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The Use of Low-Cost Technologies for the Promotion of Cultural Heritage Sites

The Case Study of Veleia

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Abstract—**In the Cultural Heritage field, thanks to the recent development of digital technologies, a large variety of sites and artifacts could benefit from their free access and promotion through the web. But despite these achievements, the high costs that are generally connected with their use often limit their widespread. As a consequence, during the last two decades, scientific research is developing new tools and methodologies aimed at overcoming this problem. In particular, for example, researches in the field of image-based technologies and the development of open-source algorithms and software aimed at helping the processing, management and visualization of 3d data through the web represent remarkable attempts to extend the use of digital technologies in the Cultural Heritage field.**

This contribution shows the main steps of a project aimed at testing low-cost technologies within the multi-scalar digitization process of sites and artifacts. Thus these technologies still cannot provide analogous results in terms of definition and accuracy that it is possible to achieve using more expensive technologies (e.g. range-based technologies), they can supply low-resolution reality-based 3d models and effective representations that can be easily accessed through the web, with evident benefits in cultural contents sharing and promotion. Within a multi-scalar approach, the building of these kinds of models represents the first step of a process that, starting from low-resolution acquisitions, can improve the detail and definition of 3d digital models of artifacts by gradually adopting different methodologies and technologies. As a consequence, this approach can provide evident benefits on the achievement of different communication purposes, ranging from simple visualizations for popular aims to accurate and faithful digital replicas that can be fruited by different and changing users. Moreover, the adoption of this approach is particularly important within education processes aimed at training expert operators able to speed and therefore to further reduce costs connected with the digitization of Cultural Heritage.

Keywords- low-cost digital technologies; multi-scalar reality-based 3d modeling; visualization; web sharing

I. INTRODUCTION

During the last two decades, despite the development of digital technologies aimed at collecting 3d reality-based information of objects and at transposing them in the digital environment, in the field of Cultural Heritage, still many Institutions aren't encouraged to adopt digital procedures and technologies as a standard practice to collect information about the heritage they are called to preserve and promote. This is mainly due to the high costs that are usually connected with these technologies; as a matter of fact, for example, range-based technologies (both hardware and software) are still generally expensive and require the intervention of expert operators both during survey campaigns and during post-processing of data. As a consequence, a wide variety of sites and artifacts that could benefit from their free access and fruition through digital technologies are still unknown to the wide audience. Nevertheless, the continuous research in the field of Structure from Motion (SfM) technologies testifies the intent to overcome the problem of high costs connected with the use of digital instruments.

The SfM approach is based on the principle that the structure of four non-coplanar points is recoverable from three orthographic projections [1]. Following this statement, research in the field of computer vision led to the possibility of reconstructing 3d scenes and camera motion through sets of 2d images. In 1988, [2] reviewed different achievements in this field by highlighting and comparing two distinct paradigms: the feature-based approach and the optical-flow-based one. These two approaches were improved some years later; [3], for example, defined correspondences between 3d points and their images by identifying geometric primitives, while [4] presented a method for finding the optical flow pattern by assuming that the velocity of a brightness pattern varies smoothly in an image belonging to a sequence. More recently, research developed different methodologies aimed at reducing the number of degrees of freedom of the correspondence problem between 3d points and their related images in two or more views. [5], for example, developed a methodology to recover 3d scene structures and camera motion by estimating the maximum likelihood of structure and motion given only 2d measurements, without the need of prior knowledge of point correspondence or camera viewpoints, while [6] developed an algorithm able to reconstruct 3d surfaces using varying illumination as a source of calculation. Other research groups use probability analysis in order to minimize the number of degrees of freedom during estimations of 3d points location and camera motion [7, 8].

In addition to these achievements, the recent widespread of open-source algorithms, software and tools developed in order to help the reconstruction of 3d scenes from 2d images (e.g. Autodesk 123D Catch, Microsoft Photosynth, Insight3d, Hypr3D, VisualSfM, ARC 3D, Bundler, SFMToolkit, ETH-V3D, V3DSfMToolkit) [9], the processing (e.g. Meshlab) [10], management and visualization of 3d data through the web (e.g. X3DOM, OSG4WEB, Google O3D, Canvas3D JS Library, CubicVR, Three, SceneJS, SpiderGL) [11] and the organization of events and workshops expressly focused on these topics represent a further attempt to extent the use of digital technologies in the Cultural Heritage field[1].

Another aspect that can influence the widespread of these survey procedures is the training of expert operators. In this direction, education can play an important role, since it can shorten time consuming, improve the further reduction of costs and therefore widen the digitization of sites and artifacts.

This contribution shows the work in progress of a project aimed at both testing low-cost technologies for the building of 3d digital models for the promotion of important but little known archaeological sites and meanwhile at training scholars in the 3d digitization of Cultural Heritage. In particular, since in this field the multi-scalar approach is an indispensable practice in order to achieve different and changing communication aims, thanks to the recent advancements in the field of digital technologies, low-resolution 3d reality-based models can actually be built using low-cost technologies. Within the digitization process, these kinds of models can provide effective representations that can be easily accessed and shared through the web, with evident benefits in knowledge sharing. Moreover, the use of these kinds of technologies is particularly important within education programs, since it represents the first step of a process that, starting from low-resolution acquisitions, can improve the detail and definition of 3d digital representations of artifacts by gradually adopting different methodologies and technologies.

This contribution shows the entire workflow of the digitization of the Forum of Veleia, a very important but little known archaeological site near Piacenza, Italy (section II), from its survey using image-based technologies, to 3d modeling, visualization and sharing through the web or using commonly spread mobile technologies, by means of open-source and low-cost technologies (section III).

II. THE CASE STUDY

Within this context, the archaeological site of Veleia was selected as an interesting case study aimed at showing how digital technologies can help the promotion of Cultural Heritage through popular communication.

The importance of this site, that is also called the “Pompeii of Northern Italy” is well known among scholars of the Roman world. The comparison with Pompeii mainly derives from its conservation conditions. As a matter of fact, since through ages a wide variety of Roman sites were destroyed or damaged because of the stratification of successive settlements, Pompeii and Veleia have almost preserved their original urban and architectural structures. The importance of the site of Veleia is stressed by the recent reset of the exhibition of this archaeological area that was promoted in 2010 by the Superintendence for the Archaeological Heritage of Emilia-Romagna on the occasion of 250 years of the discovery of the site [13]. But despite these commendable initiatives, the existence of the site of Velia is almost unknown to the wide audience.

The Roman city of Veleia, situated in the Apennines near Lugagnano, Piacenza, was accidentally discovered in the first half of the XVIII century, thanks to the finding of the Tabula Alimentaria. This big (2.86 m wide and 1.38 m tall) bronze inscription that was well known throughout the Roman age, lists the names of landowners who benefited from a loan by the Emperor Trajan (98-117 AD). The interests of these loans were allocated for the maintenance of poor children, in order to support young people and guarantee future generations of soldiers to the Empire [14]. This extraordinary find brought to light the city of Veleia, with its forum area, the basilica, the twelve marble statues portraying members of the Julio-Claudian family, its thermal centre and the surrounding houses.

Veleia was founded around the II century BC with the purpose of administrating a wide mountain area between the Taro, the Trebbia and the Luretta valleys. The name of the city derives from that of the Ligures Eleates (the *Veleiates*) population that inhabited this area. The period of greatest splendor of the city coincided with the early imperial age (around the I century AD), when Veleia was interested by an extraordinary building and urban development. As early as the II century AD, however, the population of Italy was devastated by war and famine and by the collapse of the Western Roman Empire. This depopulation process also stuck Veleia, that was progressively abandoned.

Within this archaeological site, the forum was selected as the first case study upon which testing our methodology. As a matter of fact, this area presents a series of artifacts, such as columns and bases, whose geometry and location are particularly suitable for digital reconstruction through 3d models. The Julio-Claudian Augustan age forum of Veleia represented the centre for the social, commercial and political activities of the city. On its square that is still paved with sandstone slabs, are located basements for statues dedicated to the emperors. The forum was surrounded on three sides by porticoes with shops (*tabernae*) and public buildings. The columns located along its perimeter belonged to these buildings. In particular, on the northern side, a monumental entrance stressed by a tetrastyle colonnade was probably built for religious purposes, while the southern side is marked by a raised terrace which hosted the basilica, a building with a nave and a rectangular exedrae in the head intended for the worship of the emperors. The twelve marble statues portraying members of the Julio-Claudian family were hosted in this building [15].

III. THE ADOPTED METHODOLOGY

The present project follows the 3d digital survey campaign that was conducted in 2008 on case studies that were selected within the forum of Pompeii [16], whose geometric and radiometric characteristics are very similar to the ones of Veleia. In that case, in order to find the most suitable

1. The recent “Low-cost 3D: sensori, algoritmi, applicazioni” event organized by Fabio Remondino (3DOM - FBK Trento, Italy) and Roberto Scopigno, (ISTI - CNR Pisa, Italy) in Trento, Italy (March 8-9, 2012) is an example of this need and trend [12].

methodology to adopt following the characteristics of the finds and different communication aims, the findings of Pompeii were digitized using different methodologies and technologies, ranging from image-based to range-based ones. The results of those investigations were compared taking different aspects into consideration, such as, for example, the metrological one, the quality of the restored information, time consuming, skills required and costs [17]. The analysis of those results reinforced the idea that in the Veleia project a SfM approach would have represented the best solution for our purposes.

The aim of a fast and effective transposition of the artifacts of the forum of Veleia in a digital environment that can be accessed via the web and using mobile devices and that can be acquired through low-cost technologies, suggested to adopt the pipeline illustrated in fig. 1.

Figure 1. The adopted pipeline.

A. *From 2d Images to 3d Data*

The image-3d data pipeline consists in the recovery of 3d geometry from unordered and uncalibrated 2d images. The survey of the site was organized following the rules suggested by the adopted SfM tools. As far as this last aspect is concerned, it is important to stress that this project was planned to be the first step of a 3d digital survey experience in the education process of young architects. This aspect suggested to choose software and tools that do not need particular computer skills. For this reason, evaluations on the actually available open-source SfM tools led to the choice of Autodesk 123D Catch.

Even if this software can be considered as a black-box, because it only allows the testing of the application functionality and doesn't let the user to analyze and customize its internal structure and parameters, it was preferred to others because (i) it directly re-builds triangular meshes derived from point clouds that are calculated using 2d images as inputs; (ii) it has an efficient texture blending tool; (iii) it directly provides different levels of detail of the information (both from a geometric and a radiometric point of view); (iv) it has an intuitive interface; (v) it allows the exportation of files in different and commonly used formats.

The choice of this tool required some preliminary evaluations on survey conditions and procedures such as, for example, the preservation of 50% overlap areas among adjacent photographs and the need to acquire three different views of the most significant elements of each artifact, in order to allow the manual stitching of photographs in case of errors within the camera orientation step.

Another critical aspect is represented by illumination. In order to avoid sharp shadows and marked radiometric differences within a sequence of images belonging to the same artifact, it is important to pay a special attention to illumination conditions. As far as this last aspect is concerned, in some cases we used Adobe Lightroom 4 beta which is particularly useful for the equalization of photographs; within the management of histograms process, for example, this software allows to use adjustment brushes in order to locally correct illumination conditions (fig. 2).

Moreover, during the survey campaign, the measurement of a reliable and significant dimension of each artifact is indispensable in order to assign the correct scale to 3d models during the scale/orientation pipeline. For each artifact, this dimension was generally acquired on long and sharp edges.

Fig. 3 shows the main phases of the workflow of the digitization project of the forum of Veleia. For each step, the most critical aspects and the adopted solutions, as well as the used software/hardware tools are highlighted.

B. *The 3d Data Pipeline*

The transposition of 2d images to 3d geometry was organized into two main phases: (i) the construction of the 3d polygonal mesh and (ii) the post-processing of data. As far as the first step is concerned, even if Autodesk 123D Catch doesn't allow the customization of internal parameters and therefore to control the whole process, some critical aspects were highlighted. The presence of poor overlapping areas, for example, determines lacks within the polygonal mesh. As a consequence, in order to overcome this problem, Autodesk

Figure 2. Examples of correction of illumination conditions. In (a) and (c), original images acquired using an uncalibrated Nikon D90 camera with variable focal length. In (b), elimination of highlights; in (d), correction of a backlight.

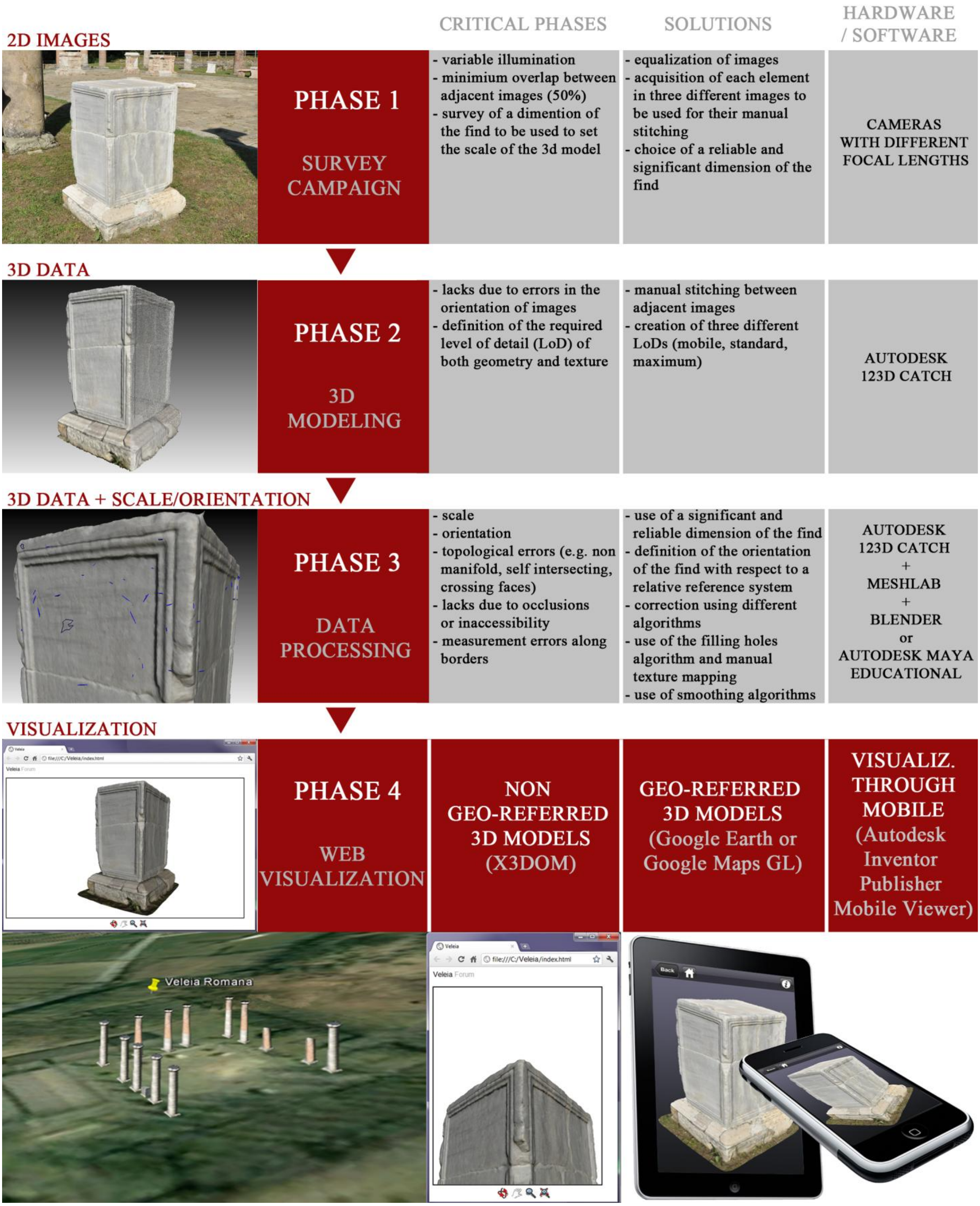

Figure 3. Scheme of our workflow: critical aspects, solutions and adopted tools.

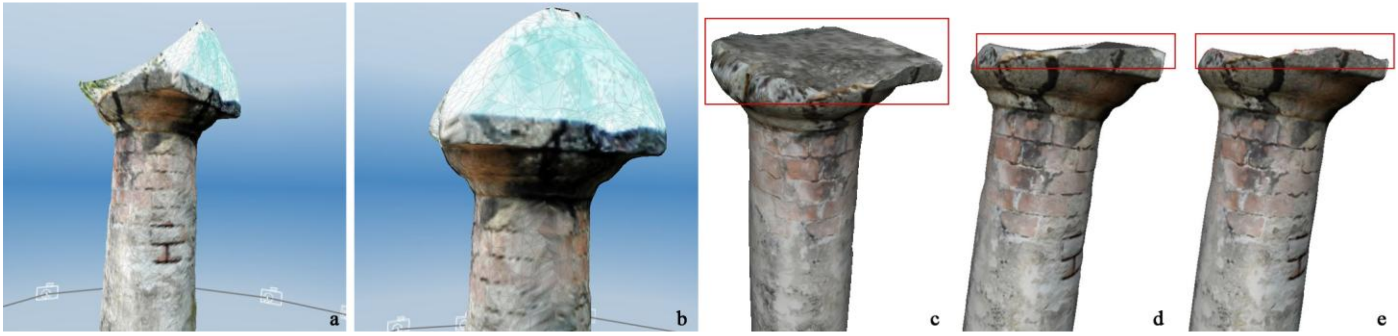

Figure 4. Lacks of information or measurement errors due to inaccessibility of portions of artifacts (a, b). In some cases, holes were filled and manually textured, in order to re-build the whole find (c). In some particular cases, topological errors along the borders (d) were perceptually reduced using the Laplacian smoothing algorithm (e).

123D Catch is provided with a manual stitching tool that allows to orient three images by recognizing four homologous points within the selected images. In other cases, holes are determined by occlusions or by poor information due to the inaccessibility of portions of 3d objects. In particular, as far as the first aspect is concerned, the problem of occlusions can be faced by using the holes filling tool that is available in most commonly used 3d modeling packages (e.g. MeshLab). Within our case study, when accuracy and detail were secondary aspects with respect to the effective representation of artifacts, the holes filling process required the following manual texture mapping of the modeled faces (we used Blender or Autodesk Maya educational). The same solution was adopted also in case of lacks of information due to inaccessibility of portions of artifacts. In addition to this last aspect, in some particular cases, the lack of information was followed by evident topological errors along the borders that were perceptually reduced using the Laplacian smoothing algorithm (fig. 4). Other topological errors, such as, for example, the presence of non-manifold, crossing or self intersecting faces were corrected using the “cleaning and repairing” filters available in MeshLab.

Within our digitization project, another critical aspect is represented by the level of detail of both the geometric and the radiometric information. As a matter of fact, Autodesk 123D Catch allows to rebuild only three levels of detail of information: mobile, standard and maximum. While the mobile and the standard qualities are respectively conceived for fast visualizations on mobile devices and on desktops, the maximum one allows to deepen investigations on the geometry of digital models. These three LoDs correspond to different characteristics of the models concerning their definition, accuracy and possibilities of management and visualization. In our case studies, for example, the number of faces of polygonal meshes decreases from 1.5 to 3.5 times from the maximum quality geometries to the standard ones, while it is reduced from 5 to 8 times from the standard to the mobile ones. As far as the heaviness of files is concerned, it decreases from 1.5 to 3 times, from the maximum quality geometry to the standard one, while it is reduced from 5 to 12 times from the standard quality to the mobile one. As far as the radiometric characteristics are concerned, the heaviness of texture files is almost constant within the maximum and the standard quality models, while it decreases from 2 to 6 times from the standard quality to the mobile one (table I).

In addition to these considerations, while the detail of the rebuilt geometry is not significantly influenced by the number of input images, this last parameter determines the accuracy of 3d reconstructions (fig. 5).

C. The Scale/Location Pipeline

The building of a 3d model from 2d images requires the definition of the scale and orientation of the model within a reference system. In this process, the acquisition of a reliable and significant dimension of the artifact is an indispensable practice to pay attention to during survey campaign. This aspect is particularly crucial, as it highlights the weakness of this technology. As a matter of fact, the selection of the most suitable measure to acquire is subjective and it is usually surveyed using a direct measurement methodology. As a consequence, the acquired information is often less accurate than what it is expected from a detailed 3d model derived from a dense point cloud.

The location of the 3d model in the digital environment needs the definition of a reference system within the 3d space.

TABLE I. CHARACTERISTICS OF SELECTED 3D MODELS REALTING DIFFERENT LEVELS OF DETAIL (MAXIMUM, STANDARD AND MOBILE QUALITY)

FIND	**# OF PHOTOS**	**# OF FACES**			**HEAVINESS OF FILES (MB)**						
					Maximum Quality		***Standard Quality***		***Mobile Quality***		
		Max Q.	***Strd. Q***	***Mob. Q.***	**.obj**	**.jpg**	**.obj**	**.jpg**	**.obj**	**.jpg**	**.ipm**
F01	25	280˙543	81˙688	11˙059	32	3	9	2.4	1.3	0.9	2
F06	40	285˙881	183˙356	23˙911	33	7	21	6	4	2.6	6
F07	34	190˙464	65˙371	12˙259	21	3.8	7	3.7	1.2	1.4	3
F18	25	205˙485	57˙643	8˙608	23	2.7	6	2.8	0.5	0.5	1.4

Figure 5. Within a pre-defined LoD, the availability of a large number of photographs determines the accuracy of 3d models, while it doesn't significantly influence the detail of the rebuilt geometry.

When the geo-location of the 3d model is not required, the most important information to be assigned to geometry within a relative reference system is the orientation of the z axis. This last specification consequently determines the location of the horizontal plane on which the 3d model is placed.

D. The Visualization Pipeline

The field of Cultural Heritage is actually strongly benefiting from knowledge sharing through web-based 3d information systems. The continuous development of plug-ins and APIs for the visualization of 3d contents on web browsers and through mobile devices testifies the growing attention towards different interactive access tools. In particular, since the last two decades, the VRML and X3D languages were developed in order to describe 3d geometries, illumination and material properties in a web browser, while the rendering of a 3d scene requires the use of specific plug-ins or applets. WebGL, for example, is an API developed with the purpose of extending the capability of JavaScript language of sharing 3d contents on the web. WebGL is based on the OpenGL ES 2.0 standard that was developed for mobile and embedded platforms that are equipped with less powerful graphic chips. Actually many graphic libraries rely on WebGL; a list of the main ones is published by Khronos Group that develops WebGL [18]. The possibility for web developers to directly access OpenGL-class graphics through JavaScript and freely mix 3d contents with HTML ones is actually enhancing the customization of rich user interfaces to be used, for example, in the Cultural Heritage and in the educational field. But even if many solutions have been recently developed, still no unique and flexible solution is actually available for applications in these fields. An overview of some of the most commonly used 3d web technologies is presented in [19, 20]; while an interesting example of a collection of 3d models of artifacts belonging to a Cultural Heritage repertoire is available at [21] developed by the 3C-COFORM project [22] in order to show the potentialities of this tool in this particular field.

One of the primary needs that can be highlighted in this field is the interoperability between these libraries and the most widespread 3d modeling packages. As a matter of fact, the wide variety of tools aimed at acquiring 3d shapes using different survey techniques is rapidly increasing; this is also due to a rising attention towards open-source or low-cost tools and software.

Within the visualization pipeline of our project, we distinguished different kinds of outputs, depending on the possibility to access (i) to non geo-referred or (ii) to geo-referred 3d models through a web browser or to access (iii) to 3d models using mobile devices.

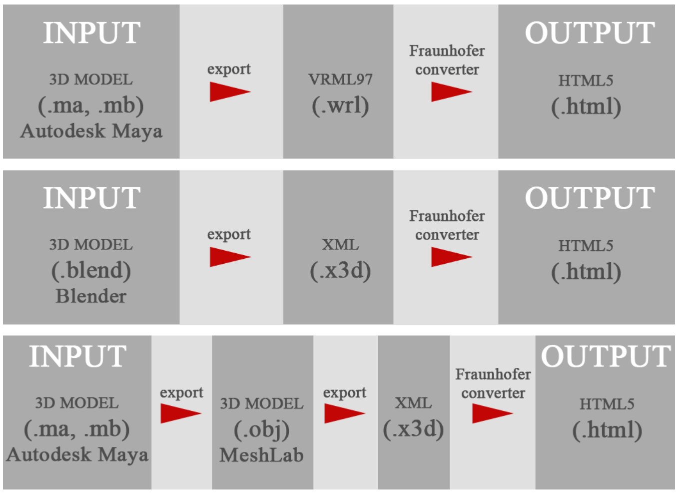

Figure 6. Different workflows adopted in order to embed 3d contents in HTML pages within our digitization project.

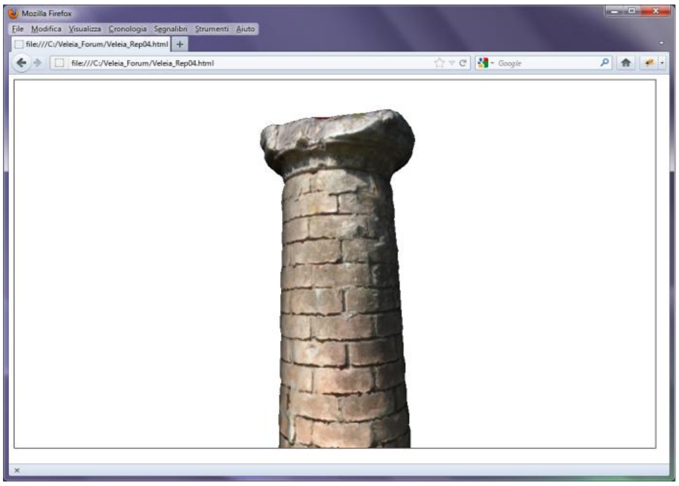

Figure 7. A simple visualization of the 3d model of a find of the forum of Veleia in a standard web browser page using the X3DOM technology.

Figure 8. Detail of a visualizations of the geo-referrend 3d models of artifacts of the forum of Veleia (a). In (b), 3d models complete the perspective view of the forum.

As far as the web access to non geo-referred models is concerned, we adopted the X3DOM technology [23], a JavaScript based interface aimed at embedding X3D inside (X)HTML pages. X3DOM is based on WebGL, doesn't need the installation of any plug-in and allows to embed 3d models that can be exported from different software (e.g. Blender, MeshLab, Autodesk Maya). As far as this last aspect is concerned, the Fraunhofer IGD Institute for Computer Graphics [24] developed a very useful tool that enables the conversion of 3d models from the VRML97 or X3D format to the X3DOM - (X)HTML5 ones. This tool can be used both in a inline version [25] and in a offline encoding using the Instant Reality's X3D plug-in [26]. In particular, within our workflow, we adopted one of the procedures illustrated in fig. 6. After this translation, the output code can be embedded in a HTML page (fig. 7). As a further development, this simple output can be enriched, for example, by integrating 3d contents with other metadata such as different multimedia documents or other web pages.

As far as the possibility to geo-refer 3d models is concerned, Google Maps has recently been improved using the WebGL technology (Google MapsGL). This standard allows the real time rendering of 3d models without the need to install any plug-in. Within our project, the pipeline from the generated 3d model to the geo-referred one required the use of Google SketchUp in order to correctly locate the 3d model inside a geographic reference system, to orient it and to assign the correct altitude with respect to the surface of terrain (fig. 8).

As far as the visualization of 3d models on the move using mobile devices is concerned, within our project we chose to use the exploration tool that is directly available inside Autodesk 123D Catch. As a matter of fact, since this software allows to build 3d models with three different degrees of geometric and radiometric complexity, we exported each model in the IPM format, which corresponds to the less detailed one (mobile quality). This file format can be visualized using the Autodesk Inventor Publisher Mobile Viewer (IPM Viewer), an open-source application expressly developed for mobile phones.

IV. CONCLUSIONS

This contribution shows the main steps of a project aimed at showing the potentialities offered by low-cost technologies in the promotion of Cultural Heritage sites through the web. As a matter of fact, since in the last two decades many qualities of open-source software have been developed in computer vision, still no unique and flexible solution is actually available for applications in the Cultural Heritage field. As a consequence, this contribution is aimed at showing a methodology that could be widely shared and adopted as a standard practice by Institutions called to promote Cultural Heritage through effective and popular communication.

In addition to these aspects, the presented case study of Veleia was chosen as exemplifying of a procedure that could be adopted also within educational contexts with the purpose of training operators and therefore extend the use of digital technologies and procedures to little known sites and artifacts. As a matter of fact, since internet has widened our possibilities to access to knowledge and to share different kinds of data, these case studies can sensibly benefit from their free access through the web.

Within this contribution, the adopted methodology is described through its whole pipeline, its main critical phases, the related solutions and technologies. In particular, our methodology allows to recover the geometry and matter characteristics of 3d objects from uncalibrated 2d images. The main phases of the whole workflow can be singled out (i) in the recovery of 3d points location and of their radiometric characteristics from sequences of photographs, (ii) in the post-processing of data and (iii) in the web visualization process. In particular, as far as this last aspect is concerned, we adopted different methodologies aimed at visualizing both geo-referred and non geo-referred 3d models in a browser window. In addition, the main steps for the easy and fast sharing of 3d contents using mobile devices were described. These simple visualizations are examples of how 3d contents can be considered as intuitive interfaces able to link and therefore enrich catalogues collecting different kinds of information in a digital environment. These digitizations can also be considered as the first step of a multi-scale process aimed at creating more detailed and complex collections and reconstructions, as they can subsequently be improved using different technologies and procedures.

As far as the time consuming aspect is concerned, the entire workflow required from 1 to 2 man-days for each artifact, depending in particular on time required for lighting conditions correction.

In addition to these aspects, this contribution shows how this simple workflow that pre-supposes the use of open-source or low-cost technologies and tools can be adopted by operators that don't have specific computer skills but nevertheless can contribute to the promotion of Cultural Heritage using digital technologies.

Even if the present project shows that the use of these methodologies can sensibly hold costs and times down, further investigations will be conducted using active technologies and methodologies aimed at comparing metrological results acquired using both approaches and therefore verify the validity of the adopted low-cost technology in terms of quality and accuracy of final results.

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VisualSfM http://www.cs.washington.edu/homes/ccwu/vsfm/
ARC 3D http://www.arc3d.be/
Bundler http://phototour.cs.washington.edu/bundler/
SFMToolkit http://www.visual-experiments.com/demos/sfmtoolkit/
ETH-V3D http://www.inf.ethz.ch/personal/chzach/opensource.html
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Figure 9. Examples of 3d models of findings belonging to the forum of Veleia that have been built using 2d images.