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# DELIVERING AND USING 3D MODELS ON THE WEB: ARE WE READY?

***DISTRIBUCIÓN Y USO DE MODELOS 3D EN LA WEB: ¿ESTAMOS LISTOS?***

Roberto Scopigno*, Marco Callieri, Matteo Dellepiane, Federico Ponchio, Marco Potenziani

Istituto di Scienza e Tecnologie dell'Informazione "Alessandro Faedo" (ISTI), CNR, via Moruzzi 1, 56124 Pisa, Italy.
roberto.scopigno@isti.cnr.it; marco.callieri@isti.cnr.it; matteo.dellepiane@isti.cnr.it; federico.ponchio@isti.cnr.it; marco.potenziani@isti.cnr.it

**Abstract:**

Digital technologies are now mature for producing high quality digital replicas of Cultural Heritage (CH) assets. The research results produced in the last decade ignited an impressive evolution and consolidation of the technologies for acquiring high-quality digital three-dimensional (3D) models, encompassing both geometry and color. What remains still an open problem is how to deliver those data and related knowledge to our society. The web is nowadays the main channel for the dissemination of knowledge. Emerging commercial solutions for web-publishing of 3D data are consolidating and becoming a de-facto standard for many applications (e-commerce, industrial products, education, etc.). In this framework, CH is a very specific domain, requiring highly flexible solutions. Some recent experiences are presented, aimed at providing a support to the archival of archaeological 3D data, supporting web-based publishing of very high-resolution digitization results and finally enabling the documentation of complex restoration actions. All those examples have been recently implemented on the open-source 3D Heritage Online Presenter (3DHOP) platform, developed at CNR-ISTI.

**Key words:** 3D digitization, virtual archaeology, cultural heritage, documentation, web-based 3D visualization, restoration

**Resumen:**

Las tecnologías digitales están ahora maduras para producir réplicas digitales de alta calidad de valores activos del patrimonio cultural (CH). Los resultados de la investigación producidos en la última década han mostrado una evolución impresionante y una consolidación de las tecnologías para la captura de modelos digitales tridimensionales (3D) de alta calidad, que abarcan la geometría y el color. Lo que queda aún por resolver está relacionado con la forma de distribuir los datos y el conocimiento relacionado con la sociedad. La web es hoy en día el principal canal utilizado para divulgar el conocimiento. Las soluciones comerciales nuevas relacionadas con la publicación en la red de datos en 3D se están consolidando y convirtiendo en un estándar de facto para muchas aplicaciones (comercio electrónico, productos industriales, educación, etc.). En este escenario, el patrimonio cultural es un dominio muy específico, que requiere soluciones muy flexibles. Se presentan algunas experiencias recientes, destinadas a proporcionar un apoyo al archivo de los datos arqueológicos 3D, la publicación web de los resultados de digitalización de muy alta resolución que permiten finalmente la documentación de trabajos de restauración complejos. Todos estos ejemplos se han implementado recientemente en la plataforma *3D Heritage Online Presenter* (3DHOP) de código abierto, desarrollada en el CNR-ISTI.

**Palabras clave:** digitalización 3D, arqueología virtual, patrimonio cultural, documentación, visualización web 3D, restauración

## 1. Introduction

Multiple digital technologies are experimented in Digital Humanities (DH); those instruments are going to play an important role in the study, dissemination and didactical activities related to our Cultural Heritage (CH). These technologies cover many different types of applications and are the results of intensive research in many scientific domains (not just Computer Science but also Optics, Physics, Chemistry, etc.). More specifically, Computer Science is offering many different opportunities to manage visual data at unprecedented levels of accuracy and ease of use. The term visual data is intended here to encompass all digital visual representations we can adopt to produce a useful sampling of either the visual characteristics (by means of: standard 2D images; more sophisticated image media, such as RTI or panoramic/360º images; standard videos or omnidirectional videos) or the geometrical/shape characteristics of a CH artefact or scene (using one of the many 3D representation incarnations).

A number of enabling technologies have been developed and matured in the last years to sample the artworks of interest. Sampling devices are then paired by processing technologies, data optimization tools (e.g. providing simplification and multiresolution features to increase the usability of very high resolution samplings), efficient archival systems, search and retrieval facilities and, finally, tools for web presentation.

The latter domain is the main focus of this paper. Nowadays the web is the place consulted by everybody searching for knowledge or digital content. This is definitely true for needs related to teaching or to

*Corresponding author: Roberto Scopigno, roberto.scopigno@isti.cnr.it

personal interest (and in this case Wikipedia or systems providing collections of PowerPoint presentations are key resources). At the same time, consulting the web is more and more common also to support academic study and research. Many CH applications would require the availability of visual data as well as tools to process those data and to get insight from those data (Scopigno et al., 2011).

All the material produced by the many digitization projects in the last decade is extremely valuable raw digital content and has to be disseminated and shared with the community of scholars and practitioners. This is unfortunately still a wish rather than a reality. The amount of time and resources dedicated to 2D/3D digitization in the last 10 years has been impressive, but only the tip of this iceberg has been exposed and offered to the community. The majority of the material produced remains hidden in the shelves or in the hard drives of the people who did the digitization. There are a number of reasons which explain the poor availability of good quality digital models:

- Intellectual property rights (IPR) issues. Digitization has still a non-negligible cost, usually payed by the owner of the artwork; many CH institutions still want to keep control over the digital data, either to make profit or to keep it safe themselves because they are worried by possible improper (commercial) use.
- Several digitization efforts occur in the framework of research projects, archaeological excavations or restoration actions. Therefore, they are part of currently active researches/studies, usually still unpublished and thus confidential. Consequently, open data access is often postponed after the end of the specific project (and in many cases it becomes a forgotten action at the end of the project).
- Finally, even in the cases where the digitization actions are leaded by very open and forward-minded curators/scientists and data dissemination is perceived as an important goal, often the lack of expertise or financial resources impede data disclosure.

Technological advances are bringing us good and ready to use solutions which could solve easily at least the last barrier mentioned above. We have solid, performant and easy to use solutions that allow producers to publish complex visual media content on the web and to share it.

The paper will first offer a brief review of some related enabling technologies in Section 2 (solutions for CH digitization and data optimization/management). Later some platforms that support the presentation on the web of CH visual media are presented in Section 3, focusing on the commercial platforms and the issues in web-based visualization. Section 4 presents the 3DHOP platform, which enables flexible presentation of 3D models on the web. Finally, Section 5 reports conclusions and a discussion about future needs and forthcoming developments.

## 2. Enabling technologies for digitization and management of sampled CH data

The progress with optical systems, digital photography and visual computing has produced a number of mature technologies for producing high-quality digital 3D replicas of CH artifacts. Most of these technologies are off-the-shelf products, in many cases also at very low cost. They allow users to produce *high-resolution models* (with high-resolution we mean sampled models counting from 5 million up to hundreds of million faces/points). Most of these technologies enable also very high-quality sampling of the geometric data, with accuracies in the order of few tens of microns (at the small scale) or a few millimeters (for technologies working at the large scale).

CH applications require digitization should not focus only to create digital models representing the shape, since we also need a very good sampling of the color or, better, of the surface reflection properties of the object or the scene digitized. Several works have presented approaches for sampling and mapping the color or the surface reflection properties (Lensch, Kautz, Goesele, Heidrich, & Seidel, 2003; Callieri, Cignoni, Corsini, & Scopigno, 2008; Dellepiane, Marroquim, Callieri, Cignoni, & Scopigno, 2012) and those solutions are now part of many off-the-shelf digitization solutions.

Once we have a digital 3D sampling of our CH artwork, the further issues are: how to encode efficiently those data; how to archive and made them accessible to the community; and how to visualize them efficiently in the framework of CH applications.

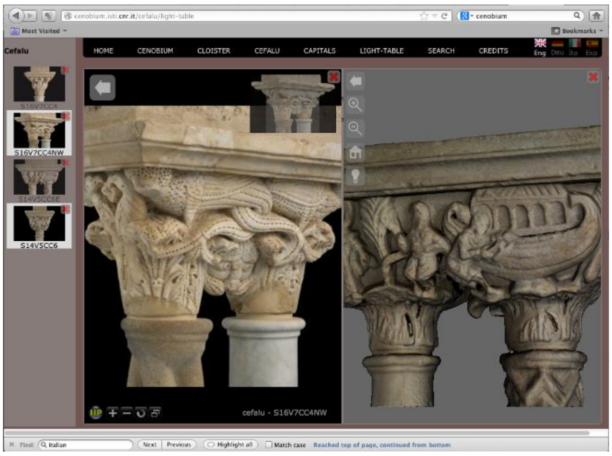
The accuracy and density of the digital sampling is the intrinsic value of the reconstructed model, because that huge quantity of geometric data shows a high potential for many applications. But, at the same time, very high-resolution data can be perceived as a problem by users (making the design of efficient computations kernels or visualizations more complex). Therefore, endorsing methods able to produce a controlled granularity of the digital models is mandatory in CH applications.

Many years of research in computer graphics have been instrumental in building an arsenal of technologies for controlled *surface simplification* and for the construction of multiresolution encoding schemes and view-dependent rendering modalities (Cignoni et al., 2004; Cignoni et al., 2005; Borgeat, Godin, Blais, Massicotte, & Lahanier, 2005; Wimmer & Scheiblauer, 2006). Providing an interactive and fluid visualization of complex models is a critical task for applications running either on the web or on mobile platforms. Many *view-dependent rendering* solutions have been presented, able to process a multi-resolution model and extracting frame-by-frame view-dependent representations that fulfil the rendering quality and the performance constrains. Some of these solutions, are now available on the entire spectrum of platforms (from desktop computers to tablets and smartphones), demonstrating that we dispose of a common enabling technology able to carry high-quality graphics to everyone and everywhere. An example is the Nexus library[1], which follows the approach proposed in Cignoni et al. (2005).

Once we have the capability to generate good quality 3D models, the next group of enabling technologies are the ones needed to *archive* and *access* those data, hopefully enriching the digital models with metadata and efficient search and retrieval functionalities. Some pioneering work on this subject has been done in the EC "3DCOFORM" project (http://www.3d-coform.eu/).

[1] http://vcg.isti.cnr.it/nexus/

*Integration of different media* is a final issue. Digital 3D models are just one of the media available and used to document the status and the beauty of CH assets. Images (both the standard ones and the more advanced 2D media such as RTI, panoramic or multispectral images) have an important role; video is a resource easier to record and to distribute to users. The improved insight that can be gathered by the use of multiple media should be taken into account in the design of archives and visualization systems. A future goal is to go beyond the consolidated 3D graphics approach (just store and use the 3D media). This means designing and developing technologies able to link different media or to present them in a coordinated or integrated manner (Snavely, Seitz, & Szeliski, 2006; Brivio et al., 2013; Messaoudi, Manuel, Gattet, De Luca, & Véron, 2014; Leoni et al., 2015; Potenziani et al., 2015).



(a) (b)

**Figure 1**: An example of the visual presentation provided by the Cenobium system (Corsini et al., 2010): a single window enables the side-by-side visualization of a) a high-resolution image and b) a 3D model, related to two capitols from the Cefalù cloister (Sicily, Italy).

## 3. Presenting 3D models on the web

The delivery of 3D content through the web started to be supported with a considerable delay with respect to other digital media such as text, still images, videos and sound. Early approaches proposed for publishing and visualizing 3D data on the web (e.g. VRLM, X3D) had a major disadvantage: they confined 3D data to a specific visualization tool, implemented as a plugin (i.e., binary executable modules external to the hosting browser) that had to be explicitly installed by users. This approach was definitely improper for the CH community, where potential users are usually not information and communication technology (ICT) experts and where the appearance of a blank screen corresponding to a request of installation of a piece of software frequently discourages the user from further exploration of the data.

The appearance of the WebGL standard in 2009 (Khronos Group, 2009) was a fundamental change. WebGL is the latest born component of the OpenGL ecosystem, and it is modeled as a JavaScript Application Programming Interface (API) that exposes a one-to-one mapping to the OpenGL ES 2.0 specifications for embedded systems. WebGL provides therefore a specification on how to render 3D data that web browsers should implement. Hence, by incorporating the WebGL approach, modern web browsers are able to natively render 3D models by using the features of the 3D graphics hardware, without needing additional plug-ins or extensions. Since WebGL is a low-level API, developing an application that uses WebGL is not an easy task and requires considerable skills in graphics programming. Therefore, WebGL is not a solution by itself to the needs and issues of the DH community. But, as we will present in the following subsections, WebGL has been the enabling basic layer for the development of several interesting tools or resources. Figure 1 shows an example of a web system developed using WebGL.

### 3.1. Commercial platforms for publishing 3D content on the web

The introduction of WebGL has ignited the development of many different approaches for managing 3D content on the web, both at the academic and commercial level. Some of these experiences have produced more sophisticated and higher-level libraries (Behr, Eschler, Jung, & Zöllner, 2009). In other cases, commercial services have been developed to support the easy publication and visualization of 3D content on the web.

#### 3.1.1. Sketchfab

An excellent representative of a commercial platform is Sketchfab[2], considered today the de-facto standard for publishing 3D content on the web. Sketchfab provides a 3D model viewer based on WebGL working either on any mobile/desktop webpage or on VR headsets. It enables the user to move freely around or inside the 3D scene using the mouse or a touch-based manipulation. In addition to static 3D models, the viewer is able to play and control interactive 3D animations. Finally, users can enable the VR mode to make the model viewable in VR headsets.

The 3D viewer is used to present the models uploaded on the Sketchfab website, but can also be embedded on external websites, notably on Facebook or on any personal web site.

Publishing content by means of Sketchfab is very easy. This tool follows the approach introduced by YouTube: after registration and activation of an account, an upload webpage allows users to insert a few data on the specific 3D data file and to upload it. All processing and conversion is done in an automatic manner on the Sketchfab platform. Sketchfab users can choose to make their 3D model files available for download under Creative Commons license.

Sketchfab is an excellent system, providing a very high-performance and high quality rendering engine. The only limitations of this platform are the lack of flexibility (there is only one incarnation of the viewer, which follows a very clean design but follows the requirements of a very wide set of possible applications). Therefore, it is not possible to configure or modify the Sketchfab viewer to support specific CH needs.

Moreover, Sketchfab supports only a mono-resolution model (it enables the use of a few levels of detail, just to switch between interactive and not interactive mode, but

[2] https://sketchfab.com/

it does not support a real multiresolution approach). To optimize download transmission times Sketchfab uses a lossy compression method when transferring the geometry. Most of the CH models published on Sketchfab are drastically simplified (geometry is usually at most around 1 million triangles) and most of the detail is encoded in the associated texture map (in other words, any user can enable the wireframe rendering mode in the viewer settings to check how geometry is usually low-res).

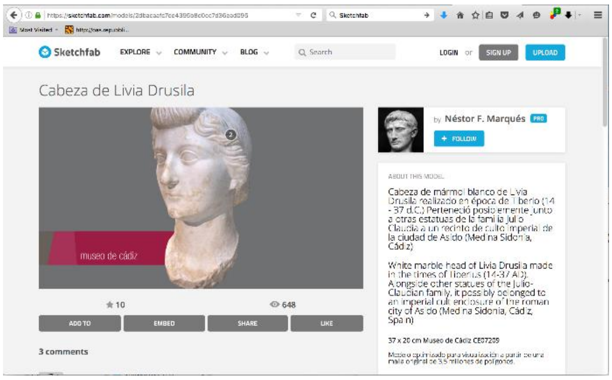



**Figure 2**: A snapshot of a 3D model published on the Sketchfab repository (3D model with hotspots and additional information).

Recently Sketchfab has revised its license policy to cope with CH institutions or users, creating an entire section of its website for museum and cultural collections, and adding "hotspots" functionalities to its basic 3D viewer. Figure 2 shows an example of a CH model with interactive annotations published online using Sketchfab.

Sketchfab reached a major impact on the CH domain. The number of models available on the Sketchfab archive depicting cultural items[3] is now quite large and it increased with a very good speed in the last couple of years. The quality of the material available is still uneven, but it includes several good quality models coming from both academic/institutional providers and practitioners/amateurs.

### 3.1.2. Smithsonian Museum X3D

The Smithsonian Museum X3D visualizer[4] is another commercial solution for the visualization of 3D CH models (we tag it commercial since it has been designed by AutoDesk to fulfil the requirements of the Smithsonian Museum). It enables the visualization of 3D digitized specimens as well as their integration with other types of data. X3D shows a higher configurability level than Sketchfab, since it has been clearly designed to cope with the diversity of the CH artefacts stored in a museum. It is possible to attach additional information to the models, to create a virtual "tour" on the objects moving among the various hotspots available on the virtual replica, and also to provide tours featuring several objects, grouped following a common concept. While efficient and visually pleasant, the viewer is currently a closed project, owned by AutoDesk and in-development with the Smithsonian museum, so its use is restricted and extendibility to other use cases/requirements is unclear.

## 3.2. Managing data complexity on the web

Existing commercial platforms for publishing 3D content on the web in most cases are designed to present 3D objects by supporting a high-quality visual appearance rather than keeping a precise geometric representation. In 3D graphics this means to replace as much possible of the model geometry with textures.

This choice is justified by aesthetical requirements: the quality of rendering is a very important aspect in public presentations/publishing, and the adoption of texture-based representation and rendering modes provides excellent visual results (when the current 3D data processing technologies are used in a correct manner). At the same time, the selection of a texture-based encoding is also justified by practical difficulties in handling complex 3D data (the data size of accurate 3D models implies excessive disk space requirements and transmission times, poor standardization and elevated intrinsic heterogeneity). These constraints become even more pressing for web environments (with limited computing resources and server disk space, and unknown available bandwidth).

The design choice of giving priority to textured 3D models copes well with the needs of many application fields, where relatively geometrically-coarse 3D models can be used without problems. Conversely, CH applications often need to rely on geometrically complex 3D models. High-resolution digitized geometries are often essential to convey correct information to final users, for both technical uses (documentation, catalogues, restoration, study and measurement), and dissemination purposes (didactical uses, virtual museum). Therefore, here are a number of cases where low-res textured models are not a proper approach, thus requiring platforms able to support the efficient transmission and visualization of very dense 3D models.

An efficient management of large geometry-based 3D models on the web can be achieved by porting the Nexus multiresolution approach (briefly introduced in Section 2) over the WebGL layer. The view-dependent rendering engine of the Nexus system has been ported from C++ to JavaScript, revealing that JavaScript performances are not a major limitation due to the minimal processing required by the Nexus library (that requires at run time just a simple traversal of the multiresolution hierarchy). The limitations of the WebGL API with respect to the more complex desktop OpenGL API are not critical here, due to the very basic OpenGL features required by Nexus. However, some extensions and modifications have been introduced while implementing the WebGL version of Nexus, enhancing it with a more aggressive solution for the compression of the geometric 3D data and by adopting a streaming approach over HTTP. The combination of these two components enables an efficient and fast data transfer even in the case of very high-resolution models.

This multiresolution engine (Nexus on WebGL) is the technology we are using in most of the CNR-ISTI projects (e.g. the Cenobium system shown in Figure 1 and the 3DHOP platform described in the following section).

[3] https://sketchfab.com/categories/cultural-heritage

[4] http://3d.si.edu/

## 4. The 3DHOP platform

3DHOP (Potenziani et al., 2015), acronym for 3D Heritage Online Presenter, is a platform designed to cope with the needs of the DH community. 3DHOP simplifies the creation of interactive visualization webpages and enables to display high-resolution 3D models with intuitive user interaction/manipulation. Moreover, using 3DHOP the 3D resources can be deeply connected with the rest of the webpage elements (see the example in Figure 3).

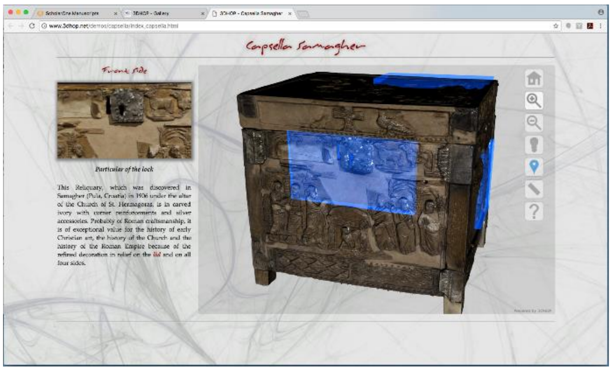


**Figure 3**: A screenshot of a web presentation built using 3DHOP (presenting a single 3D model with hotspots and additional information).

The most interesting characteristics of the 3DHOP framework are as follows:

- It can work with extremely complex 3D geometries, using a streaming-friendly multiresolution scheme (the Nexus library, already introduced in Section 2 and 3);
- It has been designed to work with web environments. So, thanks to the use of declarative-style scene creation and exposed JavaScript functions, it provides a satisfactory level of ease of use, focusing on developers with a basic background in web programming (but at same time remaining simple to approach for all other professionals);
- It is provided with a modular structure, composed by a number of basic building blocks for creating interactive visualizations, each one including a set of defaults variables, configurable, and equipped with a comprehensive documentation.

3DHOP is based on the WebGL subset of HTML5 and thus it works without the need of plugins on most modern browsers and on all platforms.

The downloadable package, together to a detailed documentation, a series of tutorials (How-Tos) and a Gallery of examples, is available for consultation and test at the project official website[5].

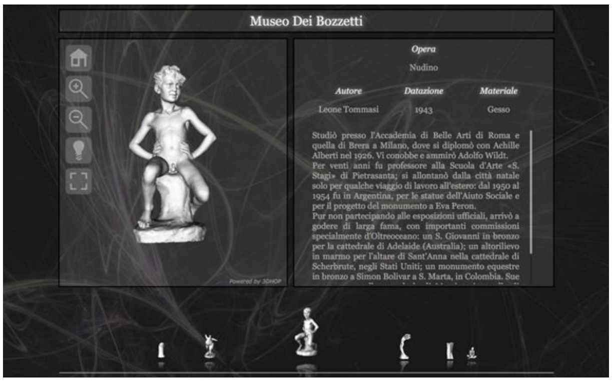
3DHOP has been released as open source software (GPL licence) in April 2014. From then to date the framework has been constantly enriched with tools and features. It began its life as a simple 3D viewer able to handle only triangular meshes with per-vertex color and equipped with a basic 4 buttons toolbar (home, zoom in, zoom out, light control). Today 3DHOP is a much more complex and flexible platform.

Pursuing the best compromise between rendering and streaming performances, the core engine of the viewer has been upgraded several times. Thanks to these improvements now 3DHOP can easily handle (in a light multiresolution compressed format) both *high-resolution meshes* and *point clouds* (tens of millions triangles/vertices and over). Concerning appearance management, it supports both textures-based and per-vertex color encodings. The texture-based encoding works either on single-resolution models or on the usual multiresolution encoding; we provide an extended Nexus conversion tool able to produce a multiresolution texture-encoded model from an input high-resolution textured mesh.

At the same time, several changes and extension have concerned the viewer usability and the interaction with the 3D scene: a revised user interface, support touch and multi-touch displays, a scene-related event handler and additional interaction trackballs, just to name a few.

Furthermore, from the first version to date, also the 3DHOP toolset has been enhanced with several new tools: full screen feature, geometric hotspot tool, selective model visibility, measurement suite, object transparency feature, and the cut-planes sectioning tool.


(a)




(b)

**Figure 4**: A couple of different layouts examples provided by 3DHOP. In a) is a layout for single object presentation, with the 3D scene equipped with the basic toolbar plus interactive hotspots linked to informative popup windows; in b) we show a layout for the management of a collection of objects, with the 3D viewer equipped with the basic toolbar, an informative panel on its right, and a slider selector over the collection of 3D models on its bottom.

[5] http://3dhop.net

However, it is important to stress that 3DHOP is not a universal platform able to support any possible application or visual communication project, but it is a framework designed to deal with specific needs. It is an ideal tool to visualize high-resolution single objects (especially with dense models coming from 3D scanning). 3DHOP a very good choice for quickly creating interactive visualization for either a single or a collection of models (as shown in Figure 4).

Conversely, 3DHOP is not suited to manage complex scenes made of several low-poly objects (this is a common case when working with CAD, procedural or hand-modelled geometries).

Additionally, thanks to its exposed JavaScript functions, 3DHOP integrates extremely well with the rest of the webpage. The ideal situation is having the logic of the visualization scheme in the page scripts, and use 3DHOP for just the 3D visualization.

Finally, 3DHOP has been designed with different levels of access, to be as straightforward as possible for the simpler cases but, at the same time, able to provide enough configurable features to support the huge variability of Cultural Heritage artworks and applications.

## 4.1. Supporting automatic web publishing

In the framework of the ARIADNE project (which concerns the development of infrastructures for the archaeology domain), the need for easy and automatic tools providing web publishing of visual media emerged as user request in a workshop held on 2013.

The result of this workshop is the ARIADNE Visual Media Service (Ponchio, Potenziani, Dellepiane, Callieri, & Scopigno, 2016), a resource providing easy publication and presentation on the web of complex visual media assets. It is an automatic service that allows users to upload visual media files on an ARIADNE server and to transform them into an efficient web format, making them ready for web-based visualization. The user is asked only to fill up a small form and to upload the raw file. All processing required to transform the data in a web-compliant and efficient format is done in an automatic manner by our server.

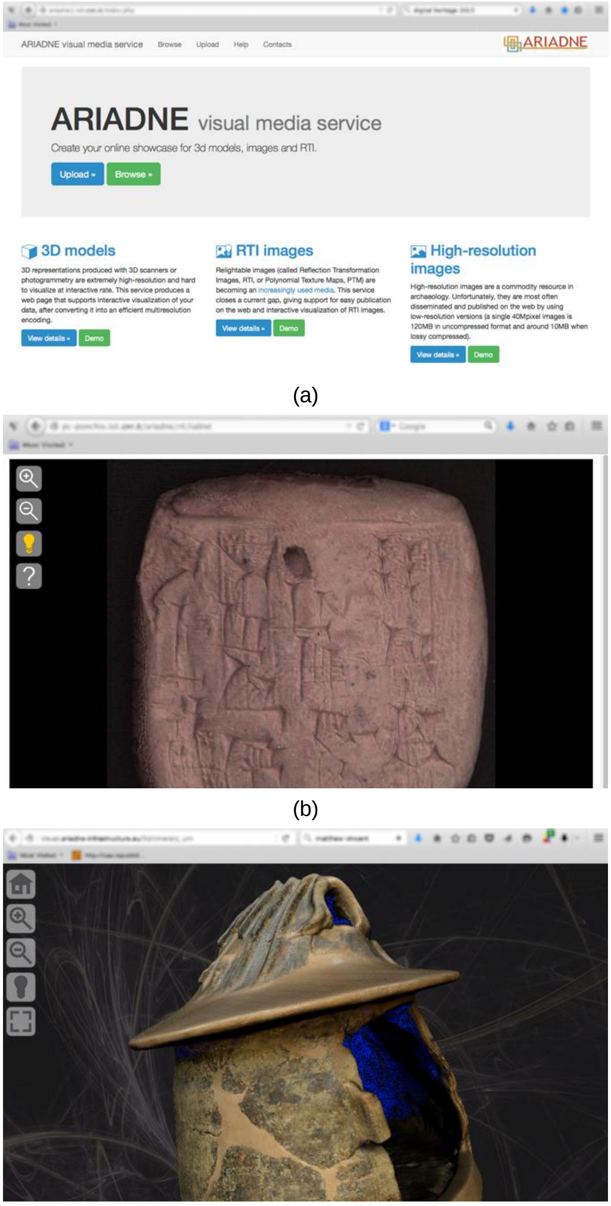
The service supports three types of visual media: high-resolution images, Reflection Transformation Images (RTI), and high-resolution 3D models.

The Visual Media Service[6] was released on January 2015, has been extended in January 2016 and supports now the web publication and browsing of:

- High-resolution 2D images (input images are converted in a multi-resolution format and can be browsed in real time, zooming in and out);
- Reflection Transformation Images (RTI), also known as Polynomial Texture Maps (PTM) images, i.e. dynamically re-lightable images (Mudge et al., 2008);
- 3D models (triangulated meshes, point clouds and textured models).

For each media type, we support automatic conversion to an efficient multiresolution representation, offering data compression, progressive transmission and view-dependent rendering. Each data type has a specific web-browser, implemented using WebGL and appearing in a standard web page (see Fig. 5).

Moreover, the new features allow for further personalization of the page: it is now possible to change the navigation paradigm and the style of the page. Moreover, new tools (i.e. for creating cut-through sections and for taking point-to-point measurements) have been made available, and they can be added to the visualization page.




(a)

(b)

(c)

**Figure 5**: Screenshots from the Ariadne Visual Media Service: a) The service landing web page; b) Visualization of an uploaded RTI of a cuneiform tablet; and c) Visualization of a 3D model of a cinerary urn.

## 4.2. Supporting restoration with a web platform

While all these tools are mostly devoted just to visualization, a recurring request from the community is to use the web platform to access 3D data and work on it in a collaborative environment. Following this trend, CNR-ISTI is currently contributing to an on-going project

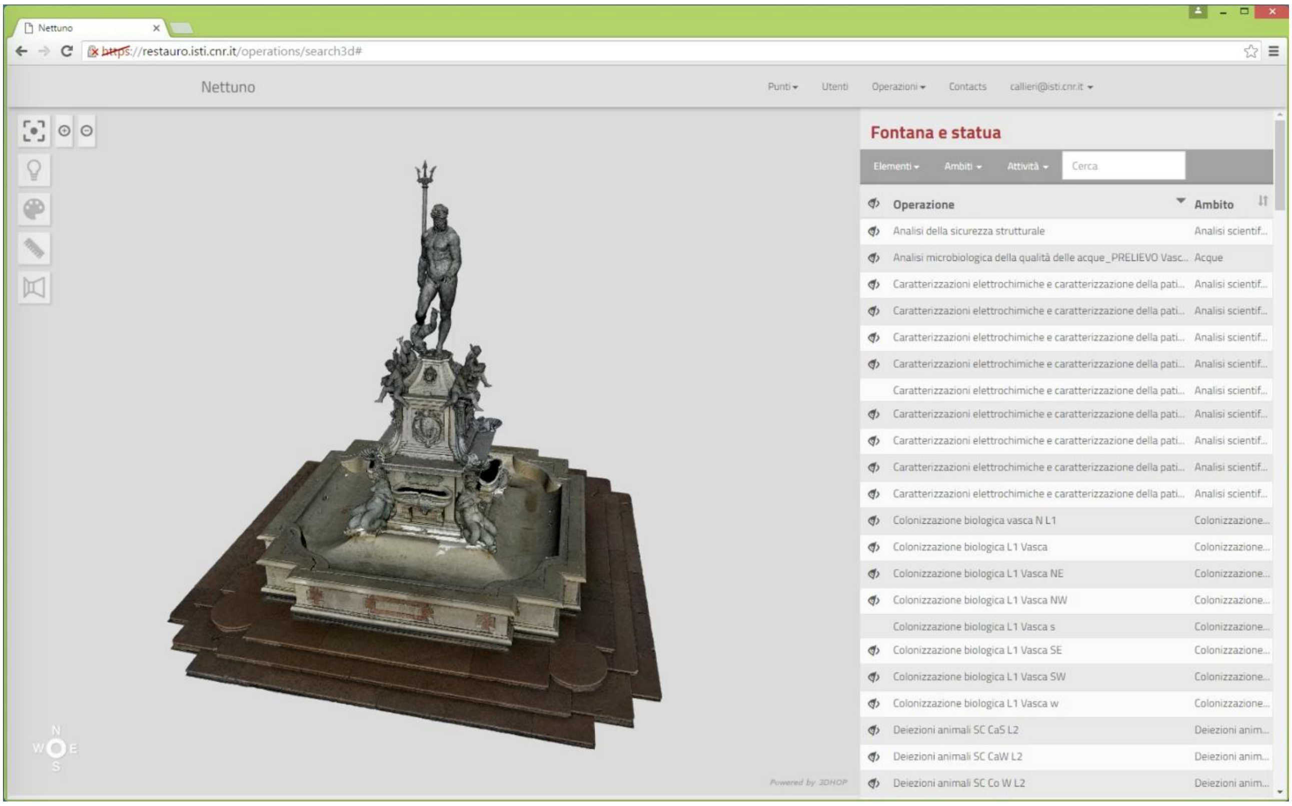
[6] http://visual.ariadne-infrastructure.eu/

concerning the restoration of the fountain of Netpune[7], a complex monument in Bologna, Italy, which is an early work by Giambologna, completed about 1567.

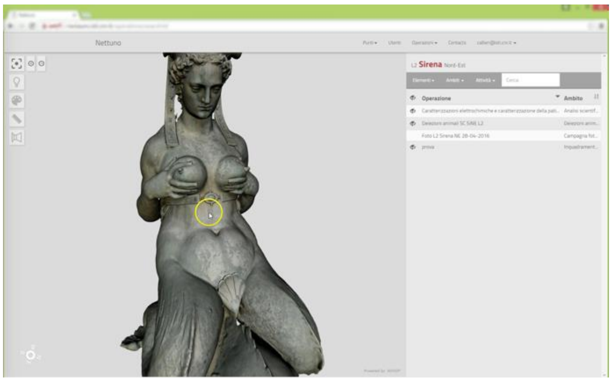
This fountain is undergoing a complex study to assess its conservation conditions, that includes a large number of scientific and visual analysis by a group of experts and restores leaded by ISCR (*Istituto Superiore per la Conservazione ed il Restauro*) and University of Bologna.

The idea is that all the technical documentation for the diagnostic phase, planning and execution of the restoration will be gathered in an online system, and everything will be geo-referenced on high-resolution 3D models (also available in streaming through the online tool). The aim was not only to document the status of the artwork before the restoration but also to support data archival and retrieval. The 3D model is therefore a central component of the information system.

The digitization of the fountain was done by staff of the University of Bologna as one of the first actions of the project. CNR-ISTI, together with colleagues of the University of Bologna, designed and implemented an information system aimed at storing all the data gathered during the phases of analysis and restoration. This system includes a database, designed specifically to support the specific data organization of this project, which is interoperating with the 3D model of the fountain. Any user can query the information system or also browse the 3D model of the fountain, using a simple web interface. The 3D model becomes a sort of spatial index to the information stored in the information system. For example, all documents or photographs related to a




(a)



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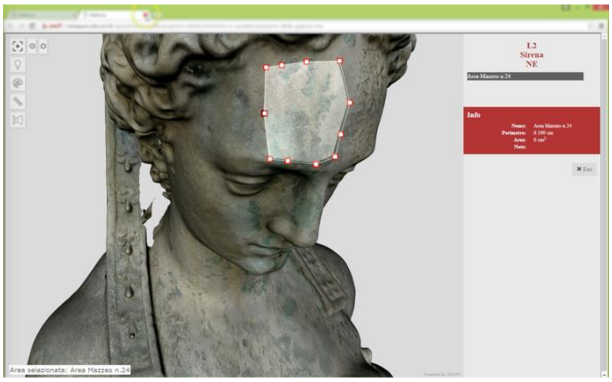

(c)

**Figure 6**: Some snapshots from the Neptune information system: a) The starting page, showing the entire monument and the access to the information system sub-components; b) After selection of a sub-element of the statue, the corresponding 3D model and all the related information can be browsed by the user; and c) Creation of a polygonal region over the head of the statue, which will become a single element of one of the conservation status reliefs.

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[7] http://nettuno.comune.bologna.it/

specific point or component of the fountain can be stored in the system by linking them to this specific position over the skin of the 3D model; therefore, all data will be geo-referenced by means of links to the 3D model. Some images of the system (currently in testing phase) are presented in Figure 6.

The system is supporting the production of the reliefs documenting the status of conservation. Instead of using an independent 2D drafting system (e.g. AutoCAD) or a Geographic Information System (GIS) system, the Neptune information system allows the operators to draw the reliefs directly on the 3D model, creating either point-based, polylines or 2D regions (see Fig. 6c) which are then stored in the relational database of the information system.

The system represents a quite complex artwork, 3D scanned at very high accuracy. 3D data management is implemented on top of 3DHOP technology and supports the web-based interactive manipulation and analysis of a huge model (in total, around 600 million triangles).

## 5. Conclusions

This paper has presented the status of the technology for web-based publishing and visualization of visual media (mostly focusing on CH 3D models). The web is nowadays perceived as the main channel of publication and dissemination of knowledge. Technology is now ready for sophisticated uses of the web (Messaoudi, Manuel, Gattet, De Luca, & Véron, 2014). The web is thus becoming the main dissemination and sharing platform for 3D content, as we shown with several examples in this paper.

The web can go beyond data archival and visualization; it could also become the domain where programs were running over data (we are making some experiments in this direction with the web-based version of MeshLabJS, http://www.meshlabjs.net/).

The DH domain is extremely rich and complex: CH professionals use many different types of visual media in their study and analysis process, or for didactical purposes. In the near future, the consolidated approach where we analyze visually each single dataset and media, will be replaced by a cross-evaluation methodology resembling more the usual human approach on the real workbench. The single object browser should be replaced by tools able to link and cross-analyze different types of knowledge and data (each one linked to the virtual clone). The usual linear approach to present knowledge on a CH artwork, typical in textual descriptions, shows all its limitations. We need new systems able to break the linear approach, supporting sophisticated capabilities for integrating and creating correlations among different media.

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## References

Behr, J., Eschler, P., Jung, Y., & Zöllner, M. (2009). X3DOM: A DOM-based HTML5/X3D integration model. *Proceedings of the 14th International Conference on 3D Web Technology (Web3D '09)* (pp. 127–135). Darmstadt, Germany. http://doi.org/10.1145/1559764.1559784

Borgeat, L., Godin, G., Blais, F., Massicotte, P., & Lahanier, C. (2005). GoLD: Interactive display of huge colored and textured models. *ACM Transactions on Graphics, 24*(3), 869–877. http://doi.org/10.1145/1073204.1073276

Brivio, P., Benedetti, L., Tarini, M., Ponchio, F., Cignoni, P., & Scopigno, R. (2013). PhotoCloud: Interactive remote exploration of joint 2D and 3D datasets. *IEEE Computer Graphics and Applications, 33*(2), 86–96. http://doi.org/10.1109/MCG.2012.92

Callieri, M., Cignoni, P., Corsini, M., & Scopigno, R. (2008). Masked photo blending: Mapping dense photographic data set on high-resolution sampled 3D models. *Computers & Graphics, 32*(4), 464–473. http://doi.org/10.1016/j.cag.2008.05.004

Cignoni, P., Ganovelli, F., Gobbetti, E., Marton, F., Ponchio, F., & Scopigno, R. (2004). Adaptive tetrapuzzles: Efficient out-of-core construction and visualization of gigantic multiresolution polygonal models. *ACM Transactions on Graphics, 23*(3), 796–803. http://doi.org/10.1145/1015706.1015802

Cignoni, P., Ganovelli, F., Gobbetti, E., Marton, F., Ponchio, F., & Scopigno, R. (2005). Batched multi triangulation. *Proceedings of the IEEE Symposium on Visualization (Info Vis '05)* (pp. 20–214). Minneapolis, Minnesota, USA. http://doi.org/10.1109/VISUAL.2005.1532797

Corsini, M., Dellepiane, M., Dercks, U., Ponchio, F., Keultjes, D., Marinello , A., …, Wolf, G. (2010). CENOBIUM - Putting together the romanesque cloister capitals of the mediterranean region. *B.A.R.-British Archaeological Reports International Series, 2118*, 189–194. Retrieved from http://vcg.isti.cnr.it/Publications/2010/CDDPCKMSSW10/

Dellepiane, M., Marroquim , R., Callieri, M., Cignoni, P., & Scopigno, R. (2012). Flow-based local optimization for image-to-geometry projection. *IEEE Transactions on Visualization and Computer Graphics, 18*(3), 463–474. http://doi.org/10.1109/TVCG.2011.75

Khronos Group. (2009). *WebGL - OpenGL ES 2.0 for the Web*. Retrieved from https://www.khronos.org/webgl/

Lensch, H., Kautz, J., Goesele, M., Heidrich, W., & Seidel, H.-P. (2003). Image-based reconstruction of spatial appearance and geometric detail. *ACM Transactions on Graphics, 22*(2), 234–257. http://doi.org/10.1145/636886.636891

Leoni, C., Callieri, M., Dellepiane, M., Rosselli Del Turco, R., O'Donnell, D., & Scopigno, R. (2015). The dream and the cross: Bringing 3D content in a digital edition. *Journal on Computing and Cultural Heritage (JOCCH) - Special Issue on Best Papers from Digital Heritage 2013 , 8*(1), 5:1–5:21. http://doi.org/10.1145/2686873

Messaoudi, T., Manuel, A., Gattet, E., De Luca, L., & Véron, P. (2014). Laying the foundations for an information system dedicated to heritage building degradation monitoring based on the 2D/3D semantic annotation of photographs. *Proceedings of the Eurographics Workshop on Graphics and Cultural Heritage.* Darmstadt, Germany. http://doi.org/10.2312/gch.20141315

Mudge, M., Malzbender, T., Chalmers, A., Scopigno, R., Davis, J., Wang, O., …, Barbosa, J. (2008). Image-based empirical information acquisition, scientific reliability, and long-term digital preservation for the natural sciences and cultural heritage. *Eurographics 2008 - Tutorials.* Crete, Greece. http://doi.org/10.2312/egt.20081050.T2

Ponchio, F., Potenziani, M., Dellepiane, M., Callieri, M., & Scopigno, R. (2016). ARIADNE visual media service: easy web publishing of advanced visual media. *Proceedings of the 43rd Annual International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA 2015)* (pp. 433–442). Siena, Italy. Retrieved from http://archaeopress.com/ArchaeopressShop/Public/download.asp?id={77DEDD4E-DE8F-43A4-B115-ABE0BB038DA7}

Potenziani, M., Callieri, M., Dellepiane, M., Corsini, M., Ponchio, F., & Scopigno, R. (2015). 3DHOP: 3D heritage online presenter. *Computers & Graphics, 52*, 129–141. http://doi.org/10.1016/j.cag.2015.07.001

Scopigno, R., Callieri, M., Cignoni, P., Corsini, M., Dellepiane, M., Ponchio, F., & Ranzuglia, G. (2011). 3D models for cultural heritage: Beyond plain visualization. *IEEE Computer, 44*(7), 48–55. http://doi.org/10.1109/MC.2011.196

Snavely, N., Seitz, S., & Szeliski, R. (2006). Photo tourism: Exploring photo collections in 3D. *ACM Transactions on Graphics, 25*(3), 835–846. http://doi.org/10.1145/1141911.1141964

Wimmer, M., & Scheiblauer, C. (2006). Instant points: Fast rendering of unprocessed point clouds. *Proceedings of the 3rd Eurographics / IEEE VGTC Conference on Point-Based Graphics* (pp. 129–137). Boston, Massachusetts, USA. http://doi.org/10.2312/SPBG/SPBG06/129-136