministry of Cultural Heritage and Activities and Tourism (MiBACT). Fifth, we explore recent uses of 3D models for web-coworking during the process of excavation management, thanks to the developments of real-time 3D acquisition techniques based on SLAM algorithms and archeorobotic devices. Finally, 3D web-coworking is also analyzed illustrating some simple web tools that afford rapid feedback in data visualization, considering not only excavation field-work but also exploration projects. This overview, based on six different case studies, represents the four fields in which 3D web technologies are currently used in commercial archaeology: scientific communication; tourism improvement; preservation of cultural heritage; and real time field-work management. Some specific topics such as tourism improvement and field-work management are investigated in greater depth in order to allow us to analyze variables deriving from customer requests (e.g. restrictions regarding sensitive geolocation or preferences for specific web platforms) and from differences among data acquisition technologies based on various sensors.

KEYWORDS
3D; web technologies; commercial archaeology; webGIS; web-coworking

Introduction
The rapid development of 3D web applications in the past decade has led to an increasing use of these technologies in the field of archaeology. This evolution involves the commercial sector, offering new opportunities and expanding the range of services that private companies can offer customers. Such business expansion is directly related to the variable nature of 3D data and to the differences between the various purposes that orient the development of web applications. In fact, from an archaeological perspective, the nature of data can change from single objects (e.g. finds), to small areas (e.g. layers or structures), to large territories (e.g. landscapes), and the target of 3D web applications can be focused on scientific communication, tourism improvement, preservation of the Cultural Heritage or real time field-work management (e.g. to organize work-flow and enhance productivity).

This paper addresses this broad topic through six case studies from the Italian company Arc-Team. Each project is analyzed under three main topics: the nature of the 3D data, the target audience of the application and the main purpose of the technology. In fact, the combination of these three elements, together with the customer desiderata, i.e., clients’ needs, strongly influences the architecture and the aspect of the final product, orienting the choice of software in back end and front end development.

Prato Piazza/Plätzwiese Project, 3D Web Visualization for Scientific Purposes
The first project we consider regards the 3D documentation and scientific communication of archaeological contexts related to World War I (WWI), on the alpine plateau of Prato Piazza/Plätzwiese, in the Dolomites (Gietl et al. 2015: 9–16). This area belongs to the National Park Fanes-Sennes-Braies/Fanes-Sennes-Prags, one of the larger parks in the Autonomous Province of Alto Adige/Südtirol (Italy), and is considered an important tourist attraction. Aspects of interest include numerous natural wonders, its rare ecosystem (UNESCO World Heritage Site the Dolomites, 26 June 2009), and its wide panorama of some of the Dolomites: the Croda Rossa d’Ampezzo/Hohe Geisl/Crep Checio, the Tre Cime di Lavaredo/Drei Zinnen/Tré Thème, the Tofane/Tofanen/Ra Tofanes, and the Monte Cristallo. It is the remains from WWI that have been and continue to be the subject of the archaeological project, including, in particular, the recently restored Forte Prato Piazza/Sperrwerk Plätzwiese.
This fort belongs to the system of Austro-Hungarian fortifications on the Italian border. It was built between 1888 and 1895. At an altitude of 2040 meters above sea level, it holds a commanding and defensive position for the Val di Landro/ Höhlensteintal from above. In 1915, at the outbreak of hostilities, the fort had already fallen from its heyday. Among the key factors contributing to the issues was the improvement of weapon technology. Moreover, it was repeatedly attacked by the Italian artillery on Monte Cristallo. For these reasons, the fort was disarmed and used only as an observatory, given notably due to its high position with an excellent view of the Italian military artillery installations. Its artillery was repositioned outdoors, in an ideal shooting post; this new system now represents the foremost remains of World War I in the plateau. In light of the above, the area under investigation (the AOI, Area Of Interest) is related with the specific branch of Modern Conflict Archaeology and consequentially the level of archaeological tolerance is high (mainly due to its recent chronology). In fact this parameter derives by the relationship between technical values (precision and accuracy of the documentation) with the archaeological assessments (chronology and informative potential of the evidences, environmental working condition, available resources and extension of the AOI). In this case, the high archaeological tolerance grants a wide range of solutions for the data acquisition stage (from very precise and accurate systems to less performative equipment).

While the archaeological context is critical (for the environmental working condition), we highlight how customer desiderata and tool functionality influences the development of the 3D web application. Funded by the Autonomous Province of Alto Adige/Südtirol, its primary goal is to share the latest research on Conflict Archaeology in the region with the scientific community and, at the same time, to show to a wider public the technology that archaeologists can use in everyday work. For this reason, the Provinzial Superintendent for Cultural Heritage of Bolzano/Bozen (Office for Archaeological Heritage) provided project guidelines requiring a balance between scientific communication and the delicate task of protecting sensitive sites. The problem stems from not only the high number of the so-called recup-ranti abusivi (illegal diggers that retrieve findings from the Great War for private collectors and the black market), but also the security risk, given the presence of numerous unexploded ordinances. Therefore, the final adopted solution was a web application that shows detailed 3D models of selected archaeological features but without specific locational information.

Another difficulty of the project is connected with the nature of the AOI, which changes from mid-mountain sites (where the main problem is dense forest cover) to high-mountain landscapes (where logistic support is often complex). Moreover, due to some locations (like tunnels, underground environments or strategic military installations perched on rocks), data acquisition required specific solutions from different branches of field archaeology, and in particular from aerial archaeology and speleoarchaeology.

**A 3D documentation strategy based on SfM-MVS**

Given the customer’s desiderata for detailed 3D models for scientific purposes without geolocation and considering certain logistical problems, we adopted a solution for the 3D documentation of archaeological features using a photographic methodology based on SfM (Structure from Motion) and MVS (Multiple View Stereovision) techniques (Bezzi et al. 2010b: 103–111). This compromise allowed for high accuracy and precision (meeting the customer request), using a sensor (the photographic device) characterized by great versatility, with the possibility to be used on board drones for remote sensing (aerial archaeology), as well as in low light conditions for underground documentations (speleoarchaeology). In this way, the adopted strategy combined the use of FLOSS (Free/Libre and Open Source Software) with the support of Open Hardware (Bezzi et al. 2009: 183–193) UAVs (Unmanned Aerial Vehicles), in order to deal with logistical difficulties, while reducing workplace hazards. More specifically, the entire project was based on ArcheOS (Bezzi et al. 2013: 165–173), a GNU/Linux archaeological distribution developed and freely released by Arc-Team since 2005 (under the terms of the GPL [General Public License]), and on the use of an ArcheoDrone (Bezzi et al. 2010a: 395–396), an Open Hardware prototype of UAV specifically design by Arc-Team in 2006, for archaeological purposes.

The documentation campaign started in summer 2012 and, despite the restrictions of the final product imposed by the Superintendent, all the data was acquired over several surveys with different GPS (Global Positioning System) and total stations, to record geolocation information and to avoid arbitrary selection during this critical phase. Data management performed through free GIS applications, such as GRASS and Quantum GIS (currently widely used in archaeology), while different cartographic Open Data helped us to develop base maps for the project. In this regard, the LIDAR (Light Detection and Ranging) DTM (Digital Terrain Model) released by the Autonomous Province of Alto Adige/ Südtirol and aerial orthophoto coverage of Italy, offered by the e-GEOS company and available via the RealVista 1.0 WMS (Web Mapping Service) was particularly useful.

The documentation work-flow, applied in normal conditions, started with the geolocation of the area of interest using GCP (Ground Control Points) recorded with differential GPS or, when not possible due to the surrounding trees, with the total station. Then, 360 degree photos were acquired in order to post-process the images via various SfM and MVS applications provided by ArcheOS, such as PPT (Bezzi and Moulon 2012: 153–170), PMVS, and later (from 2013 on) OpenMVG (Moulon et al. 2017: 60–74). Mesh-editing involved ArcheOS with the use of CloudCompare to shift and clean the point clouds, and MeshLab (Cignoni et al. 2008: 129–136) to build meshes, assign texture, and scale final models.

As mentioned above, there were some particular tasks required for the 3D documentation of strategic military posts perched on rocks or underground environments (i.e., tunnels, galleries, etc.). To capture these data necessitated a specific methodology derived from aerial archaeology and speleoarcheology. In the first case, the best solution was the use of an ArcheoDrone, equipped with a GPS receiver and a DSLR (Digital Single-Lens Reflex Camera), in combination with a data acquisition strategy optimized for remote sensing 3D reconstruction via MicMac (Rupnik et al. 2017: 1–9). This strategy, very close to pure aerial photogrammetric methods, requires good photo coverage (with sufficient overlap between images), following a bustrophedic (from right to left and from left to right in alternate lines) flight path. The
automatic processing of this kind of data through MicMac resulted in a georeferenced 3D model with the related orthophotos, without further elaborations. Obviously, the quality of 3D models derived by this methodology (photographic remote sensing) is lower than the precision and accuracy that a ground level documentation can provide (due to the distance between the sensor and the documented object), but, in this particular case, the compromise was necessary because of site locations. In the second case, for 3D documentation of tunnels and galleries, field experience led to a change in strategy based on a one-way path of photographic acquisition employing a new technique of data recording that followed two parallel lines of advancement with opposite directions. During the process, we also shifted the photographic methodology from the initial use of a tripod and external light sources for long exposure pictures, to faster acquisition with a synchronized flash. In any case, the geolocation of the 3D model was acquired using several GCP placed at the entrance of the underground environment (Gietl and Steiner 2016: 46–52).

A 3D web application without geographic information, the use of 3DHOP

The final product of this WWI documentation project had several requirements: hide visual geographic information related to the sensitive archaeological structures; create a highly detailed 3D interactive model, avoiding excessive simplification of the geometry, while maintaining a user-friendly interface; and combine the application on light and simple code in order to be quickly integrated into standard web pages (HTML code) of the official website of the Autonomous Province of Alto Adige/Südtirol.

After analysis of restrictions and desiderata of the project, the team selected the open source software 3DHOP (3D Heritage Online Presenter), an application which met these three main requirements and is already widely used in Virtual Museum web sites (Potenziani et al. 2015: 129–141); however, our application needed to be customized to account for the nature of different 3D data: objects (archaeological finds) for Virtual Museums versus areas (archaeological layers combined in structures and sites) for the case of Prato Piazza/Plätzwiese.

In any case, 3DHOP satisfied all the necessary specifications of the project. In particular, it was possible to load a high resolution 3D model converting original raw data from the PLY (Polygon File Format) into the Nexus file format (.nxs), which allows the streaming visualization of large 3D models through different LoD (Level of Details) management via OpenGL and WebGL (Ponchio and Dellepiane 2015: 199–207). This multi-resolution 3D model support is one of the main features of 3DHOP and also allows for efficient streaming in low-bandwidth conditions. Moreover, the software does not need a specialized server, nor server-side computation and, because it uses SpiderGL (a JavaScript Computer Graphic library which uses WebGL for real-time rendering) combined with jQuery (another JavaScript library), it can work directly in web browsers without additional plug-ins. This characteristic simplified the final stage of development —integration of the 3D web application into the official website of the Autonomous Province of Alto Adige/ Südtirol—and required the addition of only a few lines of HTML and JavaScript code. While aspects of this WWI project are now outdated (since the work dates back to 2012), 3DHOP is probably the best software solution for web platforms dealing with heterogeneous and complex archaeological data. In fact recent implementation of the software to add sliders and transparency is particularly well-suited for un-georeferenced small archaeological areas (layers and structures) because it allows for 3D visualizations of internal details.

The final result is currently online, accessible in German and Italian on the website of the Provincial Superintendent for Cultural Heritage of Bolzano/Bozen (http://www.provincia.bz.it/arte-cultura/beni-culturali/la-documentazione-di-sceavo.asp) (Figure 1). The layout configuration, with different accessible 3D models, is common to other regional projects developed by academic and research institutions. An example is the “Trento Città Fortezza” (http://3dom.fbk.eu/repository/files/ITM/modelli3d.html) based on the work of students of the Istituto Tecnico Tecnologico A. Pozzo and of the University of Trento, under the supervision of Professor Giovanna Massari (Department of Civil, Environmental, and Mechanical Engineering) and with the support of the Fondazione Bruno Kessler (3DOM laboratory). Nevertheless, despite the similar layout, the two projects differ in regard to research field, the nature of 3D data, and final goals. The project regarding Prato Piazza/Plätzwiese starts from an archaeological approach, sharing high detailed models documented through standard discipline methodologies with a primary objective of scientific communication among professionals and experts. On the other hand, the Trento project is based on historical studies with the aim to provide light reconstructive models, in order to "to transfer Geomatics and informatics knowledge to students of fourth classes, valorize the history and realize innovative products of interest to the territory."

Punta Linke, 3D Web Visualization for Touristic Purposes

In 2017, Arc-Team joined another project related with 3D web visualization of archaeological heritage, which also involved remains of World War I and, like the Prato Piazza/Plätzwiese project it is located in an alpine landscape; more precisely, in the Autonomous Province of Trentino (Italy). This time, the main focus was the 3D documentation of a single structure: an old, double ropeway built in 1916 named "Punta Linke" (Bassi et al. 2016: 348–352). The military ropeway installation was connected, on one side, to the town of Pejo, in the valley bottom, and, on the other, to the Coston de le baracche brusade (Side of the burn barracks) towards the Palon de la Mare (one of the highest mountains in the Ortles/Otler-Cevedale Alps), in the middle of the Forni glacier. The nearby Vioz Refuge was, during WWI, the seat of the sector command.

The site of Punta Linke underwent an excavation and restoration campaign between 2005 and 2012 sponsored by the Provincial Superintendent for Cultural Heritage of Trento (Office for Archaeological Heritage). This fact marks a difference with the project of Prato Piazza/Plätzwiese, where the archaeological remains have not been excavated or restored (with the exception of the Forte Prato Piazza/Sperrwerk Plätzwiese). Given the premises it is clear that the archaeological tolerance for such a project is even higher compared to
the case study of Prato Piazza/Plätzwiese, since the evidence was less original.

Punta Linke is open to the public and, with its altitude of 3632 meters above sea level, is the highest archaeological museum site related to WWI. The preserved area occurs in a tunnel about 30 m long, and served as military accommodation, as a workshop for maintenance of the ropeway’s engine, and as an artillery station for a light cannon. The site is visited annually by almost 2000 people, but, due to its extreme conditions, Punta Linke is reachable only by hikers with experience in glacier and alpine traversing.

Figure 1. The 3DHOP based application of Prato Piazza/Plätzwiese on the official web site of the Superintendence for Cultural Heritage of Bolzano/Bozen. The main screen shows the selected 3D model (in this case a fortified trench on the mountain Col Rotondo dei Canopi/Knollkopf). The lower area displays the other selectable options (various 3D models of archaeological evidences).
This particular situation has led the Superintendent to evaluate alternative solutions to extend site access to the wider public, including those with disabilities. For this reason, Arc-Team was tasked with developing a prototype for 3D Virtual Tour web applications, also usable for Virtual Reality applications. For this reason, the company completed the project by forging a partnership with the IUAV (Istituto Universitario di Architettura di Venezia [the higher institute of architecture of Venice]).

In the case of Punta Linke, the combination of the nature of the 3D data (a structured underground area with surrounding natural environment), the target audience of the application (tourists), and the purpose of the technology (virtual accessibility to a site difficult to reach) led to the development of a final product based on a 3D game engine. This solution had a further impact on the archaeological tolerance (very high) during the stage of data acquisition, because the 3D models must be optimized (i.e., comprise low-polygon geometry) for interaction with the end-user and graphically simplified in order to reproduce the experience of traditional video games. Nevertheless, we employed SfM and MVS for 3D documentation to collect high-resolution data that could be used in the future for other applications. A secondary consequence of this process of gamification is the reduced importance of geolocation, due to the fact that the entire application is related with a single virtual environment, without the need to connect it with a larger geo-located landscape. Regardless, geographic information was collected during survey with a differential GPS, again to allow for other uses of the data.

**3D documentation in the alpine (3629 meters above sea level)**

Using Arc-Team’s experience in high mountain glacial archaeology, the strategy applied to the case of Punta Linke was similar to that used on the Gran Zebrù/Königs spitze in 2015, when emergency 3D documentation was completed on a WW1 wooden barrack located on the top of the north face at 3851 meters above sea level. The extreme conditions faced in order to accomplish this mission are shown in Figure 2. However, logistics were ideal at the site of Punta Linke; the modern ropeway, to reach the altitude of 3000 meters above sea level, and the Vioz Refuge, which can be used as base camp, allowed for a safe working environment, without the need to use ice climbing techniques or special equipment (i.e., ropes, crampons, etc.). Therefore, we were able to transport a professional digital camera (for SfM and MVS documentation), a differential GPS (to geolocate the GCP), and a total station (to connect the photogrammetric marker placed in the tunnel with the external GCP). Unfortunately because the site is within the Stelvio/Stilfser Joch National Park, where UAVs are forbidden in the absence of special permits due to the new restrictive laws in Italy that were effective April 2014, the use of the ArcheoDrone was reconsidered.

Similar to the Gran Zebrù/Königs spitze mission, a photographic approach for 3D documentation was preferred to other systems (i.e., laser scanning) due to its versatility and the good results achieved during previous experiences in speleoarchaeology. In order to have real-time 3D feedback for better planning of the photographic survey, a low cost SLAM (Simultaneous Localization And Mapping) device was used. This system, comprising an RGB-D sensor (derived form a Kinect), a laptop with ArcheOS running the FLOSS platform ROS (Robot Operating System), and the node RTAB-Map (Real-Time Appearance-Based Mapping) produced a fast 3D model of the entire underground environment. These real-time 3D data were useful to localize the critical areas of the structure and to register a first raw 3D dataset (with high accuracy and low precision), as a backup approach in case of future malfunctions in the SfM processing stage.

**Further processing of the data for a simplified 3D model**

The second stage of the project was carried out by Dr. Fabiana Ottati using the proprietary software provided by the IUAV along with technical support by Arc-Team for further geographic data processing through FLOSS. The first step was point-cloud cleaning and mesh editing of the data produced by the SfM/MVS suite openMVG, as shown in Figure 3a. The software Geomagic Design X was used to perform these preliminary operations, Rhinoceros 5 for simplification using 3D modeling, and finally Cinema 4D was employed for better definition of materials, textures, and lighting. During this phase, in order to produce a light 3D model of the tunnel of Punta Linke, we used texture baking—an algorithmic computation that records scene information, such as colors and surface illumination—to place them inside the UV mapping space. The final step of the workflow was to situate the 3D model of Punta Linke within its surrounding natural environment. To accomplish this task, DTMs from two different geographic open data sources were used. Unfortunately, the quality of the two DTMs were different, due to the fact that the first one comes from LIDAR data, with a resolution of one square meter, while the second one derives from a vectorization of a raster map with a resolution of five square meters. To overcome this problem, we loaded the two DTMs into GIS GRASS and exported in a VTK (Visualization ToolKit) file format to be converted (within the FLOSS Paraview) into a .ply file. At this point, the 3D landscape model was imported into Rhinoceros, a 3D software program, to smooth the differences in resolution, and to merge the 3D model of Punta Linke and the digital landscape using control points.

**A 3D web application developed with a game engine**

The final 3D web application was developed within the game engine Unity using a plug-in that allowed the 3D model of the tunnel to be directly imported into Cinema 4D and for colliders to be automatically generated. The textured digital landscape was imported using the Object2Terrain script. In this way, the surrounding environment can be explored, while the horizon illusion is done with cubic skybox using a mountain panorama to keep the platform fast and light for web-based applications. We set up a First Person Controller using parameters that simulate the gait of a real person for perspective interaction. Finally, we created hotspots, defined by fluctuating lights, to provide additional information or inform users of the possibility to interact with specific 3D objects within the scene, as visible in Figure 3b.

Currently, the prototype of the Virtual Tour application is stored on an Arc-Team server (http://www.museidironzone.it/ATOR/punta_linke_v01/WebGL_build/index.html), waiting for further implementations to: enrich the collection of interactive 3D objects that appear in the virtual environment,
and improve some details through 3D modeling within the FLOSS Blender. At the same time, we are developing another implementation of the application using the open source suite OpenSpace3D.

We acknowledge that other web platform solutions employ a touristic game engine, but generally speaking different software offer similar functionalities. We seek to emphasize that field strategies of data acquisition and 3D modeling post-processing as well as software and infrastructure choices must heavily consider desiderata, project requirements and restrictions. Additionally, this case study offers an example combining the needs of commercial archaeology (represented by Arc-Team) with those of the academy seeking to professionally train students.
Over 250 years ago, Empress Maria Theresia and the Duke of Venice signed a contract that put an end to the long-standing border dispute between Tirol and the lagoon city. Today many boundary stones, placed after the so-called Treaty of Rovereto of 1753, can still be found in isolated locations, in alpine pastures or hidden in the woods. In 2017, the Sexten Tourist Association (Alto Adige/Südtirol, Italy), the municipality of Kartitsch (Osttirol, Austria) and the municipality of Comelico Superiore (Veneto, Italy) joined forces and started a pilot project with the financial support of the Interreg program V-A Austria-Italia 2014–2020 (CLLD Dolomiti Small Projects Fund). Within this project, Arc-Team was commissioned to perform an archaeological survey to localize and 3D document the preserved boundary stones of the area around the Passo Monte Croce/Kreuzbergpass, analyzing anthropomorphic changes in this border landscape. For this reason, the company is currently developing a 4D GIS to manage digital data through a chronological timeline, which starts from the Roman period evidenced by the *cas-trum* (a Roman fortified military camp) on the top of the mountain pass and goes through the limits defined by the agreements of 1753 and the WWI front, ending with the modern Alpine Wall, built in the years leading up to

![Figure 3](image-url). Some stages of the development of the Punta Linke application. A): the 3D pointcloud in MeshLab. B): model loaded in Unity, with the description of an hotspot (*THE MAIN TUNNEL The main tunnel was dug directly into the rock and ice. It served the sector command, the nearby Viaz refuge, and represents a unique evidence of the war fought at high altitude. The station linked the town of Cogolo with the site of Palon de la Mare*).
World War II under the direction of Italian dictator Benito Mussolini.

Given the interest in promoting tourism in the area, Arc-Team is internally developing a 3D web application with criteria that differs from the previous case studies. First of all, the large spatial extent of territory necessitates preservation of the geolocation of the 3D models for which we use a solution based on a Virtual Globe. Secondly, the objectives call for integration with a DBMS (Data Base Management System) as used by other webGIS, and third, the possibility to manage the data chronologically through a simple timeline (for eventual further 4D implementation). The result was a prototype based on the software Cesium, that satisfied these three requirements.

**A 3D documentation in dense forest**

The main difficulty for the 3D documentation of archaeological evidence in the territory of the Passo Monte Croce/Kreuzbergpass was the dense forest that covers most of the area, due to GPS signal attenuation and scattering. Luckily, the preserved boundary stones of the 1753 border are often placed in glades or other open areas and, even when under forest cover, it was possible to reach them with the total station to acquire data. Simple 3D models of these monuments were generated with basic SfM and MVS strategies. 3D documentation of other kinds of evidence, and, in particular, structures characterized by a linear development of tens or hundreds of meters (such as boundary drywalls or World War I trenches), required a new methodology. The solutions involved a real-time SLAM based device like the one used in the Punta Linke project. This was the only way to penetrate the dense alpine forest, considering that other techniques (i.e., SfM or laser scanning) would have been inefficient. Despite some necessary precautions such as working during a cloudy day (to use a IR based device like Kinect) and fragmenting the AOI (Area Of Interest) into several segments (to reduce SLAM errors), the final result respected the prefixed archaeological tolerance.

The lower precision of 3D SLAM models, compared to SfM and MVS models is acceptable because of a necessary reduction in the geometric quality for a faster upload for testing the web prototype. This process is part of the workflow used to prepare the models for correct placement within the Virtual Globe, which starts with some preliminary operations within CloudCompare (shifting the 3D object in a close range coordinate system), followed by some position adjustment (rotating and centering the model) and a simplification of mesh and texture within MeshLab, until the final conversion of the model into the glTF file format (a specification for the efficient transmission and loading of 3D scenes by applications).

**A 3D prototype based on a Virtual Globe**

As mentioned above, the current prototype of the 3D web application developed for the Project 1753 is at an alpha version stage ([http://91.121.82.80/cesium/Apps/1753.html](http://91.121.82.80/cesium/Apps/1753.html)). Nevertheless, the software architecture is defined and some basic functions have been already implemented.

We selected the open source JavaScript library Cesium for web-based geographic support three key reasons. This software, built on several HTML5 technologies (like WebGL) allows for: 3D model geolocation; future integration with the database currently under construction (based on PostgreSQL and PostGIS); and offers the capability of 4D visualization (through a timeline embedded in the main interface). Moreover, Cesium has no server requirements, being completely client side.

Currently, the 1753 web prototype is based on the STK World Terrain, a high-resolution, worldwide terrain elevation tile set that can be implemented in any application, for commercial and non-commercial purposes. 3D models are uploaded using the glTF file format, specifying the geographic coordinates of the centroid. In order to help users in finding the 3D archaeological features, which are located in a restricted area in northern Italy, some variables have been added so that the models are visualized on a dynamic scale that starts with a maximum ratio of 1:20000 with a minimum pixel size of 128 and reduces their dimension as the zoom approach the area of interest to a ratio of 1:1, as shown in Figure 4.

Future improvements are planned to enrich user experience including an integration with geolocational historical photos, which can be placed on the right shooting point combining its geographic coordinates with the skyline of the DTM, or a guided path through some hotspots, creating a flyover effect, modifying the setting of the general camera parameters.

**RAPTOR, A WebGIS for Archaeological Site Protection**

Since 2011, Arc-Team has been developing the system RAPTOR (Ricerca Archivi e Pratiche per la Tutela Operativa Regionale [Research system for Archives and Practices of Regional Operational Protection]), a geodatabase designed to digitize administrative procedures of the Italian Superintendent for Archaeological Heritage, to locate and map archaeological sites, to speed up information retrieval with user friendly queries and, to share scientific results among colleagues (Frassine et al. 2016: 61–71). The system was originally funded by the Superintendent for the Archaeological Heritage of Friuli Venezia Giulia; however, the Superintendent for the Archaeological Heritage of Lombardia and Veneto joined the project to define and support the use of common standards. RAPTOR is based on the open source DBMS PostgreSQL, implemented with the spatial library PostGIS, while maps with geolocational data are created by GeoServer, a FLOSS server designed for interoperability, compatible with the standards of the Open Geospatial Consortium (OGC). The web-interface (client-side) was developed in PHP code improved by JavaScript and OpenLayers library. The cataloging of archaeological data is organized into several datasheets (DBMS tables about site, project, excavation, evidence) connected to store various data types, such as raster data (photos, geolocated photomapping), vector data (geolocated drawings) and text (recording sheets, scientific reports, administrative procedures).

**A 3D improvement for a future fast feedback system**

In 2012, a site datasheet was implemented to manage 3D content (Frassine et al. 2014: 189–206) derived from archaeological documentation (via SfM, laser scanning, etc …) or archaeological reconstruction (via 3D digital modeling).
The first problem we faced was the maintenance of the user-friendly GUI (Graphical User Interface) developed thus far. For this reason, implementation of the open source JavaScript API (Application Programming Interface) WebGL was considered. At that time, WebGL was becoming the most used application in the field of 3D web content management, thanks to its ability to visualize complex 3D models within browsers and without plug-ins. Unfortunately, in 2012, WebGL was still under development and could not offer full support to all browsers and operating systems, nor to older computing hardware (which was one of the tasks of RAPTOR). Nevertheless, we bypassed this problem, using other libraries that emulated WebGL (a combination of JavaScript and the tag “canvas” of HTML5). One of these libraries, jsc3d, allowed for the integration of 3D models within web pages by adding a few lines of code. Moreover, the software was versatile enough to combine with other libraries such as jQuery and OpenLayers and compatible with commonly used 3D file formats, like .obj. However, jsc3d had some limitations such as limited interaction with 3D models (user actions were restricted to zoom, pan and rotation) and the lack of a measuring tool. Nevertheless, considering that matrices and geographic information were granted by RAPTOR itself, like any other kind of query, jsc3d was implemented into the system (a choice that is nowadays obsolete, due to the rapid development of WebGL and other software built on top of this library, such as 3DHOP).

Practically, the integration between RAPTOR and jsc3d works in the following manner. Once the site recording data-sheet is created, a new “3D” icon is added to the toolbar. This icon is connected to a form that uses a PHP script to load new data. The script adds a new folder with the site ID (if not present), saves the new data within the folder, and writes a new record into a specific table in the general database, which stores the site ID (external key), the path to the uploaded file, and a short description (not mandatory). Later, the system automatically generates a new button to access 3D data from the graphical interface. In fact, it is possible to integrate the 3D viewer of jsc3d within the “dialog” element of jQuery. Thus, if more than one model refers to the same site, the user will see a drop-down menu with all the options. This solution allowed RAPTOR to manage 3D archaeological data of any typology: from single finds to layers and structures (FIGURE 5B) to reconstructed models (FIGURE 5A). While the 3D implementation of RAPTOR based on jsc3d can be considered obsolete, the structure described above is still valid.
and can be reused with new software, such as 3DHOP for non-geolocated models. However, to include landscape data, a good solution is to adopt a Virtual Globe integration (like Cesium), similar to the prototype developed for the Project 1753. Nevertheless, from a technical point of view, the implementation based on jsc3d met the desiderata of the Superintendence, improving the management of 3D data for Cultural Heritage preservation. Importantly, the prototype raised critical issues such as the predominance in archaeology of techniques based only on 2D documentation or the lack of alignment with national standard and European Union directives for 3D data (above all the use of international projected coordinate systems and of orthometric height).

**An Experiment in Emergency Archaeology, 3D Web-Coworking**

In 2006, after joining an aerial archaeology campaign in the Armenian site of Aramus, Arc-Team started a new research branch on robotic archaeological applications, which resulted with the first professional use of self-built open hardware for UAVs (one of the first prototypes of the ArcheoDrone) in 2008. This research branch, informally called archeorobotics, led to the development of other robotic devices (Bezzi et al. 2018: 173–207) based on open hardware projects from CNC (Computer Numerical Control) machines, like 3D printers for museum applications to different prototypes of ROVs (Remotely Operated underwater Vehicles) and, recently, USVs (Unmanned Surface Vehicles) (Bezzi et al. 2018). A common element among the various robotic rover prototypes is the use of the FLOSS platform ROS in order to control the SLAM process, based on the different sensors mounted to the machines. This implementation was a fundamental starting point for pioneering uses of SLAM algorithms for 3D documentation in archaeology, especially in the field of emergency excavations. In fact, despite lower quality in data acquisition, this methodology has the benefit of direct control of the 3D generated models during the destructive stage of digging.

![Figure 5. Two images of the RAPTOR 3D extension. A): A 3D reconstructive model developed in Blender, related with a porticus of a Roman villa. B): A 3D documentation model done with PPT, showing a working stage of an excavation.](image-url)
being based on real-time process. This opportunity has opened up new perspectives, thanks to rapid communication based on web technologies.

Following this line of research, during the last two years, Arc-Team has been testing a new strategy in managing small, emergency excavations, based on the concept of 3D web-coworking: besides using traditional documentation based on SfM and MVS technology, 3D models are also generated with a portable SLAM device. This hardware comprises a SBC (Single Board Computer) or a laptop, running an experimental version of ArcheOS equipped with ROS, and by two different sensors (an RGB-D camera for indoor and a stereocam for outdoor excavations). This methodology allows field archaeologists to generate 3D pointclouds in real-time with exact metric values and without post-processing operations (FIGURE 6A,B). Nevertheless, further support from the laboratory is needed in order to build surfaces and geolocate the data to create a virtual 3D reconstruction of the stratigraphy (FIGURE 6C,D). The current work-flow, designed to improve the connection between the field and the laboratory (web-coworking) involves initial SLAM documentation followed by a user-friendly data transfer based on “fish” (file transfer over shell protocol). In this way, raw data are uploaded into a shared folder on an internal server where files can be processed by archaeologists in the laboratory (with CloudCompare, MeshLab, GRASS, and QuantumGIS) into a stratigraphic 3D model, which, continuously updated, is internally shared via web, using the cross-browser JavaScript library Three.js.

The method described above has given good results in improving the internal system for small emergency excavations management adopted by Arc-Team, especially in those investigations performed through restricted surveys (where the archaeological tolerance is very high). In fact, in these cases, GCP can be placed outside the excavation area, simplifying the georeferencing process in the laboratory — this is possible because these external fixed points can be used for the 3D orientation of every single object. In order to apply the system on a smaller scale, we are performing new tests to add a GPS receiver on the SLAM portable device for future connection with real-time geomapping software like the Cesium derived SLAMAP and a Ground-Push Plug-in, which enables one to virtually “excavate” a portion of landscape within the base-map DTM.

A 3D Web Application for Rapid Data Visualization in Archaeological Exploration

The importance of rapid feedback in 3D data visualization for archaeological excavations underlies another typology of 3D
web application, used by Arc-Team for planning archaeological explorations. Indeed a priori good knowledge of the territory is fundamental for this kind of mission in any environment. For high alpine, glacier, and deep forest landscapes, detailed maps are often available (thanks to high quality LIDAR DTMs), but basic geographic information for other areas can be less accurate, if not totally absent. This second case often occurs in speleoaarcheology and underwater archaeology, but, if for caves and galleries the best solution is to perform a specific mission to acquire 3D model, the investigation of submerged environments offers more possibilities (especially in the peculiar field of high mountain lake explorations).

During the last two years, Arc-Team was commissioned to perform underwater archaeological exploration in high altitude inland waters of the Autonomous Province of Trentino. This experience led to the definition of a protocol, which, using the dead time imposed by the acclimation of the divers, was able to provide an interactive 3D bathymetric web model of the lake for better planning of the exploration (a web-coworking system, oriented to archaeological exploration, rather then excavation). This is important because among the more than 300 inland waters of Trentino none of the high altitude lakes (over 2400 meters above sea level) has been bathymetrically mapped. This problem is complicated because basic information is missing, such as maximum water depth. The hardware, composed by a piezoelectric device connected with a GPS receiver automatically uploads a grid of points defined by latitude, longitude and water depth that can be processed using GIS. This work-flow allowed Arc-Team to safely complete the exploration of Lake Mandrone (2409 meters above sea level) and Lake Monticello (2544 meters above sea level). Of importance is that the bathymetric data collected with the sonar was uploaded in real-time through the internet and processed via QGIS in only a few hours. The same evening, a 3D web bathymetric model performed via the Python plugin Qgis2threejs was accessible to the divers for mission planning. The 3D web models generated following this strategy were able

![Figure 7](image-url)

Figure 7. Two images related with the work-flow of 3D web-coworking. A): The bathymetric mapping stage during the acclimatization day, performed with a sonar towed by a kayak. B): The final 3D model obtained combining the LIDAR DTM, the aerial orthophotos and the 3D sonar bathymetric chart.
to supply additional essential information, due to the fact that they were combining data from different geodetic sources such as LIDAR, aerial orthophotography (for the surrounding landscape) and sonar (for the bathymetry) in almost real-time. Figure 7 illustrates the complete work-flow of this strategy, showing the data acquisition stage (A) and the final result (B).

Conclusions

The case studies described are an attempt to provide an overview of the many areas where 3D web technologies are applied in commercial archeology, which can be summarized by analyzing the final purpose of the technology itself: tourism improvement, real time field-work management, scientific communication, and preservation of cultural heritage. The redundancy of presenting more case studies related to the specific topic of tourism improvement (Punta Linke and Project 1753) and field-work management (excavations and underwater explorations) allows us to analyze some of the multiple variables adopted for the different web platforms, deriving from the peculiarities of each project. These peculiarities, more than the software used for the final product, have an important impact on the development of the 3D web application. A key point that we seek to highlight is that there is no one solution that fits all. For example, in the Punta Linke Project, the client requirements (a touristic platform for a targeted audience) combined with the high archaeological tolerance and with nature of the 3D data (simplified models) had a strong impact, primary on the adopted field strategy (a simple 3D documentation) and ultimately on the choice of the 3D web technology (a game engine). On the contrary, for the Project 1753, the absence of client restrictions imposed by the customers allowed us to use a solution that grants full access not only to the 3D objects (archaeological structures), but also to the surrounding landscape (without looting issues). Also concerning the field-work management (3D web-coworking), minor differences in data acquisition (through several archaeorobotic devices) led to the adoption of various solutions in data transfer protocols, although within similarly structured 3D web technologies (based on Three.js). Moreover, we have emphasized how the four main project variables—final purpose of the technology, nature of 3D data, customers’ desiderata, and target audience—also strongly influence the development of the most techni- cal platforms for archaeological purposes, oriented to scientific communication. In fact, despite the primary target of the web solution related to Prato Piazza/Plätzwiese was the disclosure of data, the access to information (geolocation) of 3D models has been partially restricted. Finally, in the case study concerning RAPTOR (related to the preservation of cultural heritage) we had the opportunity to explore how web-based platforms could serve not only small areas (i.e., individual archaeological projects), but rather gave us the possibility to deal with 3D data deriving from different archaeological projects. This fact revealed some critical issues (above all the lack of alignment with standard during 3D data acquisition) that have to be considered in any platform oriented to serve multiple projects (with large AOI or supported by the work of different teams).

In conclusion, this contribution does not intend to be exhaustive, considering that other fields have not been explored, due to the lack of specific experiences or because not directly related to the topic of field archeology. As an example, the article does not describe the many interesting projects related to museology and museography, oriented to the presentation of 3D objects (archaeological finds), even if, when access to geolocation is restricted, the final 3D web platform can be very similar to the one produced for Prato Piazza/Plätzwiese (based on 3DHOP). Nevertheless, it is our opinion that even a partial overview of the new potential offered by the increasing use of these technologies can be useful in a wider discussion on this subject, in hopes for new ideas to improve not only tourism (and preservation) for Cultural Heritage or communication among the scientific community, but also management of archaeological projects in general.

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Notes on Contributors
Luca Bezzi (M. Phil. 2005, University of Padua) founded in 2005 the Arc-Team, an Italian company which works in the field of archaeology and cultural heritage. As a member of Arc-Team, he has worked on several archaeological campaigns in Europe (Italy and Austria), the Caucasus (Armenia and Georgia), and the Middle East (Iran). He has teaching experiences in Italy (University of Padua, Pisa, Siena, Ferrara, Trieste), Austria (University of Innsbruck), Sweden (University of Lund) and Germany (TOPOI Excellence cluster of Berlin). He has published different articles, mainly oriented to the topic of digital archaeology, FLOSS (Free/Libre and Open Source Software), field archaeology (related with different projects), and anthropology (forensic facial reconstruction).
Currently he is working for Arc-Team and his research interest are related to underwater archaeology and speleoaarchaeology.

Alessandro Bezzi (M. Phil. 2006, University of Padua) in 2005 was one of the founding member of the Arc-Team. His field experience comes from several archaeological campaigns in Europe (Italy and Austria), the Caucasus (Armenia and Georgia) and the Middle East (Iran). He gave lessons in several universities in Italy (University of Padua, Pisa, Siena), Austria (University of Innsbruck), Sweden (University of Lund) and Germany (TOPOI Excellence cluster of Berlin). His publications are mainly oriented to the topic of digital archaeology, FLOSS (Free/Libre and Open Source Software) and field archaeology. He is currently working for Arc-Team, with a special focus on archerobotic devices.

Cristian Boscaro (Ph.D. 2012, University of Venice) is an expert of 3D archaeological and architectural documentation. He has worked on different projects in Italy (to scan the Men of Altamura), Europe (Spain and France) and North Africa (Libia). He has teaching experiences in Italy (University of Venice, Siena, Ferrara and Trieste) and has written several article regarding architecture, 3D documentation, and photogrammetry. He is currently working as an architect and his research interests are connected with 3D documentation and photogrammetry.

Kathrin Feistmantl is a professional archaeologist with Arc-Team. She has worked on several archaeological campaigns in Europe (Italy) and the Caucasus (Armenia) and, currently, in Italy. Her research interests regards archaeological methodology applied to fieldwork.

Rupert Gietl (M. Phil. 2005 University of Vienna) founded Arc-Team in 2005. His working experience in field archaeology includes several campaigns in Europe (Italy and Austria), the Caucasus (Armenia and Georgia) and the Middle East (Iran). He has teaching experiences in Italy (University of Siena,) and Austria (University of Innsbruck). His published works are mainly oriented to the topic of digital archaeology, field archaeology (related with different projects), and conflict archaeology (mainly about WWI). Currently he works for Arc-Team, with a specific interest in modern conflict archaeology, glacial archaeology, and high mountain archaeology.

Giuseppe Naponiello is a professional archaeoanthropologist at Arc-Team. He is an expert of 3D web technology and cyber security. He has worked on several archaeological projects in Europe (Italy), the Caucasus (Armenia) and the Middle East (Iran). His teaching experience regards cyber security, DBMS (Database Management System) and webGIS in Italy (University of Pisa and Siena) and Austria (University of Innsbruck). His research has focused on archaeological webGIS and DBMS with FLOSS (Free/Libre and Open Source Software). Currently he is working for Arc-Team, with a specific interest for archaeological web-technologies.

Fabiana Ottati (M. Phil. 2015, University of Torino) is as expert of architectural restoration. She has worked on different projects in Italy and Europe (Spain). She is currently working as a professional in the field of architectural 3D documentation. Her main research interests are photogrammetry and 3D web-technologies.

Margarita de Guzman (M.A. 2005, Durham University) is the Director and Principal Archaeologist of Circle CRM Group Inc., based in Calgary and Edmonton, Alberta. She has over 15 years of archaeological experience and has participated on a number of archaeology projects ranging from the early Neolithic to the Medieval period, in North America (Canada), Europe (England, Italy, Austria and Hungary), the Caucasus (Armenia), as well as in the Caribbean island of St. Vincent and the Grenadines. She is currently working for the Circle CRM Group. Inc. and her main interests regard Cultural Research Management in general.

ORCID
Kathrin Feistmantl http://orcid.org/0000-0002-0457-3944

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